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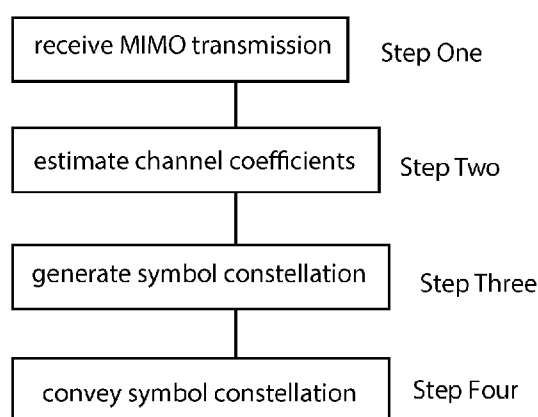


FIG. 2(a)

(57) Abstract: A transmission scheme and feedback mechanism for transmitters with constrained RF chains where a MIMO radio frequency transmission is received at a receiver from a transmitter. The MIMO radio frequency transmission is received at one or more antenna elements. At the receiver, from the received transmission, a channel coefficient for the one or more antenna elements is estimated from the received transmission. A symbol constellation is generated at the receiver. The symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements. The receiver conveys towards the transmitter the symbol constellation.



Transmission Scheme and Feedback Mechanism for Transmitters with Constrained RF Chains

[0001] TECHNICAL FIELD

5 [0002] The present application relates generally to a transmission scheme with constrained RF chains in massive MIMO (mMIMO) systems and on the feedback mechanism to efficiently transmit symbols.

[0003] BACKGROUND

10 [0004] Multiple-antenna Multiple-In Multiple-Out (MIMO) technology is used for wireless communications in wireless broadband standards like LTE and Wi-Fi. A transmitter/receiver is equipped with multiple antenna elements (AEs), and the more AEs, the more the possible signal paths resulting in better performance.

[0005] Massive MIMO (mMIMO) is a version of the MIMO technology and is also known as Large-Scale Antenna Systems, Very Large MIMO, Hyper MIMO, Full-Dimension MIMO and ARGOS. In the mMIMO version, a very large number of AEs can be operated coherently and adaptively. The large number of AEs focus the transmission and reception of signal energy into small spatial regions. The result is a significant improvement in throughput and efficiency. The improvement is even more pronounced when mMIMO is
20 combined with simultaneous scheduling of a large number of user terminals.

[0006] Among the benefits of mMIMO is the potential to use inexpensive low-power components, reduced latency, simplification of the media access control (MAC) layer, and robustness to interference and intentional jamming. There is a need for improving the mMIMO technology by making lower-cost lower-precision components work effectively
25 together, create an efficient acquisition scheme for channel state information, efficient resource allocation for newly-joined terminals, and making use of extra degrees of freedom provided by an excess of AEs.

[0007] In order to reduce the price and complexity of the mMIMO antenna array, the AEs transmit and receive using constrained radio frequency (RF) chains
30 similar to digital-to-analog converters (DAC) with only a few bit quantization and/or limited Tx-power from low end amplifiers with a limited operating region. In this case, only a few bits of information are transmitted through each of the AE. In the simplest case, the AE can transmit only one bit information. That is, the AE can be switched on or off. In general, the signal transmitted from an AE can have n-bits information (transmitted via, for example, the
35 signal amplitude and phase). In such systems with constrained RF chains, the conventional

MIMO beamforming concepts like matched filter, zero forcing filter cannot be performed. Furthermore, when the Channel State Information (CSI) is made available at the transmitter, it cannot be fully utilized to perform the transmission due to the limitation in the resolution of the transmitted signal. beamforming is another multi-antenna transmission technique that can
5 utilize a signal from a constrained RF frontend. beamforming arrays are inherently different from digital beamforming which requires high end RF chains to perform beamforming. In an beamforming array, multiple columns of dipole antennas work together with phase shifters to create a single high gain signal.

[0008] Accordingly, there is a need for a multi-antenna transmission
10 technique that can more fully utilize the available communication options in a transmission using constrained RF chains.

[0009] **SUMMARY**

[0010] Various aspects of examples of the invention are set out in the
15 claims.

[0011] In accordance with an aspect of the invention, a MIMO radio
frequency transmission is received at a receiver from a transmitter. The MIMO radio
frequency transmission is received at one or more antenna elements. At the receiver, from the
received transmission, a channel coefficient for the one or more antenna elements is estimated
20 from the received transmission. A symbol constellation is generated at the receiver. The
symbol constellation depends on possible combinations of the one or more antenna elements
and the estimated channel coefficient for the one or more antenna elements. The receiver
conveys towards the transmitter the symbol constellation.

[0012] In accordance with another aspect of the invention, an apparatus,
25 comprises:

one or more processors; and
one or more memories including computer program code,
the one or more memories and the computer program code configured, with the one or
more processors, to cause the apparatus to perform at least the following:
30 receive, at a receiver from a transmitter, a MIMO radio frequency transmission
received at one or more antenna elements;
estimate, at the receiver, from the received transmission, a channel coefficient for the
one or more antenna elements;

generate, at the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements; and convey, from the receiver towards the transmitter, the symbol constellation.

5 **[0013]** In accordance with another aspect of the invention, a computer program product comprises a computer-readable storage medium bearing computer program code embodied therein for use with a computer, the computer program code comprising:

code for receiving, at a receiver from a transmitter, a MIMO radio frequency transmission received at one or more antenna elements;

10 code for estimating, at the receiver, from the received transmission, a channel coefficient for the one or more antenna elements;

code for generating, at the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements; and

15 code for conveying, from the receiver towards the transmitter, the symbol constellation.

[0014] In accordance with another aspect of the invention, a transmitter transmits towards a receiver a MIMO radio frequency transmission for reception at the receiver at one or more antenna elements. The transmitter receives from the receiver a
20 symbol constellation. The symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more antenna elements.

[0015] In accordance with another aspect of the invention, an apparatus comprises:

25 one or more processors; and

one or more memories including computer program code,

the one or more memories and the computer program code configured, with the one or more processors, to cause the apparatus to perform at least the following:

transmit, from a transmitter towards a receiver, a MIMO radio frequency transmission

30 for reception at the receiver at one or more antenna elements; and

receive, at the transmitter from the receiver, a symbol constellation, wherein the

symbol constellation depends on possible combinations of the one or more antenna

elements and an estimated channel coefficient for the one or more antenna elements.

[0016] In accordance with another exemplary embodiment, a computer program product comprises a computer-readable storage medium bearing computer program code embodied therein for use with a computer, the computer program code comprising:

code for transmitting, from a transmitter towards a receiver, a MIMO radio frequency transmission for reception at the receiver at one or more antenna elements; and code for receiving, at the transmitter from the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more antenna elements.

[0017] In another exemplary embodiment, an apparatus comprises a means for performing any of the methods above.

[0018] BRIEF DESCRIPTION OF THE DRAWINGS

[0019] For a more complete understanding of example embodiments of the present invention, reference is now made to the following descriptions taken in connection with the accompanying drawings in which:

[0020] FIGURE 1 is a block diagram of one possible and non-limiting exemplary system in which the exemplary embodiments may be practiced;

[0021] FIGURE 2(a) is a logic flow diagram for a transmission scheme and feedback mechanism for transmitters with constrained RF chains and illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments;

[0022] FIGURE 2(b) is a logic flow diagram for a transmission scheme and feedback mechanism for transmitters with constrained RF chains and illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments;

[0023] FIGURE 3 shows the channel coefficients and the corresponding constellation points for the case of four AEs, with a one bit amplitude;

[0024] FIGURE 4 shows a set of chosen constellation points for the corresponding constellation points;

[0025] FIGURE 5 is a table indicating an exemplary predefined order and the mapping of the input bits to the constellation points; and

[0026] FIGURE 6 shows an example where the constellation symbols are constructed in a regular grid form.

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[0027] **DETAILED DESCRIPTION OF THE DRAWINGS**

[0028] The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any embodiment described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments. All of the
10 embodiments described in this Detailed Description are exemplary embodiments provided to enable persons skilled in the art to make or use the invention and not to limit the scope of the invention which is defined by the claims.

[0029] An example embodiment of the present invention and its potential advantages are understood by referring to FIGURES 1 through 5 of the drawings.

15 [0030] US Published Patent Application US2015326285 describes that a desired signal at a receiver is constructed through an over-the-air combination of the channel coefficients multiplied by a transmitted signal. In the case of one bit DACs, some of the AEs are carefully chosen and switched on such that the desired signal is constructed at the receiver. The desired signal could be QAM signal or the samples of the OFDM symbol. This
20 scheme assumes perfect channel state information at the transmitter. Furthermore, a large number of AEs are necessary to construct the desired signal. For example, if there are two AEs with one bit DACs at the transmitter and a single antenna at the receiver, assuming a high SNR, then, theoretically, each AE should be able to transmit one bit information. However, depending on the fast fading component of the channel it is not always possible to
25 generate a desired 4-QAM signal at the receiver.

[0031] A concept related to an exemplary embodiment of the present invention is described in R. Y. Mesleh, H. Haas, S. Sinanovic, C. W. Ahn and S. Yun, "Spatial Modulation," in *IEEE Transactions on Vehicular Technology*, vol. 57, no. 4, pp. 2228-2241, July 2008, where spatial modulation is discussed in the context of a single high
30 end RF and no constrained RF. The information is carried using two units: a symbol chosen from a constellation and a unique transmit antenna number that is used to transmit the symbol. If the symbol is chosen from M-QAM constellation and if there are N transmit antennas, then the received signal has $M + \log_2(N)$ bits of information.

[0032] A. Younis, N. Serafimovski, R. Mesleh and H. Haas, "Generalised
35 spatial modulation," *2010 Conference Record of the Forty Fourth Asilomar Conference on*

Signals, Systems and Computers, Pacific Grove, CA, 2010, pp. 1498-1502 describes that in order to increase the information content provided by the transmit antenna index, a symbol is transmitted simultaneously through $K < N$ antennas. Since, there are several ${}^N C_K$ combinations which is larger than N if $K > 1$, this increases the spectral efficiency to $M + \log_2({}^N C_K)$. Also, a single high end RF chain is assumed and the chosen combinations are pre-defined. Furthermore, the number K is chosen pessimistically, since it might be challenging to distinguish between two combinations if the channels coefficients are not sufficiently decorrelated.

[0033] However, in contrast, in accordance with an exemplary embodiment of the present invention, there are several constrained RFs, the receiver chooses the optimal combinations out of all $({}^N C_1 + {}^N C_2 + \dots + {}^N C_{N-K})$ combinations.

[0034] Turning to FIG. 1, this figure shows a block diagram of one possible and non-limiting exemplary system in which the exemplary embodiments may be practiced. In FIG. 1, a user equipment (UE) 110 is in wireless communication with a wireless network 100. A UE is a wireless, typically mobile device that can access a wireless network. The UE 110 includes one or more processors 120, one or more memories 125, and one or more transceivers 130 interconnected through one or more buses 127. Each of the one or more transceivers 130 includes a receiver, Rx, 132 and a transmitter, Tx, 133. The one or more buses 127 may be address, data, or control buses, and may include any interconnection mechanism, such as a series of lines on a motherboard or integrated circuit, fiber optics or other optical communication equipment, and the like. The one or more transceivers 130 are connected to one or more antennas 128. The one or more memories 125 include computer program code 123.

[0035] The UE 110 includes a MIMO receiver module 140, comprising one of or both parts 140-1 and/or 140-2, which may be implemented in a number of ways. The MIMO receiver module 140 may be implemented in hardware as MIMO receiver module 140-1, such as being implemented as part of the one or more processors 120. The MIMO receiver module 140-1 may be implemented also as an integrated circuit or through other hardware such as a programmable gate array. In another example, the MIMO receiver module 140 may be implemented as MIMO receiver module 140-2, which is implemented as computer program code 123 and is executed by the one or more processors 120. For instance, the one or more memories 125 and the computer program code 123 may be configured to, with the one or more processors 120, cause the user equipment 110 to perform one or more of the operations as described herein. The UE 110 communicates with eNB 170 via a wireless link 111.

[0036] The eNB (evolved NodeB) 170 is a base station (e.g., for LTE, long term evolution) that provides access by wireless devices such as the UE 110 to the wireless network 100. The eNB 170 includes one or more processors 152, one or more memories 155, one or more network interfaces (N/W I/F(s)) 161, and one or more transceivers 160 interconnected through one or more buses 157. Each of the one or more transceivers 160 includes a receiver, Rx, 162 and a transmitter, Tx, 163. The one or more transceivers 160 are connected to one or more antennas 158. The one or more memories 155 include computer program code 153.

[0037] The eNB 170 includes a MIMO transmitter module 150, comprising one of or both parts 150-1 and/or 150-2, which may be implemented in a number of ways. The MIMO transmitter module 150 may be implemented in hardware as MIMO transmitter module 150-1, such as being implemented as part of the one or more processors 152. The MIMO transmitter module 150-1 may be implemented also as an integrated circuit or through other hardware such as a programmable gate array. In another example, the MIMO transmitter module 150 may be implemented as MIMO transmitter module 150-2, which is implemented as computer program code 153 and is executed by the one or more processors 152. For instance, the one or more memories 155 and the computer program code 153 are configured to, with the one or more processors 152, cause the eNB 170 to perform one or more of the operations as described herein. The one or more network interfaces 161 communicate over a network such as via the links 176 and 131. Two or more eNBs 170 communicate using, e.g., link 176. The link 176 may be wired or wireless or both and may implement, e.g., an X2 interface.

[0038] The one or more buses 157 may be address, data, or control buses, and may include any interconnection mechanism, such as a series of lines on a motherboard or integrated circuit, fiber optics or other optical communication equipment, wireless channels, and the like. For example, the one or more transceivers 160 may be implemented as a remote radio head (RRH) 195, with the other elements of the eNB 170 being physically in a different location from the RRH, and the one or more buses 157 could be implemented in part as fiber optic cable to connect the other elements of the eNB 170 to the RRH 195.

[0039] The wireless network 100 may include a network control element (NCE) 190 that may include MME (Mobility Management Entity)/SGW (Serving Gateway) functionality, and which provides connectivity with a further network, such as a telephone network and/or a data communications network (e.g., the Internet). The eNB 170 is coupled via a link 131 to the NCE 190. The link 131 may be implemented as, e.g., an S1 interface.

The NCE 190 includes one or more processors 175, one or more memories 171, and one or

more network interfaces (N/W I/F(s)) 180, interconnected through one or more buses 185. The one or more memories 171 include computer program code 173. The one or more memories 171 and the computer program code 173 are configured to, with the one or more processors 175, cause the NCE 190 to perform one or more operations.

5 **[0040]** The wireless network 100 may implement network virtualization, which is the process of combining hardware and software network resources and network functionality into a single, software-based administrative entity, a virtual network. Network virtualization involves platform virtualization, often combined with resource virtualization. Network virtualization is categorized as either external, combining many networks, or parts of
10 networks, into a virtual unit, or internal, providing network-like functionality to software containers on a single system. Note that the virtualized entities that result from the network virtualization are still implemented, at some level, using hardware such as processors 152 or 175 and memories 155 and 171, and also such virtualized entities create technical effects.

[0041] The computer readable memories 125, 155, and 171 may be of any
15 type suitable to the local technical environment and may be implemented using any suitable data storage technology, such as semiconductor based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory. The computer readable memories 125, 155, and 171 may be means for performing storage functions. The processors 120, 152, and 175 may be of any type
20 suitable to the local technical environment, and may include one or more of general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and processors based on a multi-core processor architecture, as non-limiting examples. The processors 120, 152, and 175 may be means for performing functions, such as controlling the UE 110, eNB 170, and other functions as described herein.

25 **[0042]** In general, the various embodiments of the user equipment 110 can include, but are not limited to, cellular telephones such as smart phones, tablets, personal digital assistants (PDAs) having wireless communication capabilities, portable computers having wireless communication capabilities, image capture devices such as digital cameras having wireless communication capabilities, gaming devices having wireless communication
30 capabilities, music storage and playback appliances having wireless communication capabilities, Internet appliances permitting wireless Internet access and browsing, tablets with wireless communication capabilities, as well as portable units or terminals that incorporate combinations of such functions.

[0043] FIG. 2(a) is a logic flow diagram for a transmission scheme and
35 feedback mechanism for transmitters with constrained RF chains. This figure further

illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments. The blocks in FIG. 2(a) are assumed to be performed by the UE 110, e.g., under control of the MIMO receiver module 140 at least in part.

[0044] In Step one, a receiver receives from a transmitter a MIMO radio frequency transmission received at one or more antenna elements. In Step two, the receiver estimates, from the received transmission, a channel coefficient for the one or more antenna elements. In Step three, the receiver generates a symbol constellation. The symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements. At Step Four, the receiver conveys towards the transmitter the symbol constellation.

[0045] FIG. 2(b) is a logic flow diagram for a transmission scheme and feedback mechanism for transmitters with constrained RF chains. This figure further illustrates the operation of an exemplary method, a result of execution of computer program instructions embodied on a computer readable memory, functions performed by logic implemented in hardware, and/or interconnected means for performing functions in accordance with exemplary embodiments. The blocks in FIG. 2(b) are assumed to be performed by a base station such as eNB 170, e.g., under control of the MIMO transmitter module 150 at least in part.

[0046] In Step One, a transmitter transmits towards a receiver a MIMO radio frequency transmission for reception at the receiver at one or more antenna elements. In Step Two, the transmitter receives from the receiver a symbol constellation. The symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more antenna elements.

[0047] In accordance with an exemplary embodiment, a multi-antenna transmission technique is provided that fully utilizes the available freedom in a constrained RF chains in a MIMO wireless communication. The exemplary embodiment also provides a feedback mechanism that transmits a minimum amount of necessary information to convey a determined symbol constellation.

[0048] In accordance with the exemplary embodiment, a symbol constellation is dynamically generated at the receiver whose constellation points are functions of the channel coefficients between different AEs and the receiver. For example, the transmitter can activate one antenna at a time. The receiver estimates the channel

coefficients, and constructs the constellation by looking at all the possible antenna combinations that can be activated. The receiver selects some of these constellation points based on a metric, for example, the constellation points which are easily separable i.e., maximize the minimum distance between two constellation point. Then, the corresponding antenna combinations are conveyed to the transmitter to be the usable constellation symbols.

[0049] FIG. 3 and FIG. 4 show an example with channel coefficients at the receiver space, set of constellation points formed from antenna combinations and the points that are chosen for data transmission. The x-axis and y-axis represent the real part and the imaginary of the complex symbol resulting from the corresponding antenna combinations. In FIG. 4, the constellation points for data transmission are chosen such that the minimum distance between any two constellation points is maximized.

[0050] The input bit sequence is mapped to a predefined order of the selected constellation points. Then, the transmitter activates the corresponding antenna combinations to generate the desired constellation points at the receiver. As described above, only a one bit DAC is assumed. However, this can be directly extended to a multi-bit signal that the constrained RFs can transmit. In this multi-bit case, the generated constellation will have large number of constellation points compared to the single bit case.

[0051] In this exemplary embodiment, the transmitter is able to accurately construct the constellation points (assuming coherence time is large enough to perform data transmission), and CSI is not necessary at the transmitter. Thus, only the antenna combinations which give the selected constellation points need to be conveyed to the transmitter.

[0052] An exemplary embodiment may be performed in three steps: 1) channel coefficient estimation; 2) constellation generation; and 3) feedback. First, the channel from each antenna is estimated at the receiver by activating one AE at a time. The estimation duration should be large enough to estimate the channel impulse response. In this section, for simplicity of explanation, a first single tap channel is assumed. Single tap channel is the channel where the channel impulse response has only one tap, in otherwords when an AE is switched on at the transmitter, a signal sample corresponding to the channel coefficient is received at the receiver. In case of multi-tap channel, when an AE is switched on at the transmitter, multiple signal samples are received at the receiver corresponding to the multiple taps of the channel impulse response. For multi-tap channel, either receive filter like Viterbi equalizer shall be necessary to estimate the received symbol and / or the multi-tap channel shall be taken into account when constructing the constellation points at the receiver so that the effect of multi-path channel is not significant when demodulating the transmitted symbols.

[0053] After estimating the channel coefficient from each AE, the receiver can generate the symbol constellation by looking at all possible combinations of the AEs.

[0054] For example, FIG. 3 shows the channel coefficients and the corresponding constellation points for the case of four AEs, with a one bit amplitude.

5 Accordingly, there are sixteen constellation points generated in the example illustrated in FIG. 3.

[0055] In FIG. 3, it can be seen that some of the constellation points are spatially very close and it may be difficult to distinguish the neighbouring point in the low SNR region. It may be preferable to select the constellation points based on the SNR and
10 utilize only the selected points for transmission. The selection can be made based on different criteria, some of which may be listed as:

- Maximize the minimum distance between the points
- Minimize the number of antennas used for transmission
- Reduce the feedback

15 [0056] FIG. 4 shows a set of chosen constellation points for the corresponding constellation points.

[0057] After the constellation points are selected, this information is conveyed to the transmitter by providing the transmitter with the corresponding antenna combinations that construct the selected constellation points. As an example, this form of
20 feedback may need at a minimum a number of constellation points times the number of AEs. Depending on the number points chosen, it may be efficient to feedback or convey either the constellation points chosen or the ones not chosen. Two different modes can be defined based on the SNR: 1. At low SNR, due to high noise power, it is desirable to choose few constellation points which are well separated from each other. In this case, the few chosen
25 constellation points shall be reported to the transmitter. 2. At high SNR, due to the low noise power, it is desirable to select more constellation points which might be closer in terms of distance compared to the low SNR case. In this case, the constellation points which are not chosen shall be reported to the transmitter. Furthermore, a tree structure could be used to efficiently feedback the antenna combinations. Depending on the trade off between the
30 performance overhead and the performance gain e.g. throughput, bit error rate, the receiver shall do the reporting in two steps: Step1: Downselect the number of antennas it would prefer for transmission Step2: Inform the antenna combinations / constellation points formed using these antennas only. In addition, for medium SNR region, if the overhead to report antenna combinations / chosen / not chosen constellation points is larger than reporting the channel
35 coefficient itself then the receiver shall construct the constellation in a form of regular grid

and report the channel coefficients of the AEs used to construct the regular grid. FIG. 6 shows an example where the constellation symbols are constructed in a regular grid form. Note that in FIG. 6 the four corner points are generated by switching on all the AEs whose coefficients are in two adjacent quadrants of the received signal space. In this example, the transmitter can
5 construct the corner points and hence, the constellation grid points. For this the receiver need to report the number of constellation points in the grid in addition to the channel coefficients corresponding to all the AEs used to construct the channel coefficients. However, the receiver does not need to report the combination of AEs used for each of the constellation points.

[0058] The transmitter uses a predefined order to map the input bits to the
10 chosen constellation points. As an example, FIG. 5 shows a table indicating an exemplary predefined order and the mapping of the input bits to the constellation points. In this case, the chosen constellation points may be sorted in a predefined manner as shown in the table. The antenna combinations may have an increasing binary number order. In this example, since eight constellation points are chosen, the constellation points are mapped to three bits as
15 shown in the table. As can be noted from FIGs. 4 and 5, the chosen constellation points may have a regular structure and hence, the combinations that form the chosen constellation points may be fed back using some form of compression and/or coding to reduce overhead and conserve communication resources.

[0059] From the perspective of a user equipment, in accordance with an
20 exemplary embodiment, a MIMO radio frequency transmission is received at a receiver from a transmitter. The MIMO radio frequency transmission is received at one or more antenna elements. At the receiver, from the received transmission, a channel coefficient for the one or more antenna elements is estimated from the received transmission. A symbol constellation is generated at the receiver. The symbol constellation depends on possible
25 combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements. The receiver conveys towards the transmitter the symbol constellation.

[0060] The channel coefficient estimation may comprise sequentially
activating each antenna element one at a time to receive the transmission. Pre-defined pilot
30 signals shall be used to perform channel estimation. A duration of the estimating may be sufficient to estimate a channel impulse response at the one or more antenna element. The symbol constellation may be based on a signal-to-noise ratio of the possible combinations of the one or more antenna elements. Creating the symbol constellation may include at least one of maximizing a minimum distance between symbols, minimizing a number of antenna
35 elements used for transmission and reducing an amount of information provided in conveying

the symbol constellation. The symbol constellation may be conveyed as a minimum number of constellation points times the number of antenna elements comprising either an indication of active antennas or in-active antennas of the one or antenna elements. That is, the symbol constellation may include those antennas that are switched on (active) or those antennas that are switched off (in-active). An extra bit of control information may be conveyed to indicate whether the constellation is being conveyed as the active or in-active antenna elements. The number of constellation points and / or number of antennas utilized to generate the constellation points shall be determined as a tradeoff between the reporting overhead and the performance gain e.g. throughput, SNR, etc.

[0061] The symbol constellation may be conveyed as either a set of chosen constellation points or a set of not chosen constellation points. The MIMO radio frequency transmission may be received on constrained RF front ends e.g. with one bit ADCs. The MIMO radio frequency transmission may be received as a signal from a constrained radio frequency frontend having a single bit signal associated with each of the one or more antenna elements. The MIMO radio frequency transmission may be received as a signal from a constrained radio frequency frontend having a multi-bit signal associated with one or more of the one or more antenna elements.

[0062] In accordance with another exemplary embodiment, an apparatus, comprises:

one or more processors; and
one or more memories including computer program code,
the one or more memories and the computer program code configured, with the one or more processors, to cause the apparatus to perform at least the following:
receive, at a receiver from a transmitter, a MIMO radio frequency transmission
received at one or more antenna elements;
estimate, at the receiver, from the received transmission, a channel coefficient for the one or more antenna elements;
generate, at the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements; and
convey, from the receiver towards the transmitter, the symbol constellation.

[0063] In accordance with another exemplary embodiment, a computer program product comprises a computer-readable storage medium bearing computer program code embodied therein for use with a computer, the computer program code comprising:

code for receiving, at a receiver from a transmitter, a MIMO radio frequency transmission received at one or more antenna elements;

code for estimating, at the receiver, from the received transmission, a channel coefficient for the one or more antenna elements;

- 5 code for generating, at the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements; and
code for conveying, from the receiver towards the transmitter, the symbol constellation.

- 10 **[0064]** From an access point or base station perspective, in accordance with another exemplary embodiment, a transmitter transmits towards a receiver a MIMO radio frequency transmission for reception at the receiver at one or more antenna elements. The transmitter receives from the receiver a symbol constellation. The symbol constellation depends on possible combinations of the one or more antenna elements and an estimated
15 channel coefficient for the one or more antenna elements.

- [0065]** The symbol constellation may depend on the estimated channel coefficient obtained by sequentially activating each antenna element of the one or more antenna elements one at a time during a reception of the transmission from the transmitter. The symbol constellation may depend on the estimated channel coefficient where a duration
20 of the estimating is sufficient to estimate a channel impulse response at the one or more antenna elements. The symbol constellation may be based on a signal-to-noise ratio of the possible combinations of the one or more antenna elements. The symbol constellation may depend on at least one of maximizing a minimum distance between symbols, minimizing a number of antenna elements used for transmission and reducing an amount of information
25 provided in conveying the symbol constellation.

- [0066]** The symbol constellation may be received as a minimum number of constellation points times the number of antenna elements comprising either an indication of active antennas or in-active antennas of the one or antenna elements. The symbol constellation may be received as either a set of chosen constellation points or a set of not
30 chosen constellation points. The MIMO radio frequency transmission may be transmitted on constrained radio frequencies. The MIMO radio frequency transmission may be transmitted as a signal from a constrained radio frequency frontend having a single bit signal associated with each of the one or more antenna elements. The MIMO radio frequency transmission may be transmitted as a signal from a constrained radio frequency frontend having a multi-bit
35 signal associated with one or more of the one or more antenna elements.

[0067] In accordance with another exemplary embodiment, an apparatus comprises:

one or more processors; and

one or more memories including computer program code,

5 the one or more memories and the computer program code configured, with the one or more processors, to cause the apparatus to perform at least the following:

transmit, from a transmitter towards a receiver, a MIMO radio frequency transmission for reception at the receiver at one or more antenna elements; and

10 receive, at the transmitter from the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more antenna elements.

[0068] In accordance with another exemplary embodiment, a computer program product comprises a computer-readable storage medium bearing computer program code embodied therein for use with a computer, the computer program code comprising: code
15 for transmitting, from a transmitter towards a receiver, a MIMO radio frequency transmission for reception at the receiver at one or more antenna elements; and

code for receiving, at the transmitter from the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more
20 antenna elements.

[0069] Without in any way limiting the scope, interpretation, or application of the claims appearing below, a technical effect of one or more of the example embodiments disclosed herein is new transmission scheme with constrained RF chains in mMIMO systems. Another technical effect of one or more of the example embodiments
25 disclosed herein is new transmission scheme with constrained RF chains in mMIMO systems a feedback mechanism to efficiently transmit a symbol constellation based on one of a beamformed and a multiple-in multiple-out radio frequency transmission received at one or more antenna elements.

[0070] Embodiments of the present invention may be implemented in
30 software, hardware, application logic or a combination of software, hardware and application logic. The software, application logic and/or hardware may reside on a user equipment, base station or another network communication element. If desired, part of the software, application logic and/or hardware may reside for example, on user equipment, part of the software, application logic and/or hardware may reside on a base station or other access point
35 and part of the software, application logic and/or hardware may reside on one or more other

network communication elements. In an example embodiment, the application logic, software or an instruction set is maintained on any one of various conventional computer-readable media. In the context of this document, a “computer-readable medium” may be any media or means that can contain, store, communicate, propagate or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer. A computer-readable medium may comprise a computer-readable storage medium that may be any media or means that can contain or store the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer.

[0071] If desired, the different functions discussed herein may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the above-described functions may be optional or may be combined.

[0072] Although various aspects of the invention are set out in the independent claims, other aspects of the invention comprise other combinations of features from the described embodiments and/or the dependent claims with the features of the independent claims, and not solely the combinations explicitly set out in the claims.

[0073] It is also noted herein that while the above describes example embodiments of the invention, these descriptions should not be viewed in a limiting sense. Rather, there are several variations and modifications which may be made without departing from the scope of the present invention as defined in the appended claims.

List of abbreviations

ADC	analog-to-digital converter
MIMO	multiple input multiple output
RF-Chain	analog radio frequency chain
DAC	digital-to-analog converter
UE	user equipment
CSI	channel state information
GoB	grid of beams
AE	antenna elements
SNR	signal to noise ratio
mMIMO	massive MIMO
MU-MIMO	multi-user MIMO
PMI	precoder matrix indicator
LTE	long term evolution

WHAT IS CLAIMED IS

- 1) A method, comprising:

receiving, at a receiver from a transmitter, a multiple-in multiple-out radio frequency transmission received at one or more antenna elements;

5 estimating, at the receiver, from the received transmission, a channel coefficient for the one or more antenna elements;

generating, at the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements; and

10 conveying, from the receiver towards the transmitter, the symbol constellation.

- 2) The method according to claim 1, wherein the channel coefficient estimation comprises sequentially activating each antenna element one at a time to receive the transmission.

- 3) The method according to claim 1, wherein a duration of the estimation is sufficient to estimate a channel impulse response at the one or more antenna element.

- 4) The method according to claim 1, wherein the symbol constellation is based on a signal-to-noise ratio of the possible combinations of the one or more antenna elements.

- 5) The method according to claim 1, wherein creating the symbol constellation includes at least one of maximizing a minimum distance between symbols, minimizing a number of antenna elements used for transmission and reducing an amount of information provided in conveying the symbol constellation.

- 6) The method according to claim 1, wherein the symbol constellation is conveyed as a minimum number of constellation points times the number of antenna elements comprising either an indication of active antennas or in-active antennas of the one or more antenna elements.

- 7) The method according to claim 1, wherein the symbol constellation is conveyed as either a set of chosen constellation points or a set of not chosen constellation points.

8) The method according to claim 1, wherein the symbol constellation is conveyed as the number of constellation points and the channel coefficients of the antenna elements used to generate the constellation points.

5

9) The method according to claim 1, wherein the multiple-in multiple-out radio frequency transmission is received on constrained radio frequencies.

10

10) The method according to claim 1, wherein the multiple-in multiple-out radio frequency transmission is received as a signal from a constrained radio frequency frontend having a single bit signal associated with each of the one or more antenna elements.

15

11) The method according to claim 1, wherein the multiple-in multiple-out radio frequency transmission is received as a signal from a constrained radio frequency frontend having a multi-bit signal associated with one or more of the one or more antenna elements.

20

12) The method according to claim 1, wherein the antenna elements correspond to the beam ports of a grid of beams

13) An apparatus, comprising:

one or more processors; and

one or more memories including computer program code,

25

the one or more memories and the computer program code configured, with the one or more processors, to cause the apparatus to perform at least the following: receive, at a receiver from a transmitter, a multiple-in multiple-out radio frequency transmission received at one or more antenna elements;

30

estimate, at the receiver, from the received transmission, a channel coefficient for the one or more antenna elements;

generate, at the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements; and convey, from the receiver towards the transmitter, the symbol constellation.

35

14) A computer program product comprising a computer-readable storage medium bearing computer program code embodied therein for use with a computer, the computer program code comprising:

code for receiving, at a receiver from a transmitter, a multiple-in multiple-out radio frequency transmission received at one or more antenna elements ;

code for estimating, At the receiver, from the received transmission, a channel coefficient for the one or more antenna elements;

code for generating, at the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and the estimated channel coefficient for the one or more antenna elements; and code for conveying, from the receiver towards the transmitter, the symbol constellation.

15) A method, comprising:

transmitting, from a transmitter towards a receiver, a multiple-in multiple-out radio frequency transmission for reception at the receiver at one or more antenna elements; and

receiving, at the transmitter from the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more antenna elements.

16) The method according to claim 15, wherein symbol constellation depends on the estimated channel coefficient obtained by sequentially activating each antenna element of the one or more antenna elements one at a time during a reception of the transmission from the transmitter.

17) The method according to claim 15, wherein symbol constellation depends on the estimated channel coefficient where a duration of the estimating is sufficient to estimate a channel impulse response at the one or more antenna elements.

18) The method according to claim 15, wherein the symbol constellation is based on a signal-to-noise ratio of the possible combinations of the one or more antenna elements.

19) The method according to claim 15, wherein the symbol constellation depends on at least one of maximizing a minimum distance between symbols, minimizing a number of antenna elements used for transmission and reducing an amount of information provided in conveying the symbol constellation.

5

20) The method according to claim 15, wherein the symbol constellation is received as a minimum number of constellation points times the number of antenna elements comprising either an indication of active antennas or in-active antennas of the one or antenna elements.

10

21) The method according to claim 15, wherein the symbol constellation is received as either a set of chosen constellation points or a set of not chosen constellation points.

22) The method according to claim 15, wherein the multiple-in multiple-out radio frequency transmission is transmitted on constrained radio frequencies.

15

23) The method according to claim 15, wherein the multiple-in multiple-out radio frequency transmission is transmitted as a signal from a constrained radio frequency frontend having a single bit signal associated with each of the one or more antenna elements.

20

24) The method according to claim 15, wherein the multiple-in multiple-out radio frequency transmission is transmitted as a signal from a constrained radio frequency frontend having a multi-bit signal associated with one or more of the one or more antenna elements.

25

25) An apparatus, comprising:

one or more processors; and

one or more memories including computer program code,

30

the one or more memories and the computer program code configured, with the one or more processors, to cause the apparatus to perform at least the following: transmit, from a transmitter towards a receiver, a multiple-in multiple-out radio frequency transmission for reception at the receiver at one or more antenna elements; and

receive, at the transmitter from the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more antenna elements.

- 5 26) A computer program product comprising a computer-readable storage medium bearing computer program code embodied therein for use with a computer, the computer program code comprising: code for transmitting, from a transmitter towards a receiver, a multiple-in multiple-out radio frequency transmission for reception at the receiver at one or more antenna elements; and
- 10 code for receiving, at the transmitter from the receiver, a symbol constellation, wherein the symbol constellation depends on possible combinations of the one or more antenna elements and an estimated channel coefficient for the one or more antenna elements.

1/5

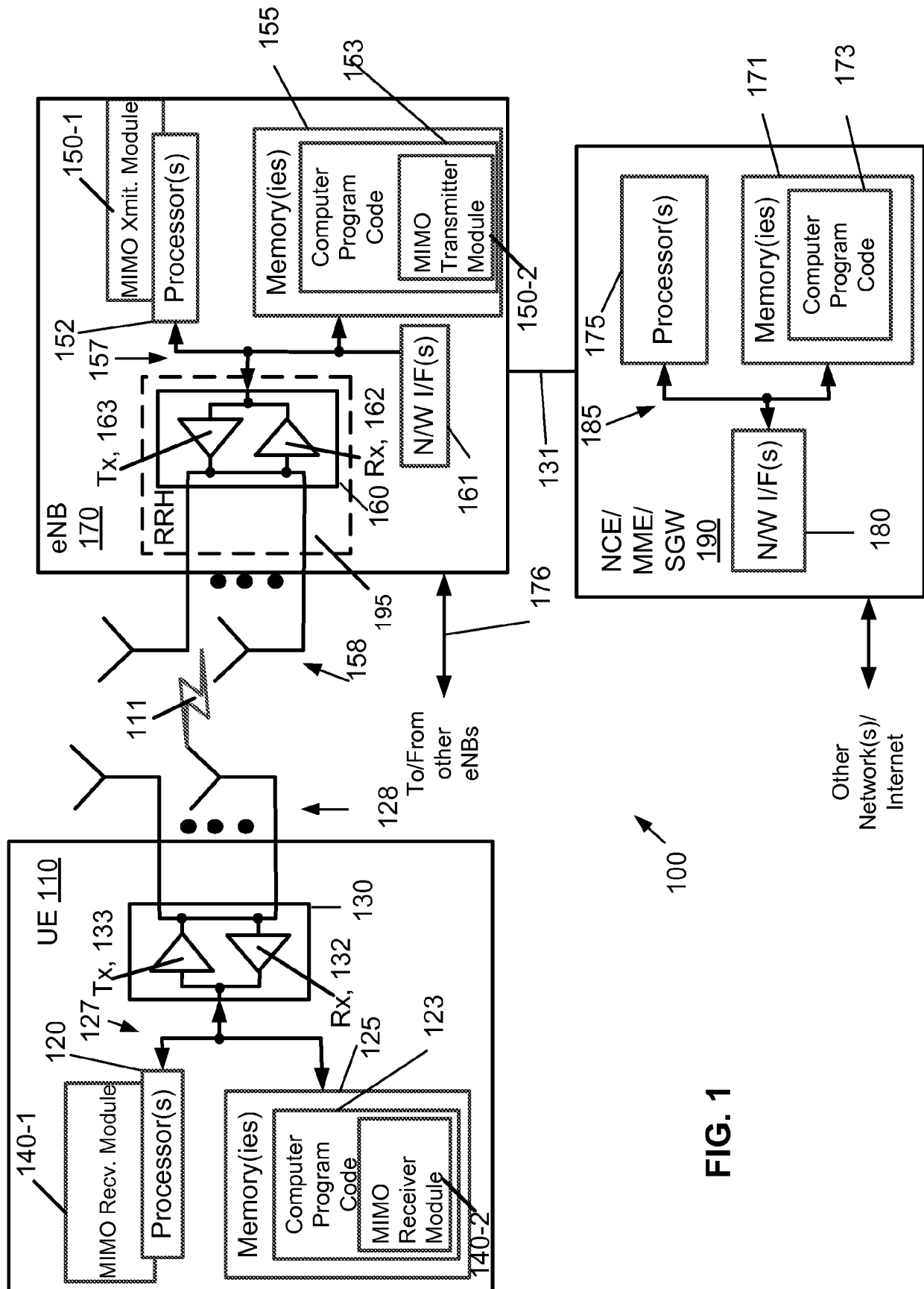
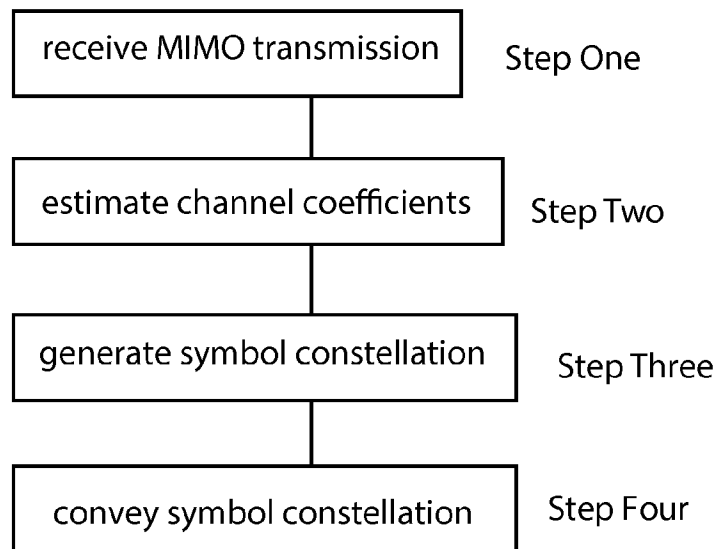
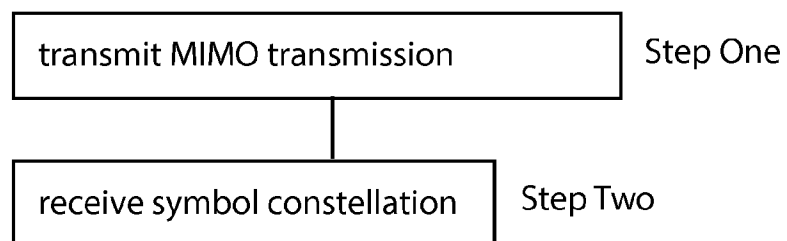


FIG. 1

**FIG. 2(a)****FIG. 2(b)**

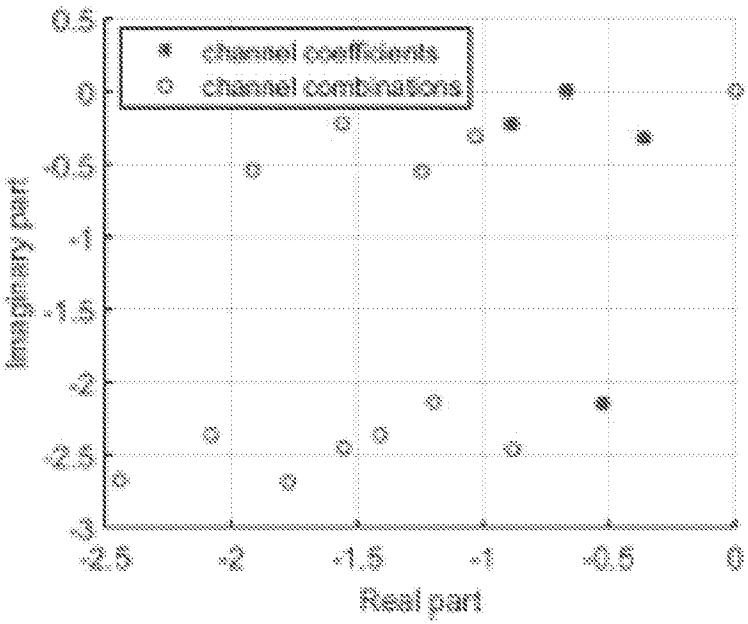


FIG. 3

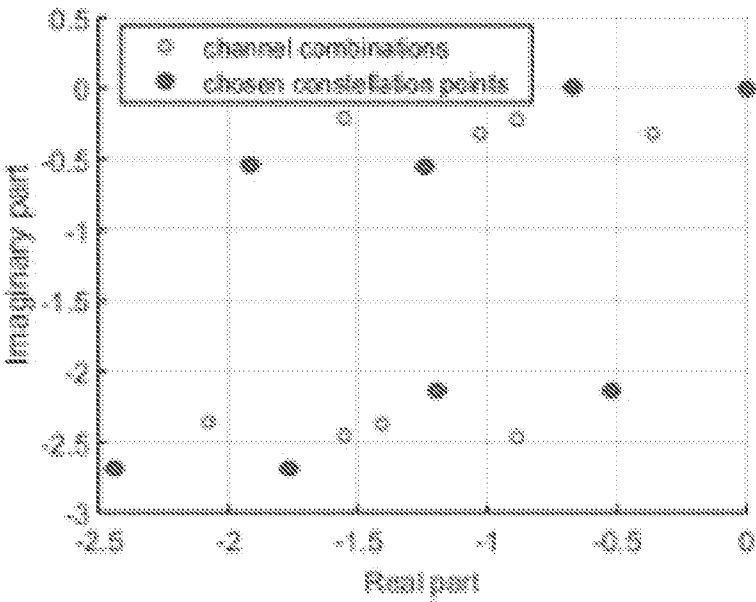


FIG. 4

Channel combinations				Mapped input bits
AE1	AE2	AE3	AE4	
0	0	0	0	000
0	0	0	1	
0	0	1	0	001
0	0	1	1	
0	1	0	0	010
0	1	0	1	
0	1	1	0	011
0	1	1	1	
1	0	0	0	
1	0	0	1	100
1	0	1	0	
1	0	1	1	101
1	1	0	0	
1	1	0	1	110
1	1	1	0	
1	1	1	1	111

FIG. 5

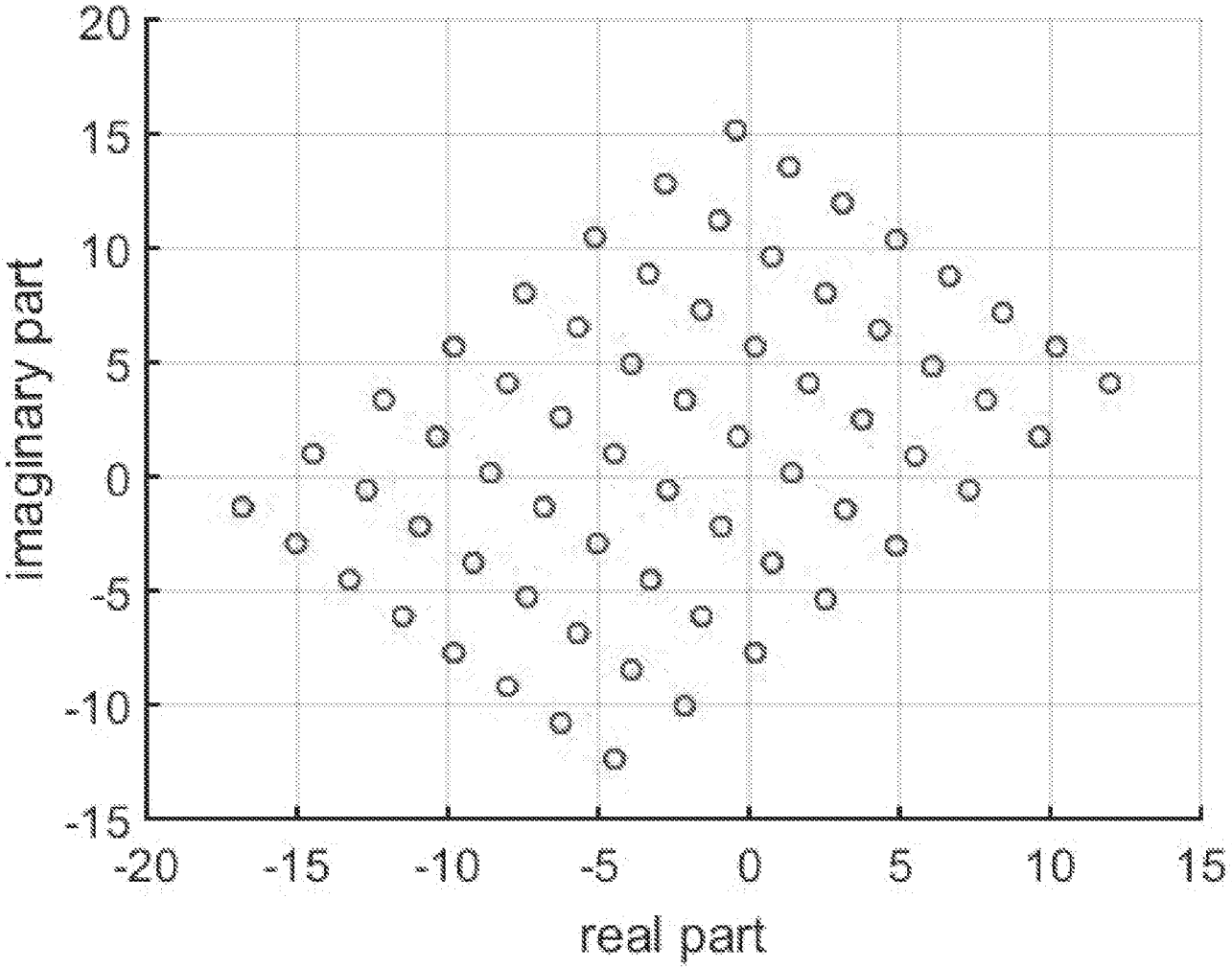


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI2016/050839

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

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)

IPC: H04B, H04L, H04W

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

FI, SE, NO, DK

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

EPODOC, EPO-Internal full-text databases, Full-text translation databases from Asian languages, WPIAP, PRH-Internal, XP3GPP, XPAIP, XPESP, XPETSI, XPI3E, XPIEE, XPIOP, XPIPCOM, XPMISC, XPOAC, XPRD, COMPD, INSPEC, TDB, NPL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016294460 A1 (KARSI MURAT [US] et al.) 06 October 2016 (06.10.2016) par. [0004], [0048], [0051]-[0052], [0073]-[0074], [0076], [0083], [0085], [0087]-[0088], [0102]-[0105], [0107]-[0111], [0128]-[0129], [0136]-[0137], [0162]-[0163], [0170]-[0172], [0181]-[0183], [0189], [0198], [0207]-[0209], [0256], [0304]-[0306], [0374], [0413], [0418]; figs. 5-10	1-26
X	WO 2016166706 A1 (HUAWEI TECH CANADA CO LTD [CA]) 20 October 2016 (20.10.2016) par. [0002], [0004]-[0006], [0038]-[0040], [0079], [0081]-[0083]; fig. 4; claims 12, 21	1, 7-8, 13-15, 21, 25-26
A	EP 2073420 A1 (SONY CORP [JP]) 24 June 2009 (24.06.2009) abstract; par. [0045], [0059], [0068]-[0074], [0082]-[0084]; figs. 3-4	

☒ 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	"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	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search 10 March 2017 (10.03.2017)	Date of mailing of the international search report 16 March 2017 (16.03.2017)
Name and mailing address of the ISA/FI Finnish Patent and Registration Office P.O. Box 1160, FI-00101 HELSINKI, Finland Facsimile No. +358 9 6939 5328	Authorized officer Ville Möttönen Telephone No. +358 9 6939 500

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI2016/050839

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015326285 A1 (ZIRWAS WOLFGANG [DE] et al.) 12 November 2015 (12.11.2015) abstract; par. [0023]-[0033]; figs. 1-5	
A	Choi J. et al. 'Near Maximum-Likelihood Detector and Channel Estimator for Uplink Multiuser Massive MIMO Systems With One-Bit ADCs', IEEE Transactions on Communications, vol. 64, no. 5, pp. 2005-2018, May 2016, doi:10.1109/TCOMM.2016.2545666; [retrieved 2017-3-8] EPOQUENET NPL XP011610016 abstract; fig. 1	

INTERNATIONAL SEARCH REPORT
Information on Patent Family Members

International application No.
PCT/FI2016/050839

Patent document cited in search report	Publication date	Patent family members(s)	Publication date
US 2016294460 A1	06/10/2016	None	
.....			
WO 2016166706 A1	20/10/2016	US 2016309344 A1	20/10/2016
.....			
EP 2073420 A1	24/06/2009	EP 2073420 B1	17/11/2010
		AT 488923 T	15/12/2010
		CN 101465832 A	24/06/2009
		CN 101465832 B	27/03/2013
		DE 602007010654 D1	30/12/2010
		DK 2073420 T3	14/02/2011
		ES 2354734 T3	17/03/2011
		PT 2073420 E	15/02/2011
		SI 2073420 T1	31/03/2011
		US 2009161780 A1	25/06/2009
		US 8270507 B2	18/09/2012
.....			
US 2015326285 A1	12/11/2015	US 9231676 B2	05/01/2016
		CN 105099533 A	25/11/2015
		EP 2953272 A2	09/12/2015
.....			

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI2016/050839

CLASSIFICATION OF SUBJECT MATTER

IPC

H04B 7/0417 (2017.01)

H04B 7/06 (2006.01)

H04L 1/06 (2006.01)

H04W 24/02 (2009.01)

H04W 72/04 (2009.01)

H04W 72/08 (2009.01)