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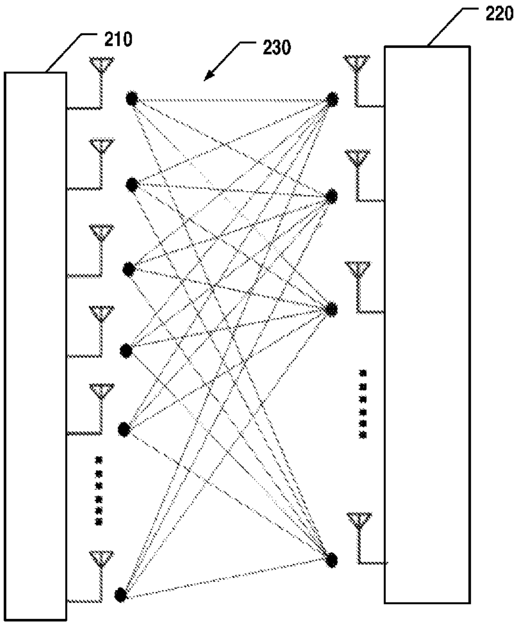

FIG. 2

(57) **Abstract:** Embodiments of apparatus and method for multiple-input and multiple-output (MIMO) detection are disclosed. In an example, a plurality of signal streams corresponding to a symbol vector are received through a channel. A metric indicative of a signal strength for each of the plurality of signal streams is determined based on a condition of the channel. A permutation of the plurality of signal streams is determined based on the metrics for the plurality of signal streams. The symbol vector is detected from the plurality of signal streams using a model based on the permutation for the plurality of signal streams.

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MULTIPLE-INPUT AND MULTIPLE-OUTPUT DETECTION BASED ON TRANSMITTED SIGNAL STREAMS PERMUTATION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application No. 62/982,593 filed February 27, 2020, entitled "REDUCED COMPLEXITY MIMO DETECTION," which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] Embodiments of the present disclosure relate to apparatus and method for wireless communication.

[0003] Wireless communication systems are widely deployed to provide various telecommunication services such as telephony, video, data, messaging, and broadcasts. The development of the wireless communication, especially the cellular communication systems, such as the 4th-generation (4G) Long Term Evolution (LTE) and the 5th-generation (5G) New Radio (NR), makes the higher speed data service critical. Multiple-input and multiple-output (MIMO) communication has been spotlighted since MIMO communication uses a spatial multiplexing method in which multipath propagation can be performed by transmitting multiple signal streams (also referred to as "layers") using multiple transmission and receiving antennas to satisfy high-speed data requirement.

SUMMARY

[0004] Embodiments of apparatus and method for MIMO detection based on transmitted signal streams permutation are disclosed herein.

[0005] In one example, an apparatus includes at least one processor and memory storing instructions. The instructions, when executed by the at least one processor, cause the apparatus to receive a plurality of signal streams corresponding to a symbol vector through a channel. The instructions, when executed by the at least one processor, also cause the apparatus to determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel. The instructions, when executed by the at least one processor, further cause the apparatus to determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams. The instructions, when executed by the at least one processor, further cause the apparatus to detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

[0006] In another example, a baseband chip includes an interface and a MIMO detection circuit operatively coupled to the interface. The interface is configured to receive a plurality of signal streams corresponding to a symbol vector through a channel. The MIMO detection circuit is configured to determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel. The MIMO detection circuit is also configured to determine a permutation of the plurality for signal streams based on the metrics for the plurality of signal streams. The MIMO detection circuit is further configured to detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

[0007] In further another example, an apparatus for wireless communication includes a symbol vector detection module and a permutation module. The symbol vector detection module is configured to receive a plurality of signal streams corresponding to a symbol vector through a channel. The permutation module is configured to determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel, and determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams. The symbol vector detection module is further configured to detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

[0008] In still another example, a method implemented by a baseband chip for MIMO communication is disclosed. A plurality of signal streams corresponding to a symbol vector are received through a channel. A metric indicative of a signal strength for each of the plurality of signal streams is determined based on a condition of the channel. A permutation of the plurality of signal streams is determined based on the metrics for the plurality of signal streams. The symbol vector is detected from the plurality for signal streams using a model based on the permutation of the plurality of signal streams.

[0009] In yet another example, a non-transitory computer-readable medium is encoded with instructions that, when executed by at least one processor of a terminal device, perform a process. The process includes receiving a plurality of signal streams corresponding to a symbol vector through a channel. The process also includes determining a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel. The process further includes determining a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams. The process further includes detecting the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The accompanying drawings, which are incorporated herein and form a part of the specification, illustrate embodiments of the present disclosure and, together with the description, further serve to explain the principles of the present disclosure and to enable a person skilled in the pertinent art to make and use the present disclosure.

[0011] FIG. 1 illustrates an exemplary wireless network, according to some embodiments of the present disclosure.

[0012] FIG. 2 illustrates an exemplary MIMO communication system, according to some embodiments of the present disclosure.

[0013] FIG. 3 illustrates a detailed block diagram of the MIMO communication system in FIG. 2, according to some embodiments of the present disclosure.

[0014] FIG. 4 illustrates a schematic diagram of an exemplary MIMO channel, according to some embodiments of the present disclosure.

[0015] FIG. 5 illustrates a detailed block diagram of an exemplary MIMO detection system, according to some embodiments of the present disclosure.

[0016] FIG. 6 illustrates a detailed block diagram of an exemplary signal streams permutation unit in the MIMO detection system in FIG. 5, according to some embodiments of the present disclosure.

[0017] FIGs. 7A and 7B illustrate block diagrams of an exemplary apparatus including a host chip, a radio frequency (RF) chip, and a baseband chip implementing the MIMO detection system in FIG. 5 in software and hardware, respectively, according to some embodiments of the present disclosure.

[0018] FIG. 8 illustrates a flow chart of an exemplary method for MIMO detection, according to some embodiments of the present disclosure.

[0019] FIG. 9 illustrates a flow chart of another exemplary method for MIMO detection with more specifics, according to some embodiments of the present disclosure.

[0020] FIG. 10 illustrates a block diagram of an exemplary receiving device, according to some embodiments of the present disclosure.

[0021] Embodiments of the present disclosure will be described with reference to the accompanying drawings.

DETAILED DESCRIPTION

[0022] Although specific configurations and arrangements are discussed, it should be understood that this is done for illustrative purposes only. A person skilled in the pertinent art will recognize that other configurations and arrangements can be used without departing from the spirit and scope of the present disclosure. It will be apparent to a person skilled in the pertinent art that the present disclosure can also be employed in a variety of other applications.

[0023] It is noted that references in the specification to “one embodiment,” “an embodiment,” “an example embodiment,” “some embodiments,” “certain embodiments,” etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases do not necessarily refer to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it would be within the knowledge of a person skilled in the pertinent art to effect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0024] In general, terminology may be understood at least in part from usage in context. For example, the term "one or more" as used herein, depending at least in part upon context, may be used to describe any feature, structure, or characteristic in a singular sense or may be used to describe combinations of features, structures or characteristics in a plural sense. Similarly, terms, such as "a," "an," or "the," again, may be understood to convey a singular usage or to convey a plural usage, depending at least in part upon context. In addition, the term "based on" may be understood as not necessarily intended to convey an exclusive set of factors and may, instead, allow for existence of additional factors not necessarily expressly described, again, depending at least in part on context.

[0025] Various aspects of wireless communication systems will now be described with reference to various apparatus and methods. These apparatus and methods will be described in the following detailed description and illustrated in the accompanying drawings by various blocks, modules, units, components, circuits, steps, operations, processes, algorithms, etc. (collectively referred to as "elements"). These elements may be implemented using electronic hardware, firmware, computer software, or any combination thereof. Whether such elements are implemented as hardware, firmware, or software depends upon the particular application and design constraints imposed on the overall system.

[0026] The techniques described herein may be used for various wireless communication networks, such as code division multiple access (CDMA) system, time division multiple access (TDMA) system, frequency division multiple access (FDMA) system, orthogonal frequency division multiple access (OFDMA) system, single-carrier frequency division multiple access (SC-FDMA) system, and other networks, including but not limited to 4G, LET, and 5G cellular networks. The terms "network" and "system" are often used interchangeably. The techniques described herein may be used for the wireless networks mentioned above, as well as other wireless networks.

[0027] The channel conditions across different transmitted signal streams (also known as "transmitted layers") vary in time and frequency in known wireless MIMO communication systems. The relative order of the signal strength for different transmitted signal streams thus may vary over time. For many existing non-linear MIMO detection algorithms, the order of detecting transmitted signal streams has a significant impact on the final detection error performance and thus, data throughput.

[0028] For example, some conventional MIMO detection methods suffer from the complexity issue, where the complexity increases dramatically with the growth of the number of transmitted signal streams at the cost of using a great amount of computational resources. Other conventional MIMO detection methods that are based on sub-optimal metrics determined based on the estimated channel matrices have acceptable complexity but suffer from low accuracy (e.g., high error rate) in MIMO detection. In one example, the conventional maximum likelihood (ML) signal detection method detects the encoded symbols based on quadrature amplitude modulation (QAM) symbol-tree search, where a transmitted symbol vector (e.g., a QAM symbol vector) representing metric values of available combinations of transmission symbol vectors is determined.

[0029] The method has an acceptable performance but at the cost of taking up too many computational resources to be practical. The complexity of the ML detection method is exponential to the number of signal streams transmitted within the MIMO system. Accordingly, ML detection methods with reduced complexity (e.g., with limited tree search scope) are used instead. For example, within near-ML detection methods, only part of the whole symbol tree is searched over. Thus, the overall detection performance may be impacted by the hardware and/or software resources assigned to the detection of each signal stream (e.g., the maximum number of QAM symbol tree nodes searched for each signal stream). Accordingly, the order for detecting transmitted signal streams has a significant impact on the final detection error performance. To ensure the performance of the MIMO detection, the detection order of the transmitted signal streams becomes crucial.

[0030] Various embodiments in accordance with the present disclosure provide systems and methods for MIMO detection with extra step(s) for permuting the transmitted signal streams before being detected using a search model. The signal streams can be permutated based on a metric indicative of the signal strength for each signal stream. The metric for each signal stream can be selected from a plurality of candidate metrics based on the MIMO detection model and/or on the MIMO channel condition (e.g., represented by an estimated channel matrix). In some embodiments, the computational resources assigned to each transmitted signal stream are determined based on the permutation in a most effective and efficient way. As a result, power consumption can be reduced, and the overall detection error performance for MIMO detection can be increased.

[0031] In some embodiments, the candidate metrics are optimal metrics that can more accurately reflect the signal strengths of each transmitted signal steam. In one example, the candidate metric may include L2 column norms of the channel matrix corresponding to the signal strength of the signal stream. In another example, the candidate metric may include L2 row norms of a pseudo-inverse of the channel matrix corresponding to a signal-to-noise and interference ratio (SINR) of the signal stream. In still another example, the candidate metric may include post-minimum mean squared error (MMSE) equalization signal-to-noise ratio (SNR) determined by applying an MMSE-based equalization to the channel matrix. In some embodiments, the metric used for signal streams permutation is selected from the above-mentioned candidate metrics according to the search model (e.g., QAM symbol-tree search algorithm), or the MIMO channel condition for realizing the optimal performance under the predetermined total computational resources assigned to the MIMO detection process. Because optimal metrics for the signal streams can be used for the MIMO detection process, the MIMO detection disclosed herein can have better error performance comparing to conventional MIMO detection schemes.

[0032] In some embodiments, the metrics for the transmitted signal streams are dynamically determined in response to the channel condition. For example, the channel matrix representing the channel condition may be instantaneously estimated when the channel condition changes relatively dramatically. This may better reflect the current channel condition and thus, lower the error rate on subsequent processes (e.g., the signal stream permutation and the subsequent detection processes) but at the cost of using more computation resources.

[0033] In some embodiments, the metrics for the plurality of signal streams are determined at an interval based on the average of the channel condition during the interval. For example, the channel matrix representing the channel condition may be estimated based on the average of the channel condition during a predetermined period of time, when the channel condition changes relatively slow (i.e., stays relatively stable). The permutation and the MIMO detection of the signal streams transmitted during that period may be based on the same estimated channel matrix. This may significantly reduce the computational resources used by the detection process at the cost of less accuracy in reflecting the current condition of the channel.

[0034] In some embodiments, the computational resources assigned to each transmitted signal stream are determined based on the permutation of the transmitted signal streams. In one example, when implementing symmetric search algorithms for MIMO detection, a fixed number of computational resources (e.g., cycle counts in hardware or million instructions per second (MIPS) in software) may be assigned to the detection of each transmitted signal stream such that the MIMO detection may have a predetermined complexity (e.g., can be predicted/calculated based on the configuration of the search model and the number of signal streams transmitted) and may take up a predetermined amount of computational resources as a result. Accordingly, it can achieve the best detection performance when relatively strong signal streams are detected first, and the relatively weak signal streams are detected later. As a result, useful information acquired in the detection of strong signal streams may be used (e.g., after eliminating the interference) for the detection of the relatively weak signal streams. In another example, when implementing asymmetric search algorithms for MIMO detection, a relatively weak signal stream may be detected first, with more computational resources being assigned, and a relatively strong signal stream may be detected later, with less computational resources being assigned

[0035] In some embodiments, the permutated signal streams may be de-permutated to the original order before permutation (e.g., restore the soft bits in the MIMO detection process to the original order) after the MIMO detection. This may ensure that the receiver accurately receives the signal streams in the same order as they were transmitted from the transmitter.

[0036] FIG. 1 illustrates an exemplary wireless network 100, in which certain aspects of the present disclosure may be implemented, according to some embodiments of the present disclosure. As shown in FIG. 1, wireless network 100 may include a network of nodes, such as a user equipment (UE) 102, an access node 104, and a core network element 106. User equipment 102 may be any terminal device, such as a mobile phone, a desktop computer, a laptop computer, a tablet, a vehicle computer, a gaming console, a printer, a positioning device, a wearable electronic device, a smart sensor, or any other device capable of receiving, processing, and transmitting information, such as any member of a vehicle to everything (V2X) network, a cluster network, a smart grid node, or an Internet-of-Things (IoT) node. It is understood that user equipment 102 is illustrated as a mobile phone simply by way of illustration and not by way of limitation.

[0037] Access node 104 may be a device that communicates with user equipment 102, such as a wireless access point, a base station (BS), a Node B, an enhanced Node B (eNodeB or eNB), a next-generation NodeB (gNodeB or gNB), a cluster master node, or the like. Access node 104 may have a wired connection to user equipment 102, a wireless connection to user equipment 102, or any combination thereof. Access node 104 may be connected to user equipment 102 by multiple connections, and user equipment 102 may be connected to other access nodes in addition to access node 104. Access node 104 may also be connected to other user equipments. It is understood that access node 104 is illustrated by a radio tower by way of illustration and not by way of limitation.

[0038] Core network element 106 may serve access node 104 and user equipment 102 to provide core network services. Examples of core network element 106 may include a home subscriber server (HSS), a mobility management entity (MME), a serving gateway (SGW), or a packet data network gateway (PGW). These are examples of core network elements of an evolved packet core (EPC) system, which is a core network for the LTE system. Other core network elements may be used in LTE and in other communication systems. In some embodiments, core network element 106 includes an access and mobility management function (AMF) device, a session management function (SMF) device, or a user plane function (UPF) device, of a core network for the NR system. It is understood that core network element 106 is shown as a set of rack-mounted servers by way of illustration and not by way of limitation.

[0039] Core network element 106 may connect with a large network, such as the Internet 108, or another Internet Protocol (IP) network, to communicate packet data over any distance. In this way, data from user equipment 102 may be communicated to other user equipments connected to other access points, including, for example, a computer 110 connected to Internet 108, for example, using a wired connection or a wireless connection, or to a tablet 112 wirelessly connected to Internet 108 via a router 114. Thus, computer 110 and tablet 112 provide additional examples of possible user equipment, and router 114 provides an example of another possible access node.

[0040] A generic example of a rack-mounted server is provided as an illustration of core network element 106. However, there may be multiple elements in the core network including database servers, such as a database 116, and security and authentication servers, such as an authentication server 118. Database 116 may, for example, manage data related to user subscription to network services. A home location register (HLR) is an example of a standardized database of subscriber information for a cellular network. Likewise, authentication server 118 may handle authentication of users, sessions, and so on. In the NR system, an authentication server function (AUSF) device may be the specific entity to perform user equipment authentication. In some embodiments, a single server rack may handle multiple such functions, such that the connections between core network element 106, authentication server 118, and database 116, may be local connections within a single rack.

[0041] As described below in detail, in some embodiments, MIMO communication can be established between any suitable nodes in wireless network 100, such as between user equipment 102 and access node 104, for sending and receiving data through a MIMO channel. A transmitting node may establish the MIMO channel with a receiving node (e.g., establishing a multipath communication link between multiple transmitting antennas and multiple receiving antennas) and transmit encoded symbols in multiple signal streams through the MIMO channel. The receiving node may receive the multiple transmitted signal streams through the MIMO channel and may detect the symbol vector using a baseband chip implementing the MIMO detection scheme disclosed herein based on the permutation of the transmitted signal streams.

[0042] Each node of wireless network 100 in FIG. 1 that is suitable for receiving data may be considered a receiving device in MIMO communication. More detail regarding the possible implementation of a receiving device is provided by way of example in the description of a receiving device 1000 in FIG. 10. Receiving device 1000 may be configured as user equipment 102, access node 104, or core network element 106 in FIG. 1. Similarly, receiving device 1000 may also be configured as computer 110, router 114, tablet 112, database 116, or authentication server 118 in FIG. 1. As shown in FIG. 10, receiving device 1000 may include a processor 1002, a memory 1004, and a transceiver 1006. These components are shown as connected to one another by a bus, but other connection types are also permitted. When receiving device 1000 is user equipment 102, additional components may also be included, such as a user interface (UI), sensors, and the like. Similarly, receiving device 1000 may be implemented as a blade in a server system when receiving device 1000 is configured as core network element 106. Other implementations are also possible.

[0043] Transceiver 1006 may include any suitable device for sending and/or receiving data. Receiving device 1000 may include one or more transceivers, although only one transceiver 1006 is shown for simplicity of illustration. An antenna 1008 is shown as a possible communication mechanism for receiving device 1000. Multiple antennas and/or arrays of antennas may be utilized for MIMO communication. Additionally, examples of receiving device 1000 may communicate using wired techniques rather than (or in addition to) wireless techniques. For example, access node 104 may communicate wirelessly to user equipment 102 and may communicate by a wired connection (for example, by optical or coaxial cable) to core network element 106. Other communication hardware, such as a network interface card (NIC), may be included as well.

[0044] As shown in FIG. 10, receiving device 1000 may include processor 1002. Although only one processor is shown, it is understood that multiple processors can be included. Processor 1002 may include microprocessors, microcontrollers, digital signal processors (DSPs), application-specific integrated circuits (ASICs), field-programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functions described throughout the present disclosure. Processor 1002 may be a hardware device having one or more processing cores. Processor 1002 may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software modules, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise. Software can include computer instructions written in an interpreted language, a compiled language, or machine code. Other techniques for instructing hardware are also permitted under the broad category of software.

[0045] As shown in FIG. 10, receiving device 1000 may also include memory 1004. Although only one memory is shown, it is understood that multiple memories can be included. Memory 1004 can broadly include both memory and storage. For example, memory 1004 may include random-access memory (RAM), read-only memory (ROM), static RAM (SRAM), dynamic RAM (DRAM), ferro-electric RAM (FRAM), electrically erasable programmable ROM (EEPROM), CD-ROM or other optical disk storage, hard disk drive (HDD), such as magnetic disk storage or other magnetic storage devices, Flash drive, solid-state drive (SSD), or any other medium that can be used to carry or store desired program code in the form of instructions that can be accessed and executed by processor 1002. Broadly, memory 1004 may be embodied by any computer-readable medium, such as a non-transitory computer-readable medium.

[0046] Processor 1002, memory 1004, and transceiver 1006 may be implemented in various forms in receiving device 1000 for performing MIMO communication functions. In some embodiments, processor 1002, memory 1004, and transceiver 1006 of receiving device 1000 are implemented (e.g., integrated) on one or more system-on-chips (SoCs). In one example, processor 1002 and memory 1004 may be integrated on an application processor (AP) SoC (sometimes known as a "host," referred to herein as a "host chip") that handles application processing in an operating system environment, including generating raw data to be transmitted. In another example, processor 1002 and memory 1004 may be integrated on a baseband processor (BP) SoC (sometimes known as a modem, referred to herein as a "baseband chip") that converts the raw data, e.g., from the host chip, to signals that can be used to modulate the carrier frequency for transmission, and vice versa, which can run a real-time operating system (RTOS). In still another example, processor 1002 and transceiver 1006 (and memory 1004 in some cases) may be integrated on a RF SoC (sometimes known as a transceiver, referred to herein as a "RF chip") that transmits and receives RF signals with antenna 1008. It is understood that in some examples, some or all of the host chip, baseband chip, and RF chip may be integrated as a single SoC. For example, a baseband chip and an RF chip may be integrated in a single SoC that manages all the radio functions for cellular communication.

[0047] Various aspects of the present disclosure related to MIMO detection may be implemented as software and/or firmware elements executed by a generic processor in a baseband chip (e.g., a baseband processor). It is understood that in some examples, one or more of the software and/or firmware elements may be replaced by dedicated hardware components in the baseband chip, including integrated circuits (ICs), such as ASICs. Mapping to the wireless communication (e.g., 4G, LTE, 5G, etc.) layer architecture, the implementation of the present disclosure may be at Layer 1, e.g., the physical (PHY) layer.

[0048] FIG. 2 illustrates an exemplary MIMO communication system 200, according to some embodiments of the present disclosure. MIMO communication system 200 may be used between suitable nodes in wireless network 100. As shown in FIG. 2, MIMO communication system 200 may include a transmitting device 210, a receiving device 220, and a MIMO channel 230 (e.g., multipath communication links between the transmitting antennas and the receiving antennas). For example, transmitting device 210 and receiving device 220 each may be an example of user equipment 102, access node 104, or core network element 106 of wireless network 100 in FIG. 1. MIMO communication system 200 may be used for increasing the data transmission rate between transmitting device 210 and receiving terminal device. Both transmitting device 210 and receiving device 220 may include a processor, a memory, and a transceiver, which may be examples of processor 1002, memory 1004, and transceiver 1006 described above in detail, respectively, with respect to FIG. 10.

[0049] As shown in FIG. 2, transmitting device 210 may process the original data (e.g., process the input bits through various function stages of coding and interleaving, modulation, symbol mapping, and layer mapping and precoding) and may transmit the processed data (e.g., the encoded symbols) in multiple signal streams to receiving device 220 through MIMO channel 230. Receiving device 220 may receive the multiple transmitted signal streams and detect the original data (e.g., the decoded bits) through reverse processes, such as de-precoding, MIMO detection, de-mapping, and channel decoding.

[0050] As an example of a MIMO communication system that implements the MIMO detection scheme described above, FIG. 3 illustrates a detailed block diagram of MIMO communication system 200, according to some embodiments of the present disclosure. As shown in FIG. 3, transmitting device 210 may include a channel coding and interleaving module 312, a modulation module 314, a symbol mapping module 316, and a layer mapping and precoding module 318 for processing the original data to be transmitted.

[0051] For example, channel coding and interleaving module 312 may be configured to add extra bits (i.e., redundancy bits) to the original data (e.g., the input bits) for error detection purposes. Modulation module 314 (e.g., a QAM modulation module) may be configured to modulate and combine different signals (e.g., different bitstreams) by modulating two carrier waves (e.g., out of phase with each other by 90°) using amplitude-shift keying (ASK) digital modulation scheme or amplitude modulation (AM) analog modulation scheme, and to add the two carrier waves together. Symbol mapping module 316 may be configured to map the combined signals to encoded symbols. Layer mapping and precoding module 318 may be configured to map the encoded symbols onto different signal streams/layers. For example, layer mapping and precoding module 318 may perform a time-space and/or a spatial multiplexing precoding where the encoded symbols on each signal stream/layer are pre-coded to a symbol vector (e.g., a QAM symbol vector) and transmitted via all transmitting antennas.

[0052] The QAM symbol vector may be transmitted to receiving antennas through MIMO channel 230 according to function (1) below:

$$\boldsymbol{y} = \boldsymbol{Hx} + \boldsymbol{n} \qquad (1),$$

where $\boldsymbol{y} \in \mathbb{C}^M$ denotes the received symbol vector corresponding to the transmitted signal streams, $\boldsymbol{x} \in \mathbb{M}^N$ denotes the transmitted QAM symbol vector, where $\mathbb{M}$ is the set of QAM symbols for a particular modulation order (e.g., 2 for QPSK, 4 for 16 QAM, 6 for 64 QAM, 8 for 256 QAM and 10 for 1024 QAM), $\boldsymbol{H} \in \mathbb{C}^{N\times M}$ denotes the channel matrix representing the condition of MIMO channel 230, and $\boldsymbol{n} \in \mathbb{C}^M$ denotes the noise vector (e.g., a Gaussian noise vector).

[0053] As an example of a MIMO channel, FIG. 4 illustrates a schematic diagram of an exemplary MIMO channel 230, according to some embodiments of the present disclosure. As illustrated in FIG. 4, transmitting device 210 may include *n* transmitting antennas (e.g., labeled Tx1, Tx2, ..., Txn, respectively) for transmitting *n* transmitted signal streams, and receiving device 220 may include *m* receiving antennas (e.g., labeled Rx1, Rx2, ..., Rxm respectively) for receiving the transmitted signal streams. The channel matrix $\boldsymbol{H}$ may include *n* columns (e.g., corresponding to conditions of the *n* transmitted signal streams) and *m* rows (e.g., corresponding to conditions of the *m* receiving antennas).

[0054] Referring back to FIG. 3, receiving device 220 may include a de-precoding module 322, a de-mapping module 326, and a channel decoding module 328 for reversing the transmitter processing operations (e.g., space-time-de-precoding, de-mapping, demodulation, decoding etc.) and may determine the original data transmitted by transmitting device 210 to generate the decoded bits. Receiving device 220 may also include a MIMO detection module 324 for detecting the transmitted QAM symbol vector $\boldsymbol{x}$ based on an estimated matrix $\hat{\boldsymbol{H}}$ of channel matrix $\boldsymbol{H}$ and the received symbol vector $\boldsymbol{y}$.

[0055] In some embodiments, MIMO detection module 324 may permutate the transmitted signal streams based on metric(s) for the signal streams and perform the MIMO detection based on the permutated signal streams. After the detection, MIMO detection module 324 may further de-permutate the signal streams back to the original order for further processing. For example, MIMO detection module 324 and de-mapping module 326 together may further perform a log-likelihood ratio (LLR) calculation (e.g., include an LLR calculation unit for calculating an LLR) based on the detected signal streams with the original order (e.g., the restored original order) and may feed the LLR calculation result as an input to the channel decoders such as Turbo decoder or low density parity check (LDPC) decoder, etc. for decoding.

[0056] As an example of MIMO detection module 324 in FIG. 3, FIG. 5 illustrates a schematic diagram of an exemplary MIMO detection system 500, according to some embodiments of the present disclosure. As illustrated in FIG. 5, MIMO detection system 500 may be configured to determine a permutation (order) of the transmitted signal streams based on an optimal metric for the signal streams selected from candidate metrics, and detect the symbol vector (e.g., QAM symbol vector) based on the permutation using a detection model. For example, MIMO detection system 500 may include a permutation module 501 that includes a signal stream permutation unit 502 for determining the permutation of the signal streams, and a channel matrix permutation unit 504 for generating a permutated channel matrix representing the permutated signal streams by applying the determined permutation to the estimated channel matrix. MIMO detection system 500 may also include a symbol vector detection module 503 including a decomposition unit 506 and a QAM tree search unit 508 for performing symbol vector detection based on the detection model (e.g., QAM tree search model). MIMO detection system 500 may further include a de-permutation module 510 for restoring the order of the soft bits in the MIMO detection process (e.g., the permuted signal streams) back to the original order without permutation.

[0057] Specifically, signal streams permutation unit 502 may be configured to determine the permutation of the signal streams based on metrics for the signal streams. The metric for each signal stream may be determined based on the estimated channel matrix $\hat{\boldsymbol{H}}$, and may be one of the candidate metrics including L2 column norms of the estimated channel matrix $\hat{\boldsymbol{H}}$, L2 row norms of a pseudo-inverse of the estimated channel matrix $\hat{\boldsymbol{H}}$, or post-MMSE equalization SNR of the signal stream. In some embodiments, the estimated channel matrix $\hat{\boldsymbol{H}}$ may be estimated instantaneously. For example, the estimated channel matrix $\hat{\boldsymbol{H}}$ may be estimated at each time a set of signal streams is transmitted. In this way, the metrics for the signal streams can be determined more accurately (e.g., the permutation is dynamically determined based on the instantaneously estimated channel matrix $\hat{\boldsymbol{H}}$) and may have better accuracy reflecting the condition of each signal stream. This may at the cost of higher computational resources. Thus, if the condition of the channel (e.g., determined based on the statistics of the channel, including but not limited to, delay spread, Doppler spread, SNR, etc.) changes dramatically, this estimation method may be used as the MIMO detection can have better overall error performance.

[0058] On the other hand, the estimated channel matrix $\hat{\boldsymbol{H}}$ may be estimated periodically based on the average of the channel condition during an interval. For example, the estimated channel matrix $\hat{\boldsymbol{H}}$ may be estimated at a predetermined interval to reflect the average of the channel condition during the interval. Accordingly, the metrics for the signal streams can be determined at the interval and may remain the same during the interval. This estimation method can save computational resources and may be suitable for a situation where the channel condition stays relatively stable.

[0059] As an example of MIMO detection system 500, FIG. 6 illustrates a detailed block diagram of exemplary signal streams permutation unit 502, according to some embodiments of the present disclosure. As illustrated in FIG, 6, the metric used for signal stream permutations can be selected from a plurality of candidate metrics 601, 602, and 603 representing the L2 column norms of the estimated channel matrix $\hat{\boldsymbol{H}}$, L2 row norms of a pseudo-inverse of the estimated channel matrix $\hat{\boldsymbol{H}}$, and the post-MMSE equalization SNR, respectively. In some embodiments, candidate metric 601 may be determined based on calculating L2 column norms of the estimated channel matrix $\hat{\boldsymbol{H}}$ indicating the signal strength of the signal stream. For example, a Matrix Hermitian transpose unit 606 may apply Hermitian Matrix transpose to the estimated channel matrix $\hat{\boldsymbol{H}}$ to inverse the columns and rows of the estimated channel matrix $\hat{\boldsymbol{H}}$, and a matrix row vector norm calculation unit 604 may calculate the matrix row vector norm accordingly to indicate the signal strength of the signal stream. Candidate metric 601 may take up the least computational resources with reduced error performance for the overall MIMO detection compared with candidate metrics 602 and 603.

[0060] In some embodiments, candidate metric 602 may be determined based on L2 row norms of a pseudo-inverse of the estimated channel matrix $\hat{\boldsymbol{H}}$. For example, a QR decomposition unit 608 may apply QR decomposition, and a matrix inversion unit 610 may determine a pseudo inverse $\hat{\boldsymbol{H}}^{+}$ of the estimated channel matrix $\hat{\boldsymbol{H}}$ based on the decomposition. Then matrix row vector norm calculation unit 604 shared with candidate metric 601 may calculate the row L2 norms of an orthogonal transformation of the pseudo inverse $\hat{\boldsymbol{H}}^{+}$ accordingly (e.g., using $\boldsymbol{R}^{-1}$ as a representation of the pseudo inverse $\hat{\boldsymbol{H}}^{+}$ where $\boldsymbol{R}$ (a triangular matrix) is the result of the QR decomposition of the estimated channel matrix $\hat{\boldsymbol{H}}$) to indicate the SINR of the signal stream (e.g., the row of the pseudo inverse $\hat{\boldsymbol{H}}^{+}$ is reversely related to the SINR of the signal stream).

[0061] In some embodiments, candidate metric 603 may be hypothetical post-MMSE equalization SNR, and a post-MMSE equalization SNR calculation unit 612 may calculate the post-MMSE equalization SNR for the signal stream. For example, to calculate candidate metric 603 for an *i*th signal stream of the transmitted signal streams, candidate metric 603 may be calculated according to equation (2):

$$\rho_i = \frac{(\boldsymbol{G})_{ii}}{1-(\boldsymbol{G})_{ii}} \qquad (2),$$

where $(\boldsymbol{G})_{ii}$ denotes the *i*th diagonal element of matrix $G = \left(\hat{\mathrm{H}}^{\mathrm{H}}\hat{\mathrm{H}} + \mathrm{I}_{\mathrm{N}}\right)^{-1}\hat{\mathrm{H}}^{\mathrm{H}}\hat{\mathrm{H}}$ representing the effective MMSE equalization gain of the signal stream.

[0062] In some embodiments, the selection of the metric (e.g., selecting from candidate metrics 601, 602, and 603) may be based on the detection model used for MIMO detection. For example, when the computational resources are limited (e.g., under a limited time constrain and with limited candidate hardware and software computational resources), a detection model implementing a search algorithm with less complexity may be used. Accordingly, a metric with less complexity, such as candidate metric 601, may be selected for calculating the permutation. In some embodiments, when the accuracy requirement (e.g., the error rate for the MIMO detection) is relatively high, and the computational resources are adequate, a detection model implementing a search algorithm with more complexity may be used. Accordingly, a metric that has higher accuracy but with more complexity in the calculation, such as candidate metric 602 or 603, may be selected for determining the permutation.

[0063] In some embodiments, the metric selection may be based on the condition of the channel as well. For example, a candidate metric with less calculating complexity, such as candidate metric 601, may be selected when a channel has a relatively good condition (e.g., higher SNR), while another candidate metric with more accuracy but more complexity, such as candidate metrics 602 or 603, may be selected when a channel has a relatively bad condition (e.g., low SNR), such that the overall MIMO detection performance can be ensured at the lowest computational power cost.

[0064] In some embodiments, the metric selection may be performed with a feedback mechanism or a feed-forward mechanism. For example, the quality of detection result of previous MIMO detection (e.g., the quality of the previous detection result) may be used for determining the metric selected for the ongoing MIMO detection following a feedback mechanism. In another example, the channel condition for the current MIMO detection may be used for selecting the metric as described above, following a feed-forward mechanism.

[0065] In some embodiments, the metric selection process may be controlled by a control signal for metric selection provided by a processor (e.g., processor 1002) in conjunction with various multiplexing mechanisms 614 according to the scheme(s) disclosed above. It is contemplated that the possible candidate metrics for indicating the strength of the signal stream, and the metric selection methods are not limited to those being disclosed herein. Any other suitable candidate metrics and metric selection methods may be applied by signal streams permutation unit 502 for calculating the permutation order of the transmitted signal streams. Nevertheless, based on the selected metric and the values of the metric for each transmitted signal stream, the transmitted signal stream can be permutated by signal stream permutation unit 502 with the permutation as its output. In some embodiments, the permutation may be represented as a transformation matrix $\boldsymbol{\Pi}$.

[0066] Referring back to FIG. 5, in some embodiment, signal streams permutation unit 502 may send the permutation of the transmitted signal streams to channel matrix permutation unit 504 for calculating the permutation channel matrix $\widetilde{\boldsymbol{H}}$ as well as to de-permutation module 510 for restoring the original order of the transmitted signal streams (e.g., restore the order of all the soft bits in the MIMO detection process). For example, signal streams permutation unit 502 may output a transformation matrix $\boldsymbol{\Pi}$ representing the permutation. For example, channel matrix permutation unit 504 may calculate a permutated channel matrix $\widetilde{\boldsymbol{H}}$ according to $\widetilde{\boldsymbol{H}} = \widehat{\boldsymbol{H}} * \boldsymbol{\Pi}$, and then send the permutated channel matrix $\widetilde{\boldsymbol{H}}$ to symbol vector detection module 503 (including decomposition unit 506 and QAM tree search unit 508) for symbol vector detection.

[0067] Decomposition unit 506 may perform QR decomposition of the permutated channel matrix $\widetilde{\boldsymbol{H}}$, and QAM tree search unit 508 may detect symbol vector $\boldsymbol{x}$ using a MIMO detection model implementing a search algorithm, such as a near-ML algorithm with reduced complexity. For example, the permutated channel matrix $\widetilde{\boldsymbol{H}}$ may be decomposed according to $\widetilde{\boldsymbol{H}} = \boldsymbol{QR}$, where $\boldsymbol{R}$ is an $N \times N$ upper-triangular matrix. The system model of MIMO communication can be further transformed according to equation (3):

$$\bar{\mathbf{y}} = \boldsymbol{Q}^{\widetilde{H}}\,\mathbf{y} = \boldsymbol{R}\boldsymbol{x} + \bar{\boldsymbol{n}} \qquad (3),$$

where $\bar{\boldsymbol{n}}$ is still an uncorrelated white Gaussian noise vector.

[0068] In some embodiments, if the permutated channel matrix $\widetilde{\boldsymbol{H}}$ is ill-conditioned, decomposition unit 506 may also generate an augmented channel matrix $\underline{\boldsymbol{H}} = \begin{bmatrix}\widetilde{\boldsymbol{H}} \\ \mathbf{I}_{\mathrm{N}}\end{bmatrix}$ by applying regularization to the permutated channel matrix $\widetilde{\boldsymbol{H}}$. Accordingly, a correction needs to be applied to the output of symbol vector detection module 503 to reduce the influence of using the augmented channel matrix $\underline{\boldsymbol{H}}$.

[0069] In some embodiments, in QAM tree search unit 508, a near-ML algorithm may be performed for calculating a near-ML solution of the transmitted QAM symbol vector $\widehat{\boldsymbol{x}}_{nML}$ according to equation (4):

$$\widehat{\boldsymbol{x}}_{\boldsymbol{nML}} = \underset{\boldsymbol{x}\in\mathbb{M}^N}{\boldsymbol{argmin}}\left\|\boldsymbol{y} - \widetilde{\boldsymbol{H}}\boldsymbol{x}\right\|^2 \qquad (4).$$

[0070] Thus, solving the MIMO detection problem can be transformed to an equivalent QAM symbol tree search problem where the root-to-leaf tree path of the QAM symbol-tree represents the transmitted QAM symbol vector $\boldsymbol{x}$, such that the leaf (e.g., the node) associated with the smallest value on each level are searched for based on the QAM symbol-tree search algorithm. The QAM symbol vector $\boldsymbol{x}$ may be of the length N and consists of QAM symbols from the N transmitted symbol streams.

[0071] In some embodiments, de-permutation module 510 is configured to restore the original order of the signal streams without the permutation. De-permutation module 510 may de-permutate the soft bits in the MIMO detection process (e.g., the permutated signal streams) to the original order (e.g., to restore the original order of the transmitted signal streams) based on the transformation matrix $\boldsymbol{\Pi}$ reflecting the permutation of the signal streams generated by signal streams permutation unit 502,. Referring back to FIG. 3, the restored symbol vector x may be the output of MIMO detection module 324 (e.g., MIMO detection system 500) and may be transmitted to de-mapping module 326 for further processing. For example, MIMO detection module 324 and de-mapping module 326 combinedly may calculate an LLR based on the restored symbol vector x.

[0072] It is contemplated that MIMO detection system 500 described above for MIMO communication may be implemented either in software or hardware. For example, FIGs. 7A and 7B illustrate block diagrams of an exemplary apparatus 700 including a host chip, a RF chip, and a baseband chip implementing the MIMO detection system in FIG. 5 in software and hardware, respectively, according to some embodiments of the present disclosure. Apparatus 700 may be an example of any suitable node of wireless network 100 in FIG. 1, such as user equipment 102 or access node 104. As shown in FIG. 7, apparatus 700 may include a RF chip 702, a baseband chip 704 (baseband chip 704A in FIG. 7A or baseband chip 704B in FIG. 7B), a host chip 706, and multiple antennas 710. In some embodiments, baseband chip 704 is implemented by processor 1002 and memory 1004, and RF chip 702 is implemented by processor 1002, memory 1004, and transceiver 1006, as described above with respect to FIG. 10. Besides on-chip memory 712 (also known as "internal memory," e.g., as registers, buffers, or caches) on each chip 702, 704, or 706, apparatus 700 may further include a system memory 708 (also known as the main memory) that can be shared by each chip 702, 704, or 706 through the main bus. Although baseband chip 704 is illustrated as a standalone SoC in FIGs. 7A and 7B, it is understood that in one example, baseband chip 704 and RF chip 702 may be integrated as one SoC; in another example, baseband chip 704 and host chip 706 may be integrated as one SoC; in still another example, baseband chip 704, RF chip 702, and host chip 706 may be integrated as one SoC, as described above.

[0073] In the uplink, host chip 706 may generate original data and send it to baseband chip 704 for encoding, modulation, and mapping. Baseband chip 704 may access the original data from host chip 706 directly using an interface 714 or through system memory 708 and then perform the functions of channel coding and interleaving module 312, modulation module 314, symbol mapping module 316, and layer mapping and precoding module 318, as described above in detail with respect to FIG. 3. Baseband chip 704 then may pass the modulated signals to RF chip 702 through interface 714. A transmitter (Tx) 716 of RF chip 702 may convert the modulated signals in the digital form from baseband chip 704 into analog signals, i.e., RF signals, and transmit the RF signals in multiple signal streams through multiple antennas 710, respectively, into the MIMO channel.

[0074] In the downlink, multiple antennas 710 may receive the RF signals in the multiple transmitted signal streams through the MIMO channel and pass the RF signals to a receiver (Rx) 718 of RF chip 702. RF chip 702 may perform any suitable front-end RF functions, such as filtering, down-conversion, or sample-rate conversion, and convert the RF signals into low-frequency digital signals (baseband signals) that can be processed by baseband chip 704. In the downlink, interface 714 of baseband chip 704 may receive the baseband signals, for example, the multiple transmitted signals streams. Baseband chip 704 then may perform the functions of de-precoding module 322, MIMO detection module 324, de-mapping module 326, and channel decoding module 328, as described above in detail with respect to FIG. 3. The original data may be extracted by baseband chip 704 from the baseband signals and passed to host chip 706 through interface 714 or stored into system memory 708.

[0075] In some embodiments, the MIMO detection schemes disclosed herein (e.g., by MIMO detection module 324 or MIMO detection system 500) may be implemented in software by baseband chip 704A in FIG. 7A having a baseband processor 720 executing the stored instructions, as illustrated in FIG. 7A. Baseband processor 720 may be a generic processor, such as a central processing unit or a DSP, not dedicated to MIMO detection. That is, baseband processor 720 is also responsible for any other functions of baseband chip 704A and can be interrupted when performing MIMO detection due to other processes with higher priorities. Each element in MIMO detection system 500 may be implemented as a software module executed by baseband processor 720 to perform the respective functions described above in detail.

[0076] In some other embodiments, the MIMO detection schemes disclosed herein, for example, by MIMO detection module 324 or MIMO detection system 500, may be implemented in hardware by baseband chip 704B in FIG. 7B having a dedicated MIMO detection circuit 722, as illustrated in FIG. 7A. MIMO detection circuit 722 may include one or more ICs, such as ASICs, dedicated to implementing the MIMO detection schemes disclosed herein. Each element in MIMO detection system 500 may be implemented as a circuit to perform the respective functions described above in detail. One or more microcontrollers (not shown) in baseband chip 704B may be used to program and/or control the operations of MIMO detection circuit 722. It is understood that in some examples, the MIMO detection schemes disclosed herein may be implemented in a hybrid manner, e.g., in both hardware and software. For example, some elements in MIMO detection system 500 may be implemented as a software module executed by baseband processor 720, while some elements in MIMO detection system 500 may be implemented as circuits.

[0077] FIG. 8 illustrates a flow chart of an exemplary method 800 for MIMO detection, FIG. 9 illustrates a flow chart of another exemplary method 900 for MIMO detection with more specifics, according to some embodiments of the present disclosure. Examples of the apparatus that can perform operations of methods 800 and 900 include, for example, apparatus depicted in FIGs. 2 – 6, 7A, and 7B or any other apparatus disclosed herein. It is understood that the operations shown in methods 800 and 900 are not exhaustive and that other operations can be performed as well before, after, or between any of the illustrated operations. Further, some of the operations may be performed simultaneously, or in a different order than shown in FIGs. 8 and 9. FIGs. 8 and 9 will be described together.

[0078] Referring to FIG. 8, method 800 starts at operation 802, in which a plurality of signal streams corresponding to a symbol vector are received through a MIMO channel. In some embodiments, the symbol vector may correspond to the original data processed (e.g., coded, modulated, and mapped) using a spatial multiplexing method (e.g., MIMO) by transmitting device 210. The MIMO channel (e.g., MIMO channel 230) may represent the multipath communication links between the transmitting antennas and the receiving antennas. As shown in FIG. 5, symbol vector detection module 503 of MIMO detection system 500 may receive multiple transmitted signal streams.

[0079] Method 800 proceeds to operation at 804, in which a metric indicative of the signal strength for each of the plurality of signal streams is determined based on the condition of the MIMO channel. As shown in FIG. 5, permutation module 501 of MIMO detection system 500 may determine the metric indicative of the signal strength for each signal stream based on the MIMO channel condition. The details of operation 804 may be illustrated in one example in FIG. 9.

[0080] For example, as illustrated in FIG. 9, in operation at 902, a first channel matrix representing the condition of the MIMO channel is estimated. The condition of the MIMO channel may be estimated instantaneously or averaged over a period of time. In some embodiments, whether the channel matrix is estimated instantaneously or over a period of time is determined based on the statistics of the channel, including but not limited to, delay spread, Doppler spread, SNR, etc.

[0081] Method 900 proceeds to operation at 904, the metric indicative of the signal strength for each signal stream is selected from the plurality of candidate metrics based on the MIMO detection model and/or the MIMO channel condition. In some embodiments, the candidate metrics include L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-MMSE equalization SNR. For example, the metric may be selected based on the MIMO detection model, such as the QAM tree search model. In another example, the metric may be selected based on the condition of the MIMO channel. The channel condition may be determined based on at least one of the statistics of the channel, including but not limited to, delay spread, Doppler spread, SNR, etc. In yet another example, the metric may be selected based on both the MIMO detection model and the MIMO channel condition

[0082] Referring back to FIG. 8, method 800 proceeds to operation at 806, in which a permutation of the plurality of signal streams is determined based on the metrics of the plurality of signal streams. That plurality of signal streams may be re-ordered in a permutation based on their calculated values of the selected metric. For example, when the search algorithm implemented by the MIMO detection model is symmetric (e.g., a fixed number of computational resources are assigned to the search of each signal stream), a signal stream with stronger strength may be detected first. In another example, when the search algorithm implemented by the MIMO detection model is asymmetric (e.g., the earlier the signal stream is detected, the larger number of computational resources are assigned to the search of the signal stream), a signal stream with weaker strength may be detected first.

[0083] As shown in FIG. 5, permutation module 501 of MIMO detection system 500 may determine the permutation of the signal streams based on the metrics of the signal streams.

[0084] Method 800 proceeds to operation at 808, in which the symbol vector is detected using the MIMO detection model based on the permutation of the signal streams. As shown in FIG. 5, symbol vector detection module 503 of MIMO detection system 500 may detect the transmitted symbol vector based on the permutation of the transmitted signal steams using the MIMO detection model. The details of operation 804 may be illustrated in one example in FIG. 9.

[0085] For example, as illustrated in FIG. 9, in operation at 906, a second channel matrix corresponding to the permuted signals streams is determined based on the first channel matrix and the permutation of the plurality of signal streams. For example, the second channel matrix may the dot product of a transformation matrix representing the permutation and the estimated channel matrix. In operation at 908, computation resource is assigned to each of the signal streams based on the permutation of the signal streams. In some embodiments, the total computational resources assigned to the signal streams are predetermined based on the MIMO detection model.

[0086] In operation 910, the symbol vector is detected using the MIMO detection model based on the permutation of the transmitted signal streams. For example, the second channel matrix may be QR decomposed, and the symbol vector may be detected based on the QAM tree search model with the computational resources assigned to each level of the QAM tree corresponding to the respective signal stream.

[0087] In operation at 912, the original order of the plurality of signal streams is restored without the permutation. For example, the permuted soft bits in the MIMO detection process (e.g., the permutated signal streams) may be de-permutated to the original order (e.g., to restore the original order of the transmitted signal streams) based on the permutation (e.g., transformation matrix $\boldsymbol{\Pi}$ reflecting the permutation).

[0088] In various aspects of the present disclosure, the functions described herein may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or encoded as instructions or code on a non-transitory computer-readable medium. Computer-readable media includes computer storage media. Storage media may be any available media that can be accessed by a receiving device, such as receiving device 1000 in FIG. 10. By way of example, and not limitation, such computer-readable media can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, HDD, such as magnetic disk storage or other magnetic storage devices, Flash drive, SSD, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a processing system, such as a mobile device or a computer. Disk and disc, as used herein, includes CD, laser disc, optical disc, DVD, and floppy disk where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[0089] According to one aspect of the present disclosure, an apparatus can include at least one processor and memory including storing instructions. The instructions, when executed by the at least one processor, cause the apparatus to receive a plurality of signal streams corresponding to a symbol vector through a channel. The instructions, when executed by the at least one processor, also cause the apparatus to determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel. The instructions, when executed by the at least one processor, further cause the apparatus to determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams. The instructions, when executed by the at least one processor, yet cause the apparatus to detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

[0090] In some embodiments, to determine the metric, execution of the instructions further causes the apparatus to select the metric from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

[0091] In some embodiments, execution of the instructions further causes the apparatus to estimate a first channel matrix representing the condition of the channel.

[0092] In some embodiments, the plurality of metrics include L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-MMSE equalization SNR.

[0093] In some embodiments, execution of the instructions further causes the apparatus to determine a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams, and detect the symbol vector based on the second channel matrix using the model.

[0094] In some embodiments, the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

[0095] In some embodiments, the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

[0096] In some embodiments, to detect the symbol vector, execution of the instructions further causes the apparatus to assign a computational resource to the plurality of signal streams based on the permutation of the plurality of signal streams.

[0097] In some embodiments, a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

[0098] In some embodiments, execution of the instructions further causes the apparatus to restore an original order of the plurality of signal streams without the permutation.

[0099] According to another aspect of the present disclosure, a baseband chip includes an interface and a multiple-input and a MIMO detection circuit operatively coupled to the interface. The interface is configured to receive a plurality of signal streams corresponding to a symbol vector through a channel. The MIMO detection circuit is configured to determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel. The MIMO detection circuit is also configured to determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams. The MIMO detection circuit is further configured to detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

[0100] In some embodiments, to determine the metric, the MIMO detection circuit is also configured to select the metric from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

[0101] In some embodiments, the MIMO detection circuit is also configured to estimate a first channel matrix representing the condition of the channel.

[0102] In some embodiments, the plurality of metrics include L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-MMSE equalization SNR.

[0103] In some embodiments, the MIMO detection circuit is also configured to determine a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams, and detect the symbol vector based on the second channel matrix using the model.

[0104] In some embodiments, the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

[0105] In some embodiments, the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

[0106] In some embodiments, to detect the symbol vector, the MIMO detection circuit is also configured to assign computational resources to the plurality of signal streams based on the permutation of the plurality of signal streams.

[0107] In some embodiments, a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

[0108] In some embodiments, the MIMO detection circuit is also configured to restore an original order of the plurality of signal streams without the permutation.

[0109] According to still another aspect of the present disclosure, an apparatus for wireless communication includes a symbol vector detection module and a permutation module. The symbol vector detection module is configured to receive a plurality of signal streams corresponding to a symbol vector through a channel and detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams. The permutation module is configured to determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel and determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams.

[0110] In some embodiments, to determine the metric, the permutation module is also configured to select the metric from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

[0111] In some embodiments, the permutation module is also configured to estimate a first channel matrix representing the condition of the channel.

[0112] In some embodiments, the plurality of metrics include L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-MMSE equalization SNR.

[0113] In some embodiments, the symbol vector detection module is also configured to determine a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams, and detect the symbol vector based on the second channel matrix using the model.

[0114] In some embodiments, the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

[0115] In some embodiments, the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

[0116] In some embodiments, to detect the symbol vector, the symbol vector detection module is also configured to assign computational resources to the plurality of signal streams based on the permutation of the plurality of signal streams.

[0117] In some embodiments, a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

[0118] In some embodiments, the symbol vector detection module is also configured to restore an original order of the plurality of signal streams without the permutation.

[0119] According to yet another aspect of the present disclosure, a method implemented by a baseband chip for MIMO communication. A plurality of signal streams corresponding to a symbol vector is received through a channel. A metric indicative of a signal strength for each of the plurality of signal streams is determined based on a condition of the channel. A permutation of the plurality of signal streams is determined based on the metrics of the plurality of signal streams. The symbol vector from the plurality of signal streams is detected using a model based on the permutation of the plurality of signal streams.

[0120] In some embodiments, to determine the metric, the metric is selected from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

[0121] In some embodiments, a first channel matrix representing the condition of the channel is estimated.

[0122] In some embodiments, the plurality of metrics include L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-MMSE equalization SNR.

[0123] In some embodiments, a second channel matrix is determined based on the first channel matrix and the permutation of the plurality of signal streams, and the symbol vector is detected based on the second channel matrix using the model.

[0124] In some embodiments, the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

[0125] In some embodiments, the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

[0126] In some embodiments, to detect the symbol vector, a computational resource is assigned to the plurality of signal streams based on the permutation of the plurality of signal streams.

[0127] In some embodiments, a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

[0128] In some embodiments, an original order of the plurality of signal streams without the permutation is restored.

[0129] According to further another aspect of the disclosure, a non-transitory computer-readable medium is encoded with instructions that, when executed by at least one processor of a terminal device, perform a process. The process includes receiving a plurality of signal streams corresponding to a symbol vector through a channel, and determining a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel. The process also includes determining a permutation of the plurality of signal streams based on the metrics of the plurality of signal streams and detecting the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

[0130] In some embodiments, to determine the metric, the metric is selected from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

[0131] In some embodiments, the process further includes estimating a first channel matrix representing the condition of the channel.

[0132] In some embodiments, the plurality of metrics include L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-MMSE equalization SNR.

[0133] In some embodiments, the process further includes determining a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams, and detecting the symbol vector based on the second channel matrix using the model.

[0134] In some embodiments, the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

[0135] In some embodiments, the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

[0136] In some embodiments, to detect the symbol vector, a computational resource is assigned to the plurality of signal streams based on the permutation of the plurality of signal streams.

[0137] In some embodiments, a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

[0138] In some embodiments, the process further includes restoring an original order of the plurality of signal streams without the permutation.

[0139] The foregoing description of the specific embodiments will so reveal the general nature of the present disclosure that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present disclosure. Therefore, such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein. It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by the skilled artisan in light of the teachings and guidance.

[0140] Embodiments of the present disclosure have been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified functions and relationships thereof are appropriately performed.

[0141] The Summary and Abstract sections may set forth one or more but not all exemplary embodiments of the present disclosure as contemplated by the inventor(s), and thus, are not intended to limit the present disclosure and the appended claims in any way.

[0142] Various functional blocks, modules, and steps are disclosed above. The particular arrangements provided are illustrative and without limitation. Accordingly, the functional blocks, modules, and steps may be re-ordered or combined in different ways than in the examples provided above. Likewise, certain embodiments include only a subset of the functional blocks, modules, and steps, and any such subset is permitted.

[0143] The breadth and scope of the present disclosure should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

WHAT IS CLAIMED IS:

1. An apparatus for wireless communication, comprising:

at least one processor; and

memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to:

receive a plurality of signal streams corresponding to a symbol vector through a channel;

determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel;

determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams; and

detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

2. The apparatus of claim 1, wherein to determine the metric, execution of the instructions further causes the apparatus to select the metric from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

3. The apparatus of claim 2, wherein execution of the instructions further causes the apparatus to estimate a first channel matrix representing the condition of the channel.

4. The apparatus of claim 3, wherein the plurality of candidate metrics comprise L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-minimum mean squared error (MMSE) equalization signal-to-noise ratio (SNR).

5. The apparatus of claim 3 or 4, wherein to detect the symbol vector, execution of the instructions further causes the apparatus to:

determine a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams; and

detect the symbol vector based on the second channel matrix using the model.

6. The apparatus of any one of claims 1-5, wherein the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

7. The apparatus of any one of claims 1-5, wherein the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

8. The apparatus of any one of claims 1-7, wherein to detect the symbol vector, execution of the instructions further causes the apparatus to assign a computational resource to each of the plurality of signal streams based on the permutation of the plurality of signal streams.

9. The apparatus of claim 8, wherein a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

10. The apparatus of any one of claims 1-9, wherein execution of the instructions further causes the apparatus to restore an original order of the plurality of signal streams without the permutation.

11. A baseband chip, comprising:

an interface configured to receive a plurality of signal streams corresponding to a symbol vector through a channel; and

a multiple-input and multiple-output (MIMO) detection circuit operatively coupled to the interface and configured to:

determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel;

determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams; and

detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

12. The baseband chip of claim 11, wherein to determine the metric, the MIMO detection circuit is further configured to select the metric from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

13. The baseband chip of claim 12, the MIMO detection circuit is further configured to estimate a first channel matrix representing the condition of the channel.

14. The baseband chip of claim 13, wherein the plurality of candidate metrics comprise L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-minimum mean squared error (MMSE) equalization signal-to-noise ratio (SNR).

15. The baseband chip of claim 13 or 14, wherein to detect the symbol vector, the MIMO detection circuit is further configured to:

determine a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams; and

detect the symbol vector based on the second channel matrix using the model.

16. The baseband chip of any one of claims 11-15, wherein the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

17. The baseband chip of any one of claims 11-15, wherein the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

18. The baseband chip of any one of claims 11-17, wherein to detect the symbol vector, the MIMO detection circuit is further configured to assign a computational resource to the plurality of signal streams based on the permutation of the plurality of signal streams.

19. The baseband chip of claim 18, wherein a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

20. The baseband chip of any one of claims 11-19, wherein the MIMO detection circuit is further configured to restore an original order of the plurality of signal streams without the permutation.

21. The baseband chip of any one of claims 11-20, wherein the MIMO detection circuit is an application-specific integrated circuit (ASIC).

22. An apparatus for wireless communication, comprising:

a symbol vector detection module configured to receive a plurality of signal streams corresponding to a symbol vector through a channel;

a permutation module configured to:

determine a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel; and

determine a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams,

wherein the symbol vector detection module is further configured to detect the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

23. The apparatus of claim 22, wherein to determine the metric, the permutation module is further configured to select the metric from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

24. The apparatus of claim 23, wherein the permutation module is further configured to estimate a first channel matrix representing the condition of the channel.

25. The apparatus of claim 24, wherein the plurality of candidate metrics comprise L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post-minimum mean squared error (MMSE) equalization signal-to-noise ratio (SNR).

26. The apparatus of claim 24 or 25, wherein to detect the symbol vector, the symbol vector detection module is further configured to:

determine a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams; and

detect the symbol vector based on the second channel matrix using the model.

27. The apparatus of any one of claims 22-26, wherein the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

28. The apparatus of any one of claims 22-26, wherein the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

29. The apparatus of any one of claims 22-28, wherein to detect the symbol vector, the symbol vector detection module is further configured to assign a computational resource to the plurality of signal streams based on the permutation of the plurality of signal streams.

30. The apparatus of claim 29, wherein a total of the computational resources assigned to the plurality of signal streams is predetermined based on the model.

31. The apparatus of any one of claims 22-30, wherein the symbol vector detection module is further configured to restore an original order of the plurality of signal streams without the permutation.

32. A method implemented by a baseband chip for multiple-input and multiple-output (MIMO) communication, comprising:

receiving a plurality of signal streams corresponding to a symbol vector through a channel;

determining a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel;

determining a permutation of the plurality of signal streams based on the metrics for the plurality of signal streams; and

detecting the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

33. The method of claim 32, wherein determining the metric comprises selecting the metric from a plurality of candidate metrics based on at least one of the model or the condition of the channel.

34. The method of claim 33, further comprising estimating a first channel matrix representing the condition of the channel.

35. The method of claim 34, wherein the plurality of candidate metrics comprise L2 column norms of the first channel matrix, L2 row norms of a pseudo-inverse of the first channel matrix, and post- minimum mean squared error (MMSE) equalization signal-to-noise ratio (SNR).

36. The method of claim 34 or 35, wherein detecting the symbol vector further comprises:

determining a second channel matrix based on the first channel matrix and the permutation of the plurality of signal streams; and

detecting the symbol vector based on the second channel matrix using the model.

37. The method of any one of claims 32-36, wherein the metrics for the plurality of signal streams are dynamically determined in response to the condition of the channel.

38. The method of any one of claims 32-36, wherein the metrics for the plurality of signal streams are determined at an interval based on an average of the condition of the channel during the interval.

39. The method of any one of claims 32-38, wherein detecting the symbol vector comprises assigning a computational resource to the plurality of signal streams based on the permutation of the plurality of signal streams.

40. The method of claim 39, wherein a total of computational resources assigned to the plurality of signal streams is predetermined based on the model.

41. The method of any one of claims 32-40, wherein detecting the symbol vector comprises restoring an original order of the plurality of signal streams without the permutation.

42. A non-transitory computer-readable medium encoded with instructions that, when executed by at least one processor of an apparatus, perform a process comprising:

receiving a plurality of signal streams corresponding to a symbol vector, through a channel;

determining a metric indicative of a signal strength for each of the plurality of signal streams based on a condition of the channel;

determining a permutation for the plurality of signal streams based on the metrics for the plurality of signal streams; and

detecting the symbol vector from the plurality of signal streams using a model based on the permutation of the plurality of signal streams.

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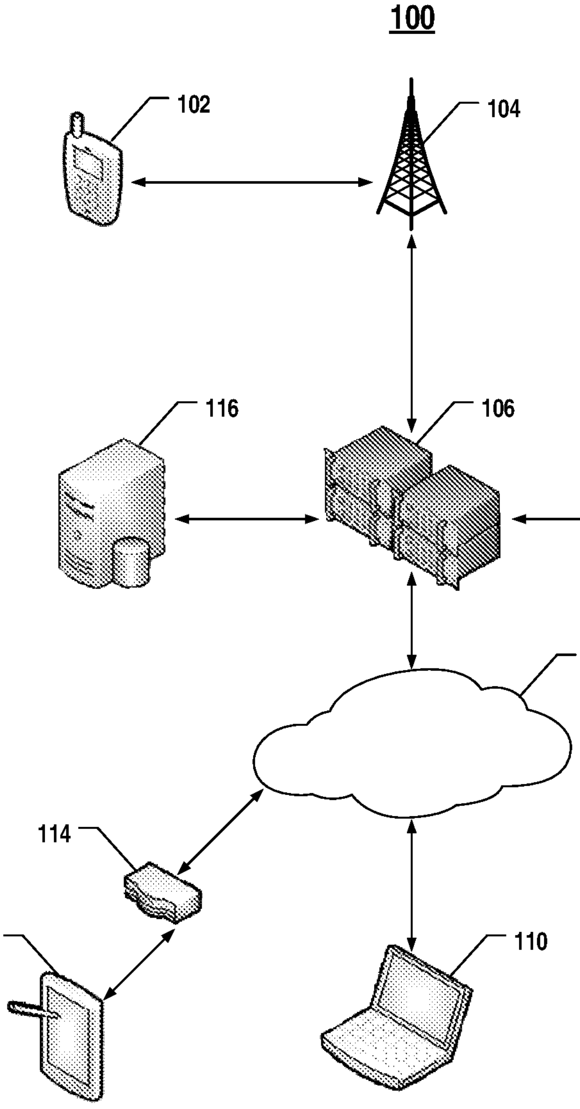

FIG. 1

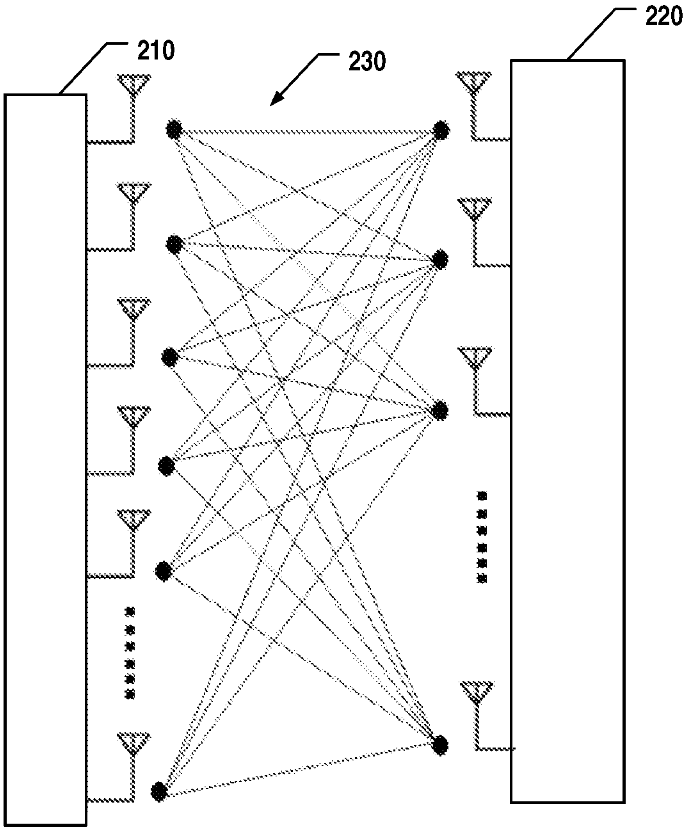
210
230
220

FIG. 2

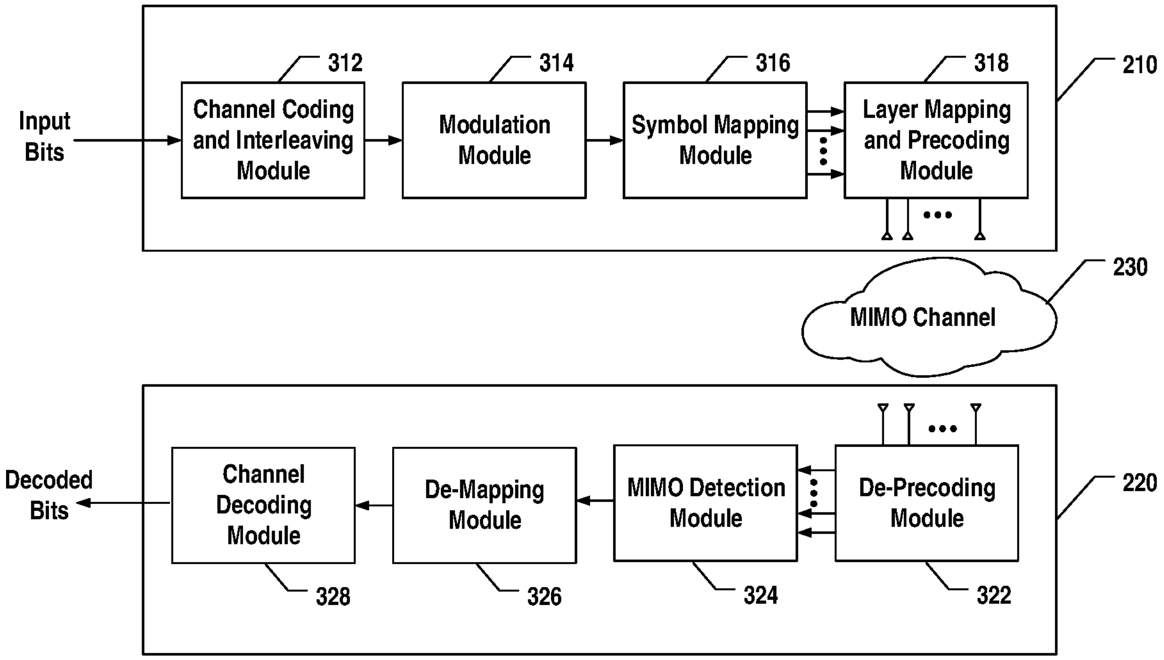
Input Bits
Channel Coding and Interleaving Module
312
Modulation Module
314
Symbol Mapping Module
316
Layer Mapping and Precoding Module
318
210
MIMO Channel
230
Decoded Bits
Channel Decoding Module
328
De-Mapping Module
326
MIMO Detection Module
324
De-Precoding Module
322
220

FIG. 3

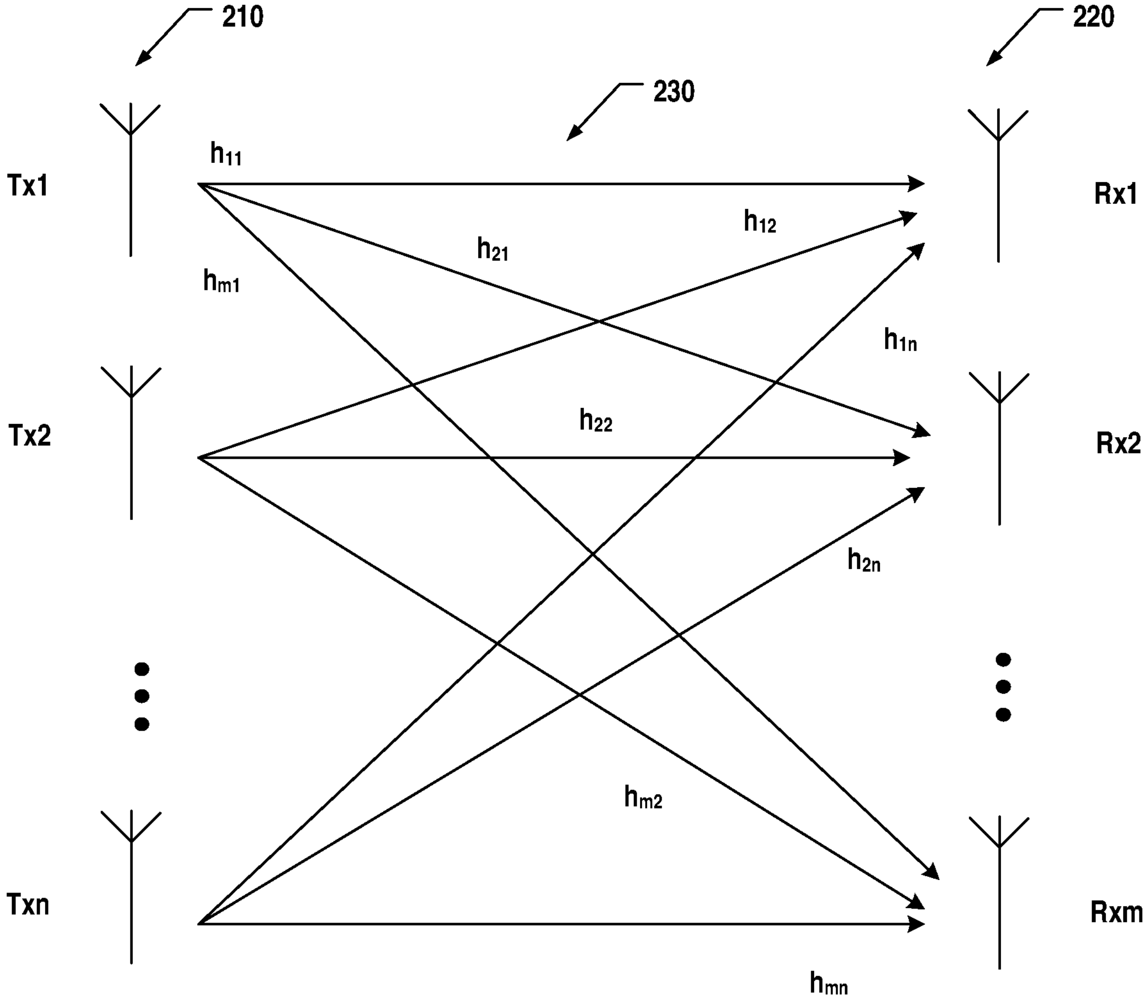
210
220
230
Tx1
Tx2
Txn
Rx1
Rx2
Rxm
h_{11}
h_{12}
h_{21}
h_{m1}
h_{1n}
h_{22}
h_{2n}
h_{m2}
h_{mn}

FIG. 4

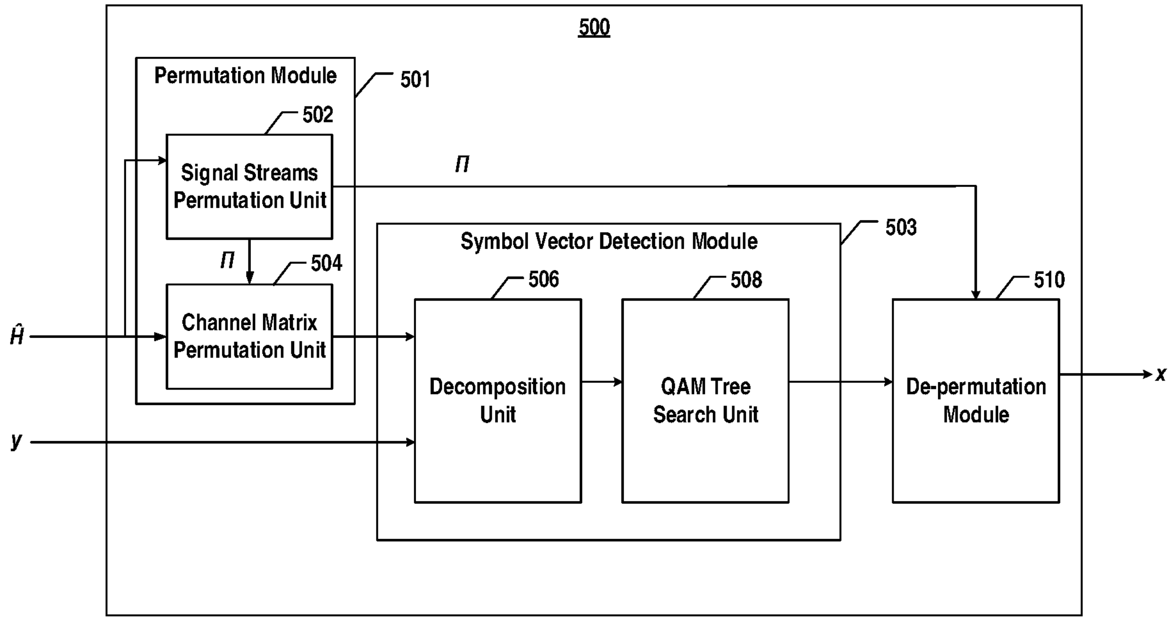
500
Permutation Module
501
502
Signal Streams Permutation Unit
Π
Π
504
Channel Matrix Permutation Unit
Ĥ
y
Symbol Vector Detection Module
503
506
Decomposition Unit
508
QAM Tree Search Unit
510
De-permutation Module
x

FIG. 5

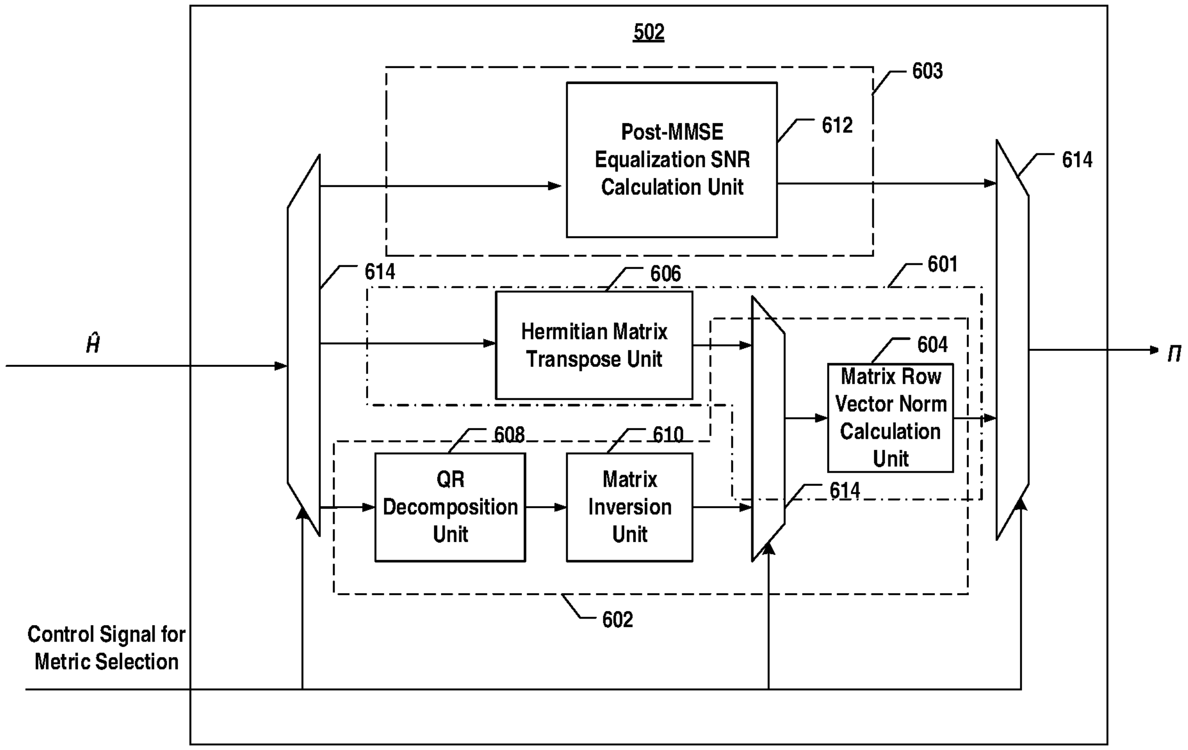
502
603
Post-MMSE Equalization SNR Calculation Unit
612
614
614
606
Hermitian Matrix Transpose Unit
601
Ĥ
604
Matrix Row Vector Norm Calculation Unit
Π
608
QR Decomposition Unit
610
Matrix Inversion Unit
614
602
Control Signal for Metric Selection

FIG. 6

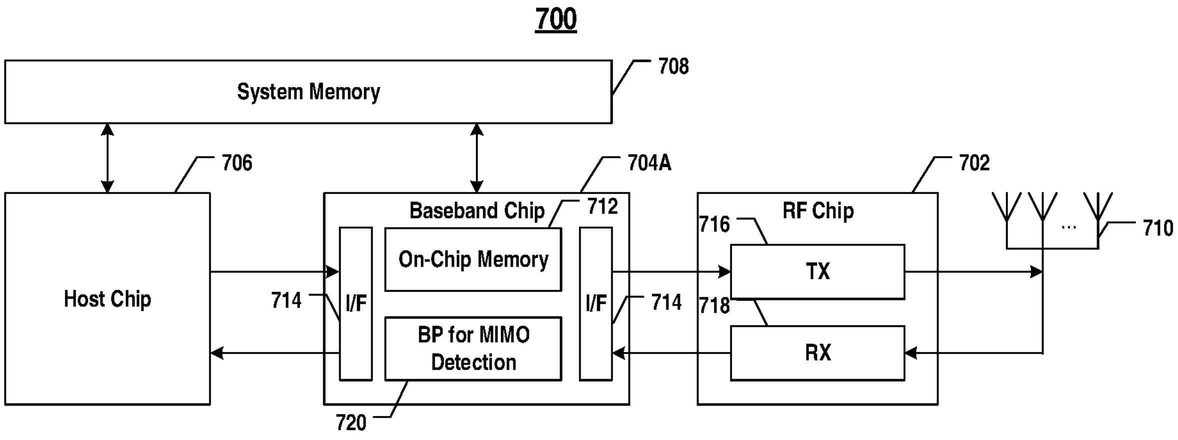
700
System Memory
708
706
704A
702
Host Chip
Baseband Chip
712
On-Chip Memory
BP for MIMO Detection
720
I/F
714
I/F
714
RF Chip
716
718
TX
RX
710

FIG. 7A

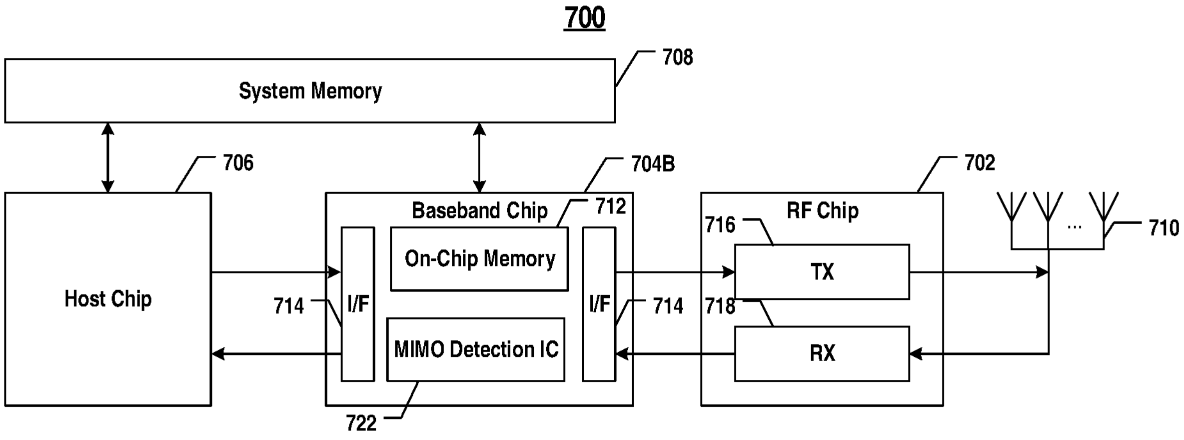
700
System Memory
708
706
704B
702
Host Chip
Baseband Chip
712
On-Chip Memory
MIMO Detection IC
722
I/F
714
I/F
714
RF Chip
716
718
TX
RX
710

FIG. 7B

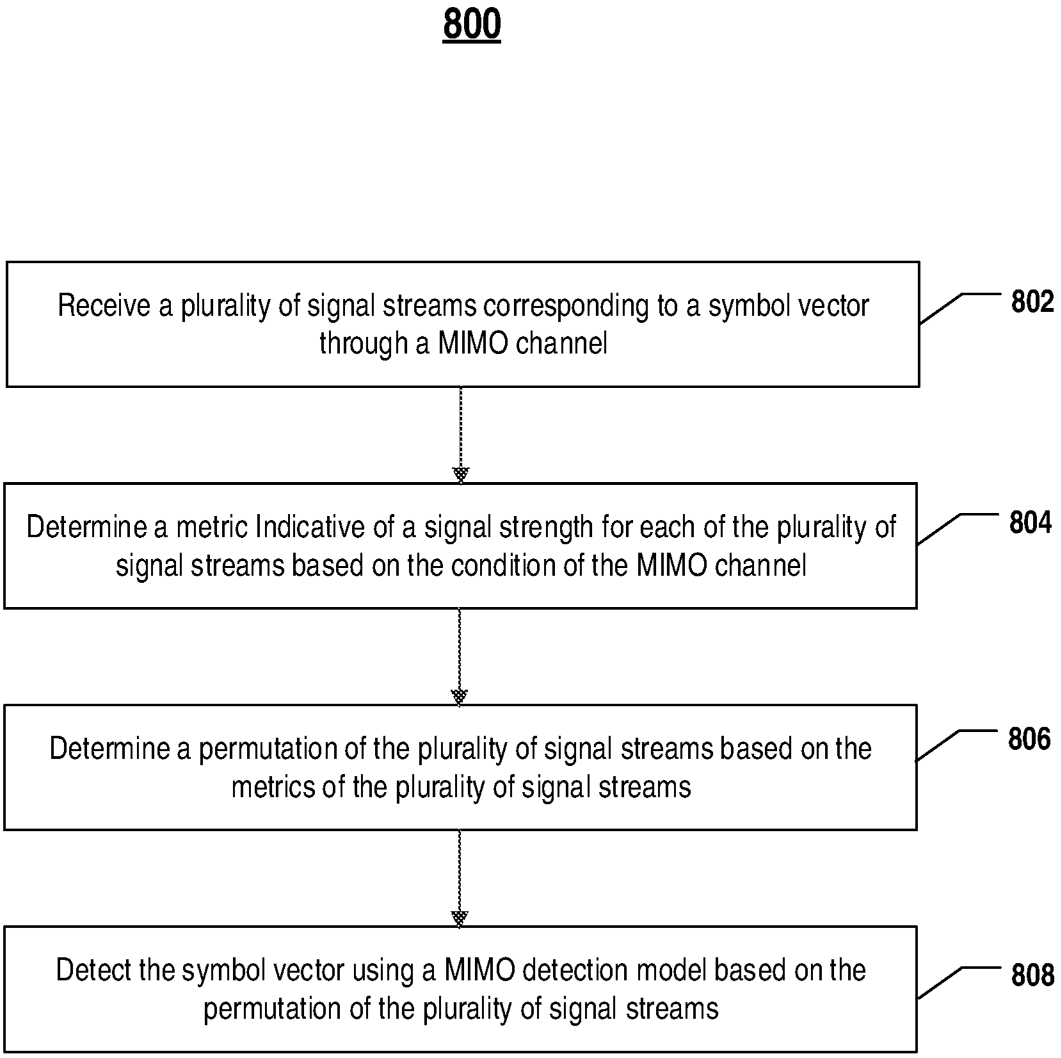
800
Receive a plurality of signal streams corresponding to a symbol vector through a MIMO channel
802
Determine a metric Indicative of a signal strength for each of the plurality of signal streams based on the condition of the MIMO channel
804
Determine a permutation of the plurality of signal streams based on the metrics of the plurality of signal streams
806
Detect the symbol vector using a MIMO detection model based on the permutation of the plurality of signal streams
808

FIG. 8

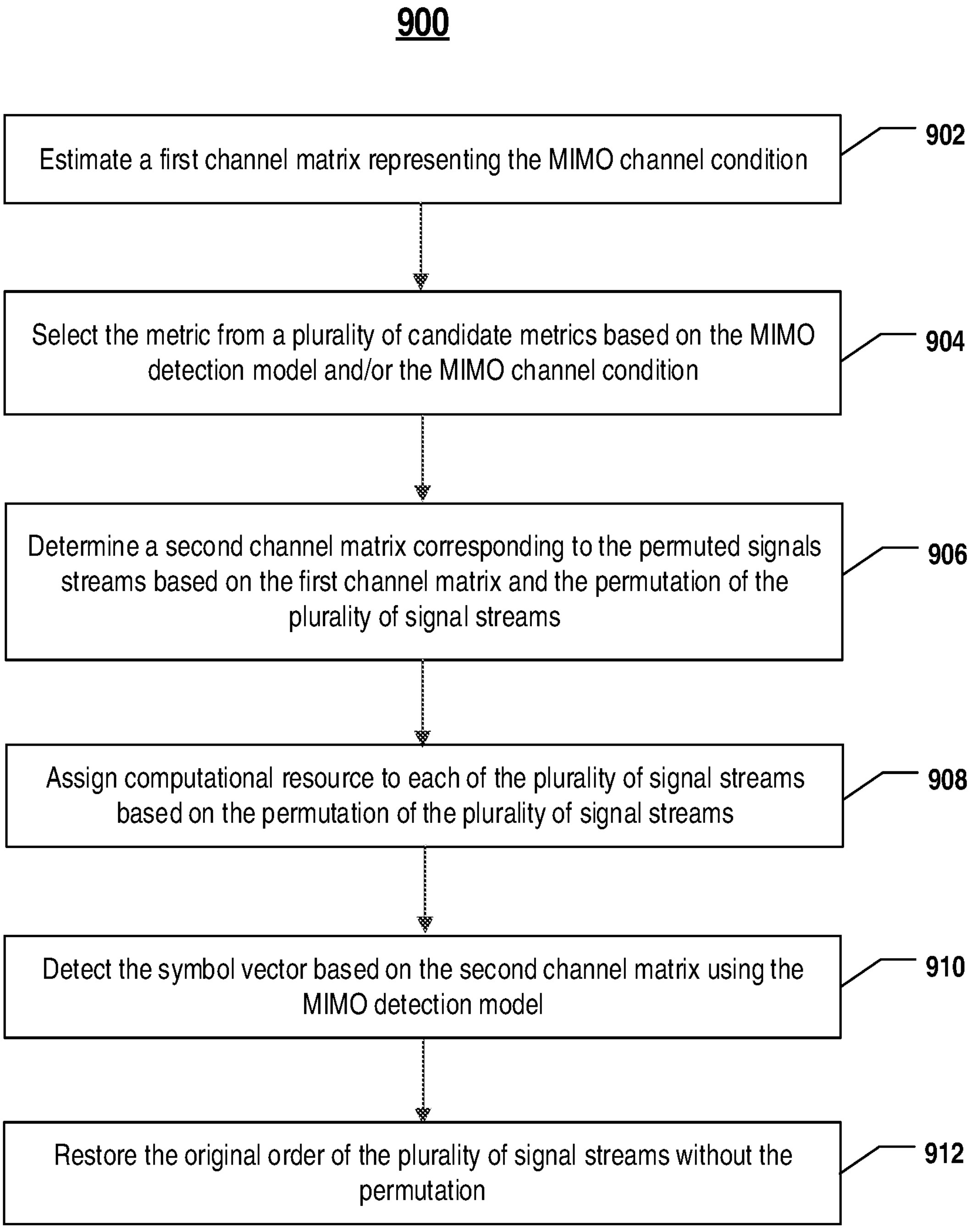
900
Estimate a first channel matrix representing the MIMO channel condition
902
Select the metric from a plurality of candidate metrics based on the MIMO detection model and/or the MIMO channel condition
904
Determine a second channel matrix corresponding to the permuted signals streams based on the first channel matrix and the permutation of the plurality of signal streams
906
Assign computational resource to each of the plurality of signal streams based on the permutation of the plurality of signal streams
908
Detect the symbol vector based on the second channel matrix using the MIMO detection model
910
Restore the original order of the plurality of signal streams without the permutation
912

FIG. 9

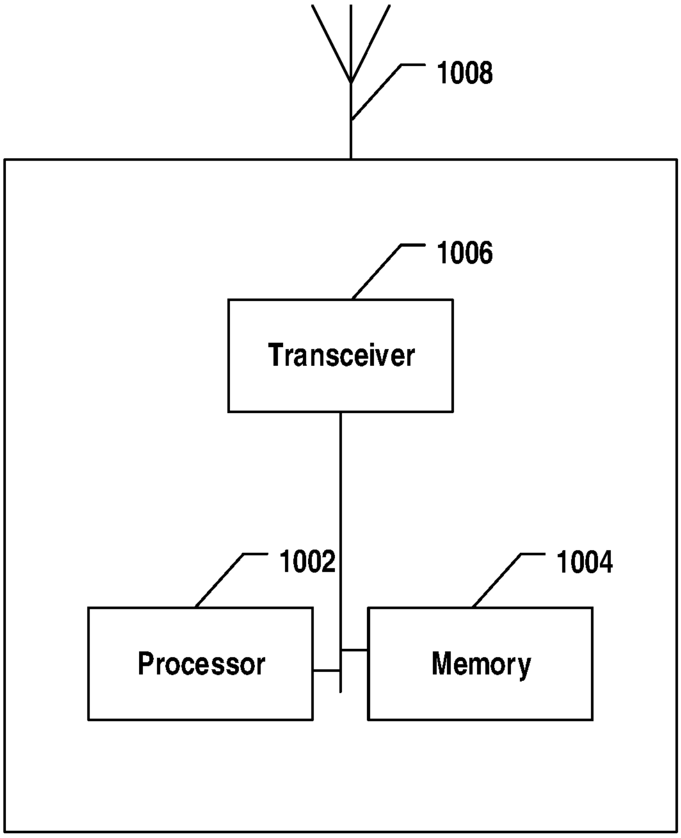

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 20/58290

A. CLASSIFICATION OF SUBJECT MATTER
IPC - H04B 7/0413; H04B 7/06; H04B 17/309 (2021.01)

CPC - H04B 7/06; H04B 7/0413; H04B 7/0691; H04B 7/0632; H04B 7/0634; H04B 17/309

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.
A	US 2008/0132281 A1 (Kim et al.) 05 June 2008 (05.06.2008) entire document, especially: para [0019], [0022], [0035], [0065], [0119]	1-5, 11-15, 22-26, 32-36, 42
A	US 2011/0280342 A1 (Kim et al.) 17 November 2011 (17.11.2011) entire document, especially: para [0040], [0051], [0055], [0062]	1-5, 11-15, 22-26, 32-36, 42
A	US 2019/0097865 A1 (ORIGIN WIRELESS, INC.) 28 March 2019 (28.03.2019) entire document	1-5, 11-15, 22-26, 32-36, 42
A	US 2018/0331732 A1 (Genghiscomm Holdings, LLC) 15 November 2018 (15.11.2018) entire document	1-5, 11-15, 22-26, 32-36, 42
A	US 2010/0150258 A1 (van Zelst) 17 June 2010 (17.06.2010) entire document	1-5, 11-15, 22-26, 32-36, 42

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"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
"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	"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
"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)	"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
"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	"&" document member of the same patent family

Date of the actual completion of the international search 26 January 2021	Date of mailing of the international search report 17 FEB 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/IB 20/58290

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.: 6-10, 16-21, 27-31, 37-41
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:

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.:

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.