Title: APPARATUS AND METHOD FOR COOPERATIVE PARTIAL DETECTION USING MIMO RELAY

Abstract: A MIMO stream transmitted by a source (S) is at least partially received by a relay (R) and a destination (D). An embodiment includes performing a partial detection of some of the streams in the relay (38), and forwarding the detected streams to the destination (40). The destination detects the message that it received from the relay (44, 46), and cancels its effect from the original received copy from the source (48). Then the destination performs a K-best detection of the remaining streams that were not forwarded by the relay (50).
APPARATUS AND METHOD FOR COOPERATIVE PARTIAL DETECTION USING MIMO RELAY

BACKGROUND OF THE INVENTION

[0001] As wireless communication devices flourish, there is a need for higher data rates and spectral efficiency. Multiple-input multiple-output (MIMO) systems can provide higher data rates and spectral efficiencies in wireless communications systems, and have been proposed and adopted for many different wireless standards, such as IEEE 802.11n, IEEE 802.16e and upcoming 3GPP LTE (Third Generation Partnership Project, Long Term Evolution).

[0002] With the promising results of MIMO for point-to-point communications, MIMO systems have been playing a significant role in a wide variety of wireless standards. Recently, there have been some attempts to study the theoretical benefits and bounds on deploying MIMO nodes in cooperative scenarios, both as relays and as source/destination pairs. In a cooperative scenario, wireless nodes cooperate to pass along information meant for other destination modes. These relay nodes can be dedicated relays, or wireless devices cooperating to increase throughput by helping to relay messages. Such cooperative communications networks have potential to increase data rates and signal ranges in a network.

[0003] However, a major problem in any MIMO system is the detection complexity. A typical maximum-likelihood (ML) detector for a MIMO system with M transmit antennas each using a modulation scheme of the order w, requires wM different search operations to choose the best possible candidate. If using an OFDM (orthogonal frequency division multiplexing) based system, this number will then be multiplied by the number of the data-bearing subcarriers. For example, for a MIMO-OFDM system with four transmit antennas, 16-QAM (quadrature amplitude modulation) modulation and 48 active subcarriers, approximately $3 \times 10^6$ comparisons are required by a receiving destination to detect the transmitted signal. A Maximum-likelihood (ML) detector for spatially multiplexed MIMO systems can determine an optimal solution with minimal BER (bit error rate), but will impose an exponential computational increase on a receiver. This significant computational complexity can place the advantages offered by MIMO data transmission out of reach of many systems and devices.
Further, this computational complexity will affect cooperative networks, because a relay needs to fully detect the signal before it can forward the data to the destination. A wireless device can be forced to spend a large portion of its computational resources in performing detect-and-forward services to relay data to another node. Therefore, adapting MIMO for a cooperative node system places a huge burden on the resources.

Many attempts have been made to reduce the complexity of MIMO detection but still provide a reasonably optimal detection for signals. One technique to reduce this complexity, known as sphere detection (SD), can be used to dramatically reduce the complexity of the MIMO detectors. Sphere detection is also known as lattice detection, and has been implemented in two main approaches for searching the solution tree: depth-first search (DFS), and breadth-first search (BFS). Sphere detectors offer a fixed average computational complexity per SNR (signal-noise ratio), however the computational complexity is still too high for many MIMO receivers and relays.

One variation of DFS sphere detector is known as a K-best detector. In this technique, a step-by-step tree search is performed, where at each level the best K candidates are kept, and tree traversal continues until all the tree levels, i.e. transmit antennas, are visited. By limiting the number of candidates at each level to K, latency may be limited to a reasonable compromise. The K-best detector’s complexity heavily depends on the value of K, wherein higher values for K, i.e. more computation, closes the gap with ML (maximum likelihood), and lower values of K limit the complexity of the detection process. K-best therefore provides a measure to control the “quality” and “accuracy” of the detector. Also, K-best detection methods offer considerably higher performance compared to linear detectors. Further, the K-best detector lends itself to architecture-friendly implementations, including potential parallelizing. Therefore K-best detectors have been proposed as valuable solution with reasonable detection performance and manageable complexity.

However, despite the advantages of the K-best detector, it still can have too much complexity and overhead for MIMO cooperative communications. Full detect-and-forward in the relay can require a significant amount of resources in, particularly if the relay decides to perform a close-to-optimum detection. This effect can be important for the cases where the relay is a MIMO user (rather than a fixed dedicated relay) giving up some of its resources to assist another MIMO user.
BRIEF SUMMARY OF THE INVENTION

[0008] The following presents a simplified summary in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is not intended to identify key or critical elements of the invention or to delineate the scope of the invention. The following summary merely presents some concepts of the invention in a simplified form as a prelude to the more detailed description provided below.

[0009] At least some embodiments are directed towards novel cooperative partial detection systems and methods for MIMO relay networks. A partial detection scheme is based on performing a sub-optimal partial detection of some of the streams by the relay, and forwarding the detected streams to the destination. Therefore, the destination has two received vectors that it may use to detect the original transmitted symbol vector.

[0010] In order to utilize these two received vectors, the destination according to one embodiment performs a two-stage detection. In the first stage, the destination detects the symbol vector that it received from the relay, and cancels the effect of this symbol vector from the original received symbol vector from the source. In the second stage, the destination performs the detection of the remaining streams that were not forwarded in the symbol vector from the relay. All the detection steps in the destination may be based on a close-to-ML (maximum likelihood) K-best detection, wherein the relay may perform a novel partial K-best detection. An embodiment using this cooperative detection can be readily applied in the PHY layer of both uplink and downlink situations, by modifying the transmission and receiving schemes employed in those situations. Other embodiments are applicable for the transceiver design of WiMAX (Worldwide Interoperability for Microwave Access) and LTE as well as any other next generation standard, e.g. IMT Advanced (International Mobile Telecommunications-Advanced), which considers MIMO nodes.

[0011] An embodiment may include receiving a MIMO (multiple-input multiple-output) encoded symbol vector, the symbol vector encoding a plurality of streams; re-ordering columns in the encoded symbol vector based on column norm; detecting a subset of the plurality of streams in the symbol vector using a K-best detector, wherein the subset of streams is less than a total number of the plurality of streams; and transmitting a second MIMO encoded symbol vector encoding the subset of streams. This may include performing
a QR decomposition on baseband signals in the symbol vector. Further, receiving a MIMO encoded symbol vector may include receiving the symbol vector on multiple antennas.

[0012] An embodiment may include an apparatus comprising one or more processors configured to perform operations that include receiving a MIMO encoded symbol vector, the symbol vector encoding a plurality of streams; re-ordering columns in the encoded symbol vector based on column norm; detecting a subset of the plurality of streams in the symbol vector using a K-best detector, wherein the subset of streams is less than a total number of the plurality of streams; and transmitting a second MIMO encoded symbol vector encoding the subset of streams. This apparatus may include a relay in a MIMO cooperative network, or a mobile terminal. An embodiment may include one or more processors further configured to perform a QR decomposition on baseband signals in the symbol vector. An embodiment may include multiple antennas, and the one or more processors configured to perform receiving the symbol vector on the multiple antennas.

[0013] An embodiment may comprise a computer readable medium including computer readable instructions that, when provided to a processor, cause the processor to perform receiving a MIMO encoded symbol vector, the symbol vector encoding a plurality of streams; re-ordering columns in the encoded symbol vector based on column norm; detecting a subset of the plurality of streams in the symbol vector using a K-best detector, wherein the subset of streams is less than a total number of the plurality of streams; and transmitting a second MIMO encoded symbol vector encoding the subset of streams.

[0014] An embodiment may include receiving a first MIMO encoded symbol vector, the first symbol vector encoding a plurality of streams; receiving a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams; detecting the subset of the plurality of streams in the second symbol vector; canceling the detected subset of streams from the first symbol vector; detecting remaining streams of the plurality of streams in the first symbol vector; and concatenating the first symbol vector and the second symbol vector. Detecting streams may be performed using a K-best detector. Further, a second symbol vector may be received from a relay in a cooperative MIMO network.

[0015] An embodiment includes an apparatus comprising one or more processors configured to perform operations that include receiving a first MIMO encoded symbol vector, the first symbol vector encoding a plurality of streams; receiving a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams; and canceling the detected subset of streams from the first symbol vector. Further, a second symbol vector may be received from a relay in a cooperative MIMO network.
vector, the second symbol vector encoding a subset of the plurality of streams; detecting the subset of the plurality of streams in the second symbol vector; canceling the detected subset of streams from the first symbol vector; detecting remaining streams of the plurality of streams in the first symbol vector; and concatenating the first symbol vector and the second symbol vector. Detecting streams may be performed using a K-best detector. Further, a second symbol vector may be received from a relay in a cooperative MIMO network. The apparatus may comprise a mobile terminal.

[0016] An embodiment may comprise a computer readable medium including computer readable instructions that, when provided to a processor, cause the processor to perform receiving a first MIMO encoded symbol vector, the first symbol vector encoding a plurality of streams; receiving a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams; detecting the subset of the plurality of streams in the second symbol vector; canceling the detected subset of streams from the first symbol vector; detecting remaining streams of the plurality of streams in the first symbol vector; and concatenating the first symbol vector and the second symbol vector.

[0017] An embodiment may includes an apparatus comprising means for receiving a MIMO encoded symbol vector; means for detecting a subset of the plurality of streams in the symbol vector; wherein the subset of streams is less than a total number of the plurality of streams; and means for transmitting a second MIMO encoded symbol vector encoding the subset of streams. Another embodiment may include an apparatus comprising means for receiving a first MIMO encoded symbol vector encoding a plurality of streams, and a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams; means for detecting the subset of the plurality of streams in the second symbol vector; means for canceling the detected subset of streams from the first symbol vector; means for detecting remaining streams of the plurality of streams in the first symbol vector; and means for concatenating the first symbol vector and the second symbol vector.

[0018] At least some embodiments may facilitate and improve transmit power requirements. The transmit power is divided between the source and destination. However, as simulation results for an embodiment have shown, the typical power ratios that yield significant performance improvement are high (i.e. close to one). Therefore the relay does not need to spend a lot of its own transmit power in assisting the source. This minimal requirement of transmit power along the minimal requirement for processing power (as previously
described) for the relay is a great advantage for an embodiment where the relay is another MIMO end-user unit, which is assisting the source in its transmission.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] A more complete understanding of the present invention and the advantages thereof may be acquired by referring to the following description in consideration of the accompanying drawings, in which like reference numbers indicate like features, and wherein:

[0020] Figure 1 illustrates an example wireless relay network;

[0021] Figure 2a and b illustrate a first and second data transmission between nodes according to an embodiment;

[0022] Figure 3 illustrates a transmission and receiving process according to an embodiment;

[0023] Figure 4 illustrates a details of a process according to an embodiment;

[0024] Figure 6 illustrates a partial tree search according to an embodiment; and

[0025] Figure 7 illustrates an apparatus including an implementation of an embodiment.

DETAILED DESCRIPTION OF THE INVENTION

[0026] In the following description of the various embodiments, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration various embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural and functional modifications may be made without departing from the scope of the present invention.

[0027] Figure 1 illustrates an example relay network with three nodes: source S, relay R and destination D. The source node S transmits the MIMO encoded message, that is received by both the relay R and the destination D. For this example, the source S, relay R and destination D are equipped with M_s, M_r and M_d antennas respectively. Given the practical limitations of deploying full duplex radios, the relay for this example operates in half-duplex, or "cheap" mode.
As illustrated in Figure 1, the respective channel matrices are denoted by $H_{sr}$, $H_{rd}$ and $H_{sd}$ which are of sizes $M_r \times M_s$, $M_d \times M_r$, and $M_d \times M_s$, and correspond to the channel matrices between respectively the source S and the relay R, the relay R and the destination D, and the source S and the destination D. All these channel matrices have independent elements, each drawn from a circularly symmetric Gaussian random distribution with zero mean and variance of one, $CN(0;1)$.

In accordance with cooperative MIMO transmissions as known in the art, the relay R will decode the message, typically using K-best algorithm, and then re-encode and re-transmit the entire MIMO message to the destination D.

In this scenario, the $H_{sr}$ matrix is known in the relay R; and $H_{rd}$ and $H_{sd}$ matrices are known in the destination D. Therefore, the receivers of each communication link have complete channel knowledge, with the exception that the destination D should also be made aware of the ordering of the $H_{sr}$ column norms in the relay R. The destination D typically will require this information in order to restore the detected streams in their original order. Typically the norms of the channel matrix changes at a slower rate than the actual channel coefficients, and requires smaller number of bits. Thus, this information can be communicated from the relay R to the destination D through a low rate control channel.

An embodiment of the present invention allows the relay R to perform a partial decoding of $H_{sr}$ and provide the partial decoding to destination D. The communication between the source S and the destination D is performed in two time slots. In the first time slot, the source S broadcasts its message to both the relay R (as shown by $H_{sr}$) and the destination D (as shown by $H_{sd}$); and in the second time slot, the relay R, using an $M \leq M_r$ subset of its antennas, transmits its message to the destination D while the source S is silent.

More details regarding this embodiment is shown in Figure 2. In the first time slot, Figure 2a the relay R and destination D each receive a copy of the source multi-stream data. The relay R detects part of the transmitted vector, and refers to it as $x_r$, and in the second time slot it forwards the detected vector $x_r$ to the destination D, Figure 2b. Then the destination D detects the vector received from the relay R, performs interference cancellation of the detected streams from the vector received during the first time slot, and then detects the remaining streams. This process will be described in further detail below.
[0033] Figure 3 provides details of processes as performed by the relay R and the destination D according to one or more embodiments of the present invention. At step 30, the source S transmits the multi-stream symbol vector, that is transmitted as shown by arrow 32, which is at least partially received by both the destination D, step 34, and relay R, step 36. The relay R then performs a partial detection of the stream, step 38, and then transmits the partially detected stream to the destination D, step 40.

[0034] Turning to Figure 4, details of the partial detecting 38 by the relay R are provided. According to an embodiment the relay R performs a process with a partial K-best detector, utilizing similar preprocessing operations as that of a conventional K-best detector. First, the channel matrix columns are swapped based on their norms, so that the last column has the largest norm, step 54. This ordering will be denoted by $\Pi$.

[0035] Next, optional step 56 may be performed, which is a real-valued decomposition that will decompose all the complex valued elements into real numbers by doubling the size of the vectors and matrices.

[0036] Next, at step 58, QR decomposition triangularizes the channel matrix, or its equivalent real-valued channel matrix, (similar to normal K-best detection, and the tree traversal starts. It begins from the top level, $i=m$ (or $i=2m$ in case of real-valued decomposition), where $m$ is the number of transmit antennas, and therefore, $m$ or $2m$, is the number of the columns of the channel matrix, or its equivalent real-valued channel matrix. Unlike the conventional K-best method, the tree traversal of the partial K-best method according to this embodiment terminates in one of the middle levels, and the corresponding minimum distance at that level is considered as the "partial" detected symbol vector. The number of visited antennas is referred to as the expansion factor, $ef$.

[0037] Figure 5 shows this partial K-best detection for an example case with 16-QAM modulation. This corresponds to a tree structure for a partial K-best MIMO (6x6) detector with K set to 3. Note that the expansion factor is set to $ef = 4$; thus the expanded tree has $ef = 4$ levels; whereas if the detector chose to do the full K-best detection, the tree would have $m=6$ levels, which would require visiting almost twice as many nodes as that of partial K-best shown in this example. Note that if the optional real-valued decomposition was performed, then the tree size may have been doubled.
Finally, the detected streams are transmitted by the relay R, step 40 Figure 4. The destination D may be informed about the different ordering of the columns. This information changes at a slow rate, therefore the destination D may be informed through a low rate control channel (as previously discussed), or alternatively, this information, may be provided on the 'header' or preamble part, of the transmission.

Returning to Figure 3, the process as performed by destination D will now be discussed. In the first time slot, the destination D received the multi-stream data $x_s$ from the source S, step 34. In the second time slot, the destination D receives the partial detected vector $x_r$, step 44. The destination D next detects the $x_r$ vector, and refers to this as detected vector $x_d^{(2)}$. This detection is typically performed using the full k-best detector. Next, at step 48, the $x_d^{(2)}$ vector is cancelled from $y_d^{(1)}$:

$$y_d^{(imp)} = y_d^{(1)} - H_{sd}^{(1:x_f)} x_d^{(2)}$$

Note that only those columns of $H_{sd}$ that correspond to the $x_d^{(2)}$ elements are used for interference cancellation.

Therefore $y_d^{(imp)}$ encodes the remaining streams in $x_s$ that were not detected in the relay R and therefore not forwarded to the destination D in $x_d^{(2)}$. At step 50, these remaining streams in $y_d^{(imp)}$, are detected and referred to as $x_d^{(1)}$. This detection is also typically performed using the full k-best detector.

At step 52, because of the power reordering of the streams that have been performed in the relay, the two vectors, $x_d^{(1)}$ and $x_d^{(2)}$ are concatenated and re-ordered to form the final detected vector:

$$x_d = \Pi^{(-1)} \{concat(x_d^{(2)}, x_d^{(1)})\}$$

where $\Pi^{(-1)}$ represents the reverse ordering of the ordering applied in the relay R.

Figure 6 is a chart of BER (bit error rate) of an embodiment compared to prior direct link methods. The simulation utilized a 6x6, 16-QAM system with the relay located at different distances from the source, $d=0.2, \ldots, 0.4$, and for different ratio of power splitting $\mu = 0.6, 0.7, 0.8$, between the source S and the relay R. Setting $k = (12, 10, 7)$ and $K_{dl} = 10$
(direct link simulation) guarantees a proper comparison of processing power when comparing the different methods. The expansion factor was set to $ef=3$; therefore, the relay $R$ detects and forwards the strongest 3 streams to the destination $D$, and the destination $D$ detects those three streams from the relay $R$, followed by detecting the remaining three using the copy it received from the source $S$. The chart in Figure 6 suggests all the cooperative scenarios improve the performance compared to the base direct-link scenario. The improvement varies between 4 and 5 dB for higher range of transmit power, and 1.5 to 2 dB for lower transmit power. In all cases, similar total processing power (in the relay and the destination) was utilized as in the case of the direct-link (no-relay) simulation.

[0047] Although this embodiment has been described in terms of one relay, other embodiments may include multiple cooperative relays working between the source $R$ and the destination $D$.

[0048] Embodiments may be implemented in a wide variety of wireless communications systems. For instance, in the context of uplink scenarios, an embodiment can be applied in the MIMO terminal transmitting its spatially multiplexed signals to the base station. Also, an embodiment may be used in assisting the base station in uplink multi-user detection scenarios, where multiple users with smaller number of antennas try to use the same channel for sending the data to the base station. As for the downlink, the MIMO relay can be used for communicating data from the base station to terminals with multiple antennas.

[0049] Embodiments of the present invention may be implemented in any type of apparatus or device with wireless capabilities, including transmitters, relays, mobile terminals and mobile phones. An example device comprising a mobile terminal 60 is shown in Figure 7. The mobile terminal 60 may comprise a network-enabled wireless device, such as a cellular phone, a data terminal, a pager, GPS receiver, portable video viewing device, a laptop computer or combinations thereof. Further, the mobile terminal may comprise any combination of network-enabled wireless devices and non network-enabled devices. Although device 60 is shown as a mobile terminal, it is understood that the invention may be practiced using non-portable or non-movable devices.

[0050] As a network-enabled device, the mobile terminal 60 may communicate over a radio link to a wireless network (not shown) including but not limited to WiMAX and LTE as well as any other current or future generation standard, e.g. IMT Advanced, which considers
MIMO nodes. For MIMO cooperative communications, the mobile terminal may have one, or a plurality of antennas 62. Such antennae may be separated into receive-only antennas, transmit-only antennas, or transmit/receive antennas. The mobile terminal 60 may also include radio network receiver, transmitter and relay components 63 to provide and manage one or more layers of radio communications protocol, including MIMO communications.

[0051] Examples of other wireless networks include third-generation (3G) cellular data communications networks, fourth-generation (4G) cellular data communications networks, Global System for Mobile communications networks (GSM), wireless local area networks (WLANs), or other current or future wireless communication networks. Mobile terminal 60 may also communicate with a web server through one or more ports (not shown) on the mobile terminal that may allow a wired connection to the Internet, such as universal serial bus (USB) connection, and/or via a short-range wireless connection (not shown), such as a BLUETOOTH™ link or a wireless connection to WLAN access point. Thus, mobile terminal 60 may be able to communicate with a web server in multiple ways.

[0052] As shown in Figure 7, the mobile terminal 60 may comprise a processor 64, a display 66, memory 68, and user input features 70, such as keypads, touch screens, audio input etc. It may also include a short-range and/or long range radio transmitter/receiver 63, a global positioning system (GPS) receiver (not shown) and possibly other sensors. The processor 64 is in communication (not shown) with memory 68 and may execute instructions stored therein. The user input features 70 are also in communication with (not shown) the processor 64 for providing inputs to the processor. In combination, the user input 70, display 66 and processor 64, in concert with instructions stored in memory, may provide a graphical user interface (GUI), which allows a user to interact with the device and modify displays shown on display 66.

[0053] The mobile terminal 60 may also comprise audio output features 72, which allows sound and music to be played. Such audio output features may include hardware features such as single and multi-channel analog amplifier circuits, equalization circuits, speakers, and audio output jacks. Such audio output features may also include digital/analog converters and filtering circuits. Other components, such as audio and media decompressors and decoders may be implemented as hardware devices, or as software instructions to be performed by the processor 64 or any combination thereof.
[0054] In accordance with processing instructions 74 in memory 68, the processor 64 may perform embodiments of the present invention. Such instructions may also be stored in the radio network components 63, in firmware or other forms of storage, and/or implemented in various hardware forms. Further, separate components may perform embodiments of the present invention without the direct involvement of the processor 64.

[0055] Other embodiments of the present invention may be implemented in a dedicated relay, which may not include one or more of the user interface features of the mobile terminal 60. Such relays may utilize specialized hardware to perform steps in parallel, or as a pipelined process. Such relays may include multiple processors or other hardware to handle multiple partial detect and forward operations simultaneously.

[0056] At least some embodiments may facilitate and improve BER (bit error rate) performance over a no-relay transmission scenario. For one embodiment, a simulation showed a BER improvement of up to 5 dB over a direct-link only communication. Further, the simulation showed that for each placing of the relay in between the source and the destination, there is a particular power ratio splitting which reveals a maximum SNR (signal to noise ratio) benefit.

[0057] At least some embodiments may facilitate and improve performance of cooperative networks without burdening a relay and/or destination to utilize too much of its processing and transmit power.

[0058] At least some embodiments may facilitate and improve distributed processing, in that complex decoding (detecting) operations may be distributed around a cooperative MIMO network. The total number of computations in a relay and destination may be fixed. If desired, the total number of computations may be kept equal to the number of operations normally performed by the destination in a direct-link, no relay system. Further, an embodiment can make sure that a relay need not sacrifice significant amounts of its resources, in that the operations may be split between the relay and destination in such a way that the relay still performs less computation compared to the destination.

[0059] At least some embodiments may facilitate and improve potential VLSI (very large scale integration) implementations. A K-best detector is a suitable architecture-oriented MIMO detector, and can be readily employed to perform the partial or full detection stages in the relay and destination according to an embodiment. Thus, an embodiment does not
impose extra area requirements (circuitry real estate) on any wireless units (relays, transceivers, etc.).

[0060] Additionally, the methods and features recited herein may further be implemented through any number of computer readable mediums that are able to store computer readable instructions. Examples of computer readable media that may be used comprise RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, DVD or other optical disk storage, magnetic cassettes, magnetic tape, magnetic storage and the like.

[0061] One or more aspects of the invention may be embodied in computer usable data and computer-executable instructions, such as in one or more program modules, executed by one or more computers or other devices. Generally, program modules comprise routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types when executed by a processor in a computer or other device. The computer executable instructions may be stored on a computer readable medium such as a hard disk, optical disk, removable storage media, solid state memory, RAM, etc. As will be appreciated by one of skill in the art, the functionality of the program modules may be combined or distributed as desired in various embodiments. In addition, the functionality may be embodied in whole or in part in firmware or hardware equivalents such as integrated circuits, field programmable gate arrays (FPGA), and the like. Particular data structures may be used to more effectively implement one or more aspects of the invention, and such data structures are contemplated within the scope of computer executable instructions and computer usable data described herein.

[0062] While illustrative systems and methods as described herein embodying various aspects of the present invention are shown, it will be understood by those skilled in the art, that the invention is not limited to these embodiments. Modifications may be made by those skilled in the art, particularly in light of the foregoing teachings. For example, each of the elements of the aforementioned embodiments may be utilized alone or in combination or sub combination with elements of the other embodiments. It will also be appreciated and understood that modifications may be made without departing from the true spirit and scope of the present invention. The description is thus to be regarded as illustrative instead of restrictive on the present invention.
[0063] Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.
I/We Claim:

1. A method comprising:
   receiving a MIMO (multiple-input multiple-output) encoded symbol vector,
   the symbol vector encoding a plurality of streams;
   re-ordering columns in said encoded symbol vector based on column norm;
   detecting a subset of the plurality of streams in the symbol vector using a K-
   best detector, wherein the subset of streams is less than a total number of the plurality of
   streams; and
   transmitting a second MIMO encoded symbol vector encoding the subset of
   streams.

2. The method of claim 1 further including:
   performing a QR decomposition on baseband signals in the symbol vector.

3. The method of claim 1 wherein the process of receiving a MIMO encoded symbol
   vector includes receiving the symbol vector on multiple antennas.

4. An apparatus comprising:
   one or more processors configured to perform operations that include:
   receiving a MIMO (multiple-input multiple-output) encoded symbol
   vector, the symbol vector encoding a plurality of streams;
   re-ordering columns in said encoded symbol vector based on column
   norm;
   detecting a subset of the plurality of streams in the symbol vector using
   a K-best detector, wherein the subset of streams is less than a total number of
   the plurality of streams; and
   transmitting a second MIMO encoded symbol vector encoding the
   subset of streams.

5. The apparatus of claim 4 wherein the apparatus is a relay in a MIMO cooperative
   network.

6. The apparatus of claim 4 wherein the apparatus is a mobile terminal.
7. The apparatus of claim 4 wherein the one or more processors are further configured to perform a QR decomposition on baseband signals in the symbol vector.

8. The apparatus of claim 4 further including multiple antennas, and the one or more processors are further configured to perform receiving the symbol vector on the multiple antennas.

9. A computer readable medium including computer readable instructions that, when provided to a processor, cause the processor to perform:
   receiving a MIMO (multiple-input multiple-output) encoded symbol vector, the symbol vector encoding a plurality of streams;
   re-ordering columns in said encoded symbol vector based on column norm;
   detecting a subset of the plurality of streams in the symbol vector using a K-best detector, wherein the subset of streams is less than a total number of the plurality of streams; and
   transmitting a second MIMO encoded symbol vector encoding the subset of streams.

10. A method comprising:
    receiving a first MIMO (multiple-input multiple-output) encoded symbol vector, the first symbol vector encoding a plurality of streams;
    receiving a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams;
    detecting the subset of the plurality of streams in the second symbol vector;
    canceling the detected subset of streams from the first symbol vector;
    detecting remaining streams of the plurality of streams in the first symbol vector; and
    concatenating the first symbol vector and the second symbol vector.

11. The method of claim 10, wherein the process of detecting streams is performed using a K-best detector.

12. The method of claim 10 wherein the process of receiving a second symbol vector includes receiving the second symbol vector from a relay in a cooperative MIMO network.
13. An apparatus comprising:
   one or more processors configured to perform operations that include:
      receiving a first MIMO (multiple-input multiple-output) encoded symbol vector, the first symbol vector encoding a plurality of streams;
   receiving a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams;
   detecting the subset of the plurality of streams in the second symbol vector;
   canceling the detected subset of streams from the first symbol vector;
   detecting remaining streams of the plurality of streams in the first symbol vector; and
   concatenating the first symbol vector and the second symbol vector.

14. The apparatus of claim 13, wherein the process of detecting streams is performed using a K-best detector.

15. The apparatus of claim 13 wherein the process of receiving a second symbol vector includes receiving the second symbol vector from a relay in a cooperative MIMO network.

16. The apparatus of claim 13, wherein the apparatus includes a mobile terminal..

17. A computer readable medium including computer readable instructions that, when provided to a processor, cause the processor to perform:
   receiving a first MIMO (multiple-input multiple-output) encoded symbol vector, the first symbol vector encoding a plurality of streams;
   receiving a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams;
   detecting the subset of the plurality of streams in the second symbol vector;
   canceling the detected subset of streams from the first symbol vector;
   detecting remaining streams of the plurality of streams in the first symbol vector; and
   concatenating the first symbol vector and the second symbol vector.
18. An apparatus comprising:
   means for receiving a MIMO (multiple-input multiple-output) encoded symbol vector encoding a plurality of streams;
   means for detecting a subset of the plurality of streams in the symbol vector; wherein the subset of streams is less than a total number of the plurality of streams; and
   means for transmitting a second MIMO encoded symbol vector encoding the subset of streams.

19. An apparatus comprising:
   means for receiving a first MIMO (multiple-input multiple-output) encoded symbol vector encoding a plurality of streams, and a second MIMO encoded symbol vector, the second symbol vector encoding a subset of the plurality of streams;
   means for detecting the subset of the plurality of streams in the second symbol vector;
   means for canceling the detected subset of streams from the first symbol vector;
   means for detecting remaining streams of the plurality of streams in the first symbol vector; and
   means for concatenating the first symbol vector and the second symbol vector.
Fig. 1

Time slot 1
relay detects:
\[ x_r = [\hat{x}_1, ..., \hat{x}_{ef}, -] \]
source transmits:
\[ x_s = [\bar{x}_1, ..., \bar{x}_{M_s}] \]

Fig. 2a

Time slot 2
relay transmits:
\[ x_r = [\hat{x}_1, ..., \hat{x}_{ef}, -] \]

Fig. 2b
Source S
Transmit Multi-Stream Data

32

Relay R
Receive Multi-stream Data

36

Partially Detect a Subset of Streams in the Data

38

Transmit the Detected Streams

40

Destination D
Receive Multi-Stream Data

34

\( x_s \)

44

Receive Multi-Stream Data \( x_r \)

46

Detect Streams in \( x_r \) Using K-Best Detector

48

Cancel the \( x_r \) Streams Out of the First Vector \( x_s \)

50

Detect the Remaining Streams in \( x_s \) Using K-Best Detector

52

Concatenate vectors \( x_s \) and \( x_r \), and Re-order

Fig. 3
Swap the Channel Matrix Columns so Last Column Has Largest Norm

Perform Real-valued Decomposition On Baseband Signals (Optional)

Perform Tree Traversal, Terminating at Middle Level

Transmit Partially Detected Symbol Vector and Ordering

Fig. 4

Fig. 5
Comparison of direct link (no relay) detection with cooperative (with relay) detection for 6x6, 16-QAM

Direct Link (No Relay)
- Cooperative MIMO, \( d_{sr} = 0.2, \mu = 0.6 \)
- Cooperative MIMO, \( d_{sr} = 0.3, \mu = 0.7 \)
- Cooperative MIMO, \( d_{sr} = 0.4, \mu = 0.8 \)

BER vs. \( P \)

Fig. 6
B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L  H04B

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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Date of the actual completion of the international search: 30 June 2009

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