



- (51) **International Patent Classification:**
H04L 25/00 (2006.01)
- (21) **International Application Number:**
PCT/CN2015/082292
- (22) **International Filing Date:**
25 June 2015 (25.06.2015)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (71) **Applicant:** SOUTHEAST UNIVERSITY [CN/CN]; No. 2 Sipailou, Xuanwu, Nanjing, Jiangsu 210096 (CN).
- (72) **Inventors:** MENG, Xin; No.2 Sipailou, Xuanwu, Nanjing, Jiangsu 210096 (CN). XIA, Xianggen; No.2 Sipailou, Xuanwu, Nanjing, Jiangsu 210096 (CN). GAO, Xiqi; No.2 Sipailou, Xuanwu, Nanjing, Jiangsu 210096 (CN).
- (74) **Agent:** JIANGSU AIXIN LAW FIRM; 18th Fl.-E, Jinyinghanchongxincheng Building, No. 1 Hanzhongmen Main Street, Nanjing, Jiangsu 210029 (CN).
- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

- (54) **Title:** OMNIDIRECTIONAL SPACE-TIME BLOCK CODING IN MASSIVE MIMO SYSTEMS

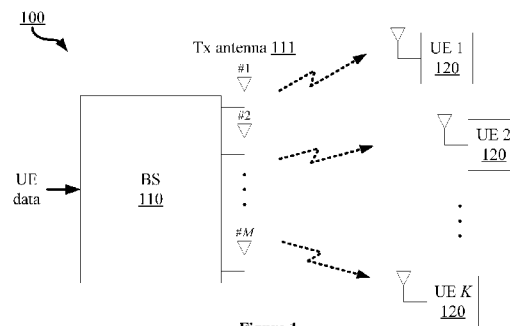


Figure 1

- (57) **Abstract:** Described herein is an omnidirectional space-time coding scheme allowing signals to transmit from a base station to multiple user equipments in a massive MIMO system with reduced pilot overhead and system complexity. The transmission scheme uses a low-dimensional space-time coding scheme to generate a $K \times T_d$ code block, and based on the $K \times T_d$ code block, using an $M \times K$ precoding matrix W to generate an $M \times T_d$ code block for transmission over a large number of transmitting antennas, wherein K is much smaller than M .

OMNIDIRECTIONAL SPACE-TIME BLOCK CODING IN MASSIVE MIMO SYSTEMS

Field of the Invention

The presented invention relates to cellular mobile communication systems using massive arrays of antennas at the base station (BS) side, and more particularly, to a transmission approach allowing the multi-antenna BS to use omnidirectional space-time block codes (STBCs) to broadcast the common information to multiple user equipments (UEs) in massive multiple-input multiple-output (MIMO) systems.

Background of the Invention

An emerging research area in multi-user MIMO communications is so-called massive MIMO or large-scale MIMO systems. Unlike conventional multi-user MIMO systems that employ less than ten antennas at the BS, a BS in massive MIMO systems is typically equipped with much larger numbers of antennas, e.g., one hundred or more, which can be far more than the number of UEs, e.g., 40, to be served by such BS.

Compared with conventional MIMO systems, massive MIMO systems have many significant benefits. For example, with a substantial increase in the number of BS antennas, each antenna unit can be made much smaller with a much lower cost. Also, since a large number of antennas can provide more spatial freedom, the BS in any given cell can use the same time-frequency resources to communicate with multiple UEs simultaneously, which can significantly improve the spectral efficiency. The system power efficiency can also be improved because the massive antenna units allow for a better spatial orientation between the BS and each UE in the cell for downlink and uplink transmissions, which can significantly reduce the transmission power from both the BS and UE sides. In addition, when there exist a sufficient number of BS antennas, the random channels between each UE and the BS can be nearly orthogonal to each other, which can help eliminate inter-cell and inter-user interferences and noise.

Despite the above mentioned technological advantages, however, current applications of

massive MIMO may be constrained in view of existing transmission schemes. For example, in a traditional cellular system, a public channel is often used to carry important common signals from the BS to UEs, such as synchronization signals, reference signals within the cell, control command signals, multimedia broadcast multicast service (MBMS) signals, and the like. These common signals are targeted for all the UEs served by the BS rather than only certain active UEs. This is the case when the BS is broadcasting the common control information or paging an inactive UE. Since inactive UEs may be in silent or sleep mode, the BS cannot obtain these UEs' downlink channel state information (CSI) through uplink training in time division duplex (TDD) systems or downlink training and then feedback in frequency division duplex (FDD) systems. Therefore, the BS cannot serve them with spatially directional signaling. As an alternative approach, the transmission scheme for the public channel should be such designed that it provides omnidirectional signaling to ensure a cell-wide coverage.

Most existing transmission schemes providing omnidirectional signaling, such as single-antenna transmission or cyclic delay diversity (CDD), may be incompatible with a massive MIMO system. For example, for the single-antenna transmission, one single antenna is selected from the transmit antennas of the BS to broadcast signals while the other antennas are kept silent. In this case, the transmitted signal radiates isotropically in all spatial directions since there is no constructive/destructive effect among antennas. However, it at the same time leads to transmission power losses compared with the case that all antennas are used for broadcasting signals. This power loss may be tolerable when the number of BS antennas is small, e.g., the losses are 3 dB and 6 dB in a two-antenna and a four-antenna system, respectively. However, when the BS has a large number of antennas, the power loss may be fatal and the communication link may fail to work. Therefore, equal transmission power on each antenna is required to sufficiently utilize all the power-amplifier (PA) capacities of the BS antenna array. CDD is a simple and useful technique recommended for digital video broadcasting (DVB) and Long-Term Evolution (LTE). However, it has been shown in the related reference that CDD is just pseudo-omnidirectional, i.e., the omnidirectional coverage is achieved only when different subcarriers are averaged. When focusing on one single subcarrier, the radiation power mainly focuses on a small angle region. Obviously the UE outside this region cannot receive a strong enough signal. In addition, with the increase in the number of antennas in a massive MIMO system, pilot expenses may increase for

CDD.

Besides omnidirectional coverage and PA utilization, spatial diversity is another important issue needed to be concerned, which improves the reliability of the communication link. Therefore, a need exists for an improved transmission scheme that can provide omnidirectional signaling with efficient PA utilization and transmit diversity in a massive MIMO system without causing additional pilot expenses or system complication.

Summary of the Invention

The presently disclosed embodiments are directed to solving issues relating to one or more of the problems presented in the prior art, as well as providing additional features that will become readily apparent by reference to the following detailed description when taken in conjunction with the accompanying drawings.

The present invention provides several transmission approaches in terms of omnidirectional STBC suitable for massive MIMO downlink broadcasting, with low expense of pilot overhead and low complexity of system implementation, so that the signals transmitted from the BS have the same signal powers in any spatial direction, thereby ensuring a full coverage of the cell; the transmitting signals from all antenna units equipped in the BS can have the same signal powers, thereby maximizing the power efficiency of each radio frequency unit and massive arrays of antennas; further, the diversity order can be as much as that of a low-dimensional STBC employed herein.

The illustrative embodiment of the present invention comprises: generating one $K \times T$ STBC within T transmission intervals (either in the time or frequency domain); applying an $M \times K$ precoding matrix to this $K \times T$ STBC to generate one $M \times T$ STBC, wherein K is much smaller than M ; and transmitting said $M \times T$ STBC over M transmitting antennas in a BS of said massive MIMO system.

Further features and advantages of the present disclosure, as well as the structure and operation of various embodiments of the present disclosure, are described in detail below with reference to the accompanying drawings.

Brief Description of the Drawings

Fig. 1 is a block diagram showing an exemplary downlink transmission scenario between a massive MIMO BS and some representative UEs, in which embodiments of the invention can be implemented.

Fig. 2 is a diagram providing a simplified view of exemplary transmission paths or channels in the downlink transmission scenario of Fig. 1, in which embodiments of the invention can be implemented.

Fig. 3 is a flow diagram presenting part of an exemplary omnidirectional STBC scheme on the BS side in a massive MIMO system in which embodiments of the invention can be implemented.

Fig. 4 is a flow diagram presenting part of an exemplary omnidirectional STBC scheme on the UE side in a massive MIMO system in which embodiments of the invention can be implemented.

Detailed Description of Exemplary Embodiments

The following description is presented to enable a person of ordinary skill in the art to make and use the invention. Descriptions of specific devices, techniques, and applications are provided only as examples. Various modifications to the examples described herein will be readily apparent to those of ordinary skill in the art, and the general principles defined herein may be applied to other examples and applications without departing from the spirit and scope of the invention. Thus, embodiments of the present invention are not intended to be limited to the examples described herein and shown, but are to be accorded the scope consistent with the claims.

The word “exemplary” is used herein to mean “serving as an example or illustration.” Any aspect or design described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects or designs.

Reference will now be made in detail to aspects of the subject technology, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to like elements throughout.

It should be understood that the specific order or hierarchy of steps in the processes disclosed

herein is an example of exemplary approaches. Based upon design preferences, it is understood that the specific order or hierarchy of steps in the processes may be rearranged while remaining within the scope of the present disclosure. The accompanying method claims present elements of the various steps in a sample order, and are not meant to be limited to the specific order or hierarchy presented.

Embodiments disclosed herein are directed to a downlink transmission approach in terms of omnidirectional STBC in a massive MIMO system. Without limiting the generality of the inventive embodiments, the transmission scheme described herein allows the system to have the following characteristics in any given cell:

- 1) All transmitting signals by the BS to UEs, in any spatial direction, have identical signal powers so as to ensure a full coverage of the cell;
- 2) All antenna units equipped in the BS have identical transmission powers so as to maximize the power efficiency of each radio frequency channel and massive arrays of antennas;
- 3) The spatial diversity order can be as good as that of the low-dimensional STBC herein.

Specifically, in one embodiment, the transmission approach uses a low-dimensional space-time coding scheme to generate a $K \times T$ STBC matrix $\mathbf{X}$, and based on $\mathbf{X}$, using an $M \times K$ precoding matrix $\mathbf{W}$ to generate an $M \times T$ STBC matrix $\mathbf{WX}$ for transmission over M transmitting antennas within T transmission intervals, wherein K may be much smaller than M .

In a massive MIMO system, the BS sends massive amounts of data to multiple UEs via downlink transmissions, in support of which various transmission schemes may be implemented. For example, Fig. 1 presents one exemplary data transmission scenario that enables downlink transmission from a BS to multiple UEs in all directions. As seen in Fig. 1, the BS is configured with M transmit antennas, e.g., Tx antennas #1, #2, ... # M , where M can be over 64, for example, 128 or 256. Each UE can be equipped with one or more receive antennas. For purposes of illustration only, each of the multiple UEs herein below is assumed to have a single receive antenna. But it should be understood that such assumption does not limit the application of the inventive embodiments in terms of how many antennas are configured in each UE.

When information bit streams are transmitted from the BS to UEs, they are usually processed in the BS to generate transmit signals. Eventually the transmit signals are transmitted by multiple transmitter units connected to multiple antenna units, such as the M number of antennas, via a

downlink transmission to UEs in accordance with a particular transmission scheme. The transmission paths or channels between the BS and UEs are illustrated in Fig. 2, as will be described in details below.

As shown in Fig. 2, on the transmitting side, there are M transmit antennas #1, #2,...,# M . When signals are transmitted from the transmit antennas to the receive antenna, they travel through transmission paths or channels, which are represented as an M -dimensional channel vector $\mathbf{h}=[h_1, h_2, \dots, h_M]^T$. $\mathbf{h}$ provides important channel information for the receiving side to decode the received signal. Here a frequency flat fading channel is assumed for purposes of illustration only, which can be considered as a subcarrier channel in the OFDM transmission framework.

A. Omnidirectional STBC in a Massive MIMO System

Fig. 3 is a flow diagram presenting part of the omnidirectional STBC scheme from the BS perspective in a massive MIMO system. As shown in Fig. 3, on the transmitter side, the transmission process 300 starts at step 310, where one or more information bit streams b_i are obtained after channel encoding and interleaving. At step 320, a low-dimensional STBC encoding scheme is applied to the binary bit streams b_i to generate a $K \times T_d$ codeword matrix, denoted as $\mathbf{X}_d=[\mathbf{x}_d(1), \dots, \mathbf{x}_d(T_d)]$. This low-dimensional STBC encoding scheme can have various designs, which will be described in detail in the next subsection. The low dimension, denoted by K , can be as low as 2, 4 or 8, far less than the number of antennas M (e.g., 64, 128, or 256) in the massive MIMO system. As such, the coded signal is a K -dimensional vector signal $\mathbf{x}_d(n)$ at each transmission interval n .

The transmission process 300 then proceeds to step 330 for pilot sequence insertion. Specifically, the coded signal $\mathbf{X}_d$ is periodically (in the time domain or frequency domain or both) inserted with a sequence of K -dimensional pilot vector signals of length T_p . The pilot signal is denoted as $\mathbf{x}_p(n)$ for $n=1, 2, \dots, T_p$. As a result of the pilot insertion, a signal $\mathbf{x}(n)$, is generated, which is also a K -dimensional vector signal of length $T_d + T_p$. Next, at step 340, the K -dimensional signal is spatially spread or expanded using a precoding matrix to obtain an

M -dimensional vector signal as the transmit signal, wherein $\mathbf{W}$ is an $M \times K$ precoding matrix. At step 350, the M -dimensional signal is transmitted by the large-scale array of antennas as the digital baseband signal in the specific time and frequency resources for a public channel to UEs in all spatial directions.

Fig. 4 presents a receiving process 400 of the omnidirectional STBC approach according to embodiments of the invention. As shown in Fig. 4, at the receiver end, the process 400 starts at step 410 where the digital baseband signal transmitted over the transmission channels or paths is received by a single receive antenna at the receiver. The received signals, denoted as $y(n)$, include received pilot signals $y_p(n)$ for $n=1,2,\dots,T_p$ and received data signals $y_d(n)$ for $n=1,2,\dots,T_d$. Based on the received pilot signals $y_p(n)$ for $n=1,2,\dots,T_p$, channel estimation can be performed to obtain estimated values of the channel parameters at step 420. With the estimated values of channel parameters and the received data signals, at step 430, space-time decoding can be performed to recover the original binary bits. The recovered binary bits 440, denoted as $\hat{b}_l$, gives the UE useful data from the BS.

It should be noted that in wireless transmission systems that adopt channel encoding, the original binary bits b_l is usually resulted from channel coding and interleaving, and therefore, the recovered binary bits $\hat{b}_l$ needs to go through additional processing, such as de-interleaving and channel decoding, in order to recover the original information bit sequence. These steps are not shown in details in the above processes 300 and 400, but can be incorporated without departing the spirit of the invention.

Also, as will be described below, the above-mentioned channel estimation is actually an estimate of the parameters of an equivalent channel in the precoding space, and the space-time decoding is also performed in the equivalent channel.

Assuming that the channel is approximately invariant over the current resource block, the digital baseband signal received by the receiver can be expressed by the following equation:

$$\begin{aligned} y(n) &= \mathbf{h}^T \mathbf{W} \mathbf{x}(n) + z(n) \\ &= \tilde{\mathbf{h}}^T \mathbf{x}(n) + z(n) \end{aligned} \quad (1)$$

where $\mathbf{h}$ represents the channel between the BS and the UE, which comprises an

M -dimensional channel vector, $z(n)$ represents the additive white Gaussian noise (AWGN), and $\tilde{\mathbf{h}}$ represents the equivalent channel in the precoding space, which is a K -dimensional channel vector.

If, assuming in any given period of pilot insertion, there are T_p pilot vector signals and T_d data vector signals, then the received pilot signals and data signals can be expressed by the following two equations, respectively:

$$\begin{aligned} y_p(n) &= \tilde{\mathbf{h}}^T \mathbf{x}_p(n) + z_p(n), n = 1, 2, \dots, T_p \\ y_d(n) &= \tilde{\mathbf{h}}^T \mathbf{x}_d(n) + z_d(n), n = 1, 2, \dots, T_d \end{aligned} \quad (2)$$

where $z_p(n)$ and $z_d(n)$ represent the corresponding noise terms. Using these two equations, channel estimation and space-time decoding can be performed at the receive side.

Further, if it is denoted that

$$\begin{aligned} \mathbf{y}_p &= [y_p(1), y_p(2), \dots, y_p(T_p)]^T \\ \mathbf{X}_p &= [\mathbf{x}_p(1), \mathbf{x}_p(2), \dots, \mathbf{x}_p(T_p)] \end{aligned} \quad (3)$$

then the least square estimation (LSE) of equivalent channel $\tilde{\mathbf{h}}$ can be obtained from the following equation:

$$\hat{\tilde{\mathbf{h}}} = (\mathbf{X}_p^* \mathbf{X}_p^T)^{-1} \mathbf{X}_p^* \mathbf{y}_p \quad (4)$$

In order to estimate the equivalent channel $\tilde{\mathbf{h}}$ at the receiver end, the pilot length T_p needs to be greater than or equal to K , but it can be far less than M . This means that, the increase of M would not affect T_p and thus would not cause additional pilot overhead. This is clearly advantageous to conventional transmission schemes, which, as aforementioned, would require the pilot length T_p to be at least M . Compared to existing transmission schemes, the above-described transmission scheme according to embodiments of the invention can reduce the pilot overhead by up to M / K times.

Based on the estimated value of $\tilde{\mathbf{h}}$, the above equation (2) for data signal, and the specific space-time coding method used in the system, the receiver end can obtain the recovered binary bits $\hat{b}_l$. Again, the original data signal b_l can be resulted from additional processing steps, such

as channel coding and interleaving. In that case, the recovered binary bits $\hat{b}_l$ needs to go through additional processing, such as de-interleaving and channel decoding, in order to recover the original information bit sequence.

It should be appreciated that the above-described processes at the transmitter side and receiver side are for illustration only, and many variations or additional steps may be applied without departing the spirit of the invention. Also, all signals in transmission are described in singular form in the above processes, but it should be understood that a plurality of signals can be transmitted in actual implementations.

B. Design Examples of the Omnidirectional STBC

The key components in the above-described omnidirectional STBC approach are the encoding procedure of the low-dimensional STBC matrix $\mathbf{X}_d$ and the corresponding precoding matrix $\mathbf{W}$. Thus, how to design such two matrices and the corresponding encoding procedure properly becomes a determinative factor for the transmission scheme to provide efficient and effective transmission.

In general, to ensure transmission performance, the transmission scheme needs to be so designed as to allow the system to possess the following characteristics in any given cell: 1) The signals transmitted from the BS, in any spatial direction, have the same signal powers, thereby ensuring a full coverage of the cell; 2) The transmitting signals from all antenna units equipped in the BS can have the same signal powers, thereby maximizing the power efficiency of each radio frequency unit and massive arrays of antennas; and 3) The diversity order of the high-dimensional STBC $\mathbf{W}\mathbf{X}_d$ can be the same as that of the low-dimensional STBC $\mathbf{X}_d$.

The omnidirectional STBC matrix may be designed according to the following criteria:

- 1) All M rows of each column of $\mathbf{W}\mathbf{X}_d$ have the same 2-norm.
- 2) All M rows of each column of the matrix that results from $\mathbf{W}\mathbf{X}_d$ left-multiplying an matrix constructed from the array manifold in discrete spatial directions (e. g. an M -point DFT matrix for the uniform linear antenna array) have the same 2-norm.
- 3) The diversity order of the high-dimensional STBC $\mathbf{W}\mathbf{X}_d$ can be the same as that of the

low-dimensional STBC $\mathbf{X}_d$.

Below are some design examples of $\mathbf{X}_d$, $\mathbf{W}$, and the corresponding encoding procedure according to the above criteria for the case with an uniform linear antenna array. Moreover, the corresponding decoding procedures are also presented.

Example 1: The resulted binary bits b_l after channel encoding and interleaving are divided into groups. The bits in each group are mapped to four PSK symbols x_1, x_2, x_3, x_4 , where $x_1, x_2 \in S_{\text{PSK}}$ and $x_3, x_4 \in e^{j\pi/L} S_{\text{PSK}}$. $S_{\text{PSK}} = \{1, e^{j2\pi/L}, \dots, e^{j2\pi(L-1)/L}\}$ denotes the PSK constellation and L in S_{PSK} is an even integer determining the modulation order. For example, $L=2$ and $L=4$ correspond to BPSK and QPSK, respectively. Then these four modulation symbols x_1, x_2, x_3, x_4 are used to construct the following 4×4 (corresponding to $K = T_d = 4$) STBC matrix

$$\mathbf{X}_d = \begin{bmatrix} x_1 & x_2^* & x_3 & x_4^* \\ x_2 & -x_1^* & x_4 & -x_3^* \\ x_3 & x_4^* & x_1 & x_2^* \\ x_4 & -x_3^* & x_2 & -x_1^* \end{bmatrix}. \quad (5)$$

Next, the STBC matrix $\mathbf{X}_d$ in (5) is multiplied with the following $M \times 4$ precoding matrix

$$\mathbf{W} = \text{diag}(\mathbf{a})(\mathbf{1}_{M/4} \otimes \mathbf{I}_4), \quad (6)$$

where $\mathbf{a}$ is a CAZAC sequence of length M , e.g., a Zadoff-Chu sequence, $\text{diag}(\mathbf{a})$ represents the diagonal matrix whose diagonal elements comprising the vector $\mathbf{a}$, $\mathbf{1}_{M/4}$ is a column vector of length $M/4$ whose elements are all 1, $\otimes$ represents the Kronecker product. Finally, the resulting $M \times 4$ STBC matrix $\mathbf{W}\mathbf{X}_d$ are transmitted from the M transmit antennas within 4 transmission intervals, either in the time or frequency domain.

The corresponding decoding procedure is as follows. Let $\mathbf{y}_d = [y_d(1), y_d(2), \dots, y_d(T_d)]^T$ be the received signal at the UE side within T_d transmission intervals. The maximum likelihood (ML) decoding of the four modulation symbols x_1, x_2, x_3, x_4 can be expressed as

$$(\hat{x}_1, \hat{x}_2, \hat{x}_3, \hat{x}_4) = \arg \min_{\substack{x_1, x_2 \in S_{\text{PSK}} \\ x_3, x_4 \in e^{j\pi/L} S_{\text{PSK}}}} \text{tr}((\mathbf{y}_d - \mathbf{X}_d^T \tilde{\mathbf{h}})(\mathbf{y}_d - \mathbf{X}_d^T \tilde{\mathbf{h}})) \quad (7)$$

where $\tilde{\mathbf{h}} = \mathbf{W}^T \mathbf{h}$ is the equivalent channel in the precoding domain, which can be obtained from (4).

Example 2: The resulted binary bits b_i after channel encoding and interleaving are divided into groups. The bits in each group are mapped to two rotated-QAM symbols s_1 and s_2 , where $s_1, s_2 \in e^{j\arctan(2)/2} S_{\text{QAM}}$. $S_{\text{QAM}} = d \cdot \{\pm 1 \pm j, \pm 3 \pm j3, \dots, \pm(2L-1) \pm j(2L-1)\}$ denotes the standard QAM constellation. d and L in S_{QAM} are used to normalize the mean energy and determine the modulation order, respectively. For example, $d = 1/\sqrt{10}$ and $L = 2$ correspond to 16QAM while $d = 1/\sqrt{42}$ and $L = 4$ correspond to 64QAM. Then these two modulation symbols are used to generate four modulation symbols x_1, x_2, x_3, x_4 with the following scheme

$$\begin{cases} x_1 = \sqrt{2}(1+j)\Re(s_1) \\ x_2 = \sqrt{2}(1-j)\Re(s_2) \\ x_3 = \sqrt{2}(1+j)\Im(s_1) \\ x_4 = \sqrt{2}(j-1)\Im(s_2) \end{cases} \quad (8)$$

where $\Re(\cdot)$ and $\Im(\cdot)$ denote the real part and the imaginary part, respectively. Then, these four modulation symbols are used to construct the following 4×4 (corresponding to $K = T_d = 4$) STBC matrix

$$\mathbf{X}_d = \begin{bmatrix} x_1 & x_2^* & 0 & 0 \\ x_2 & -x_1^* & 0 & 0 \\ 0 & 0 & x_3 & x_4^* \\ 0 & 0 & x_4 & -x_3^* \end{bmatrix}. \quad (9)$$

Next, the STBC matrix $\mathbf{X}_d$ in (9) are multiplied with the following $M \times 4$ precoding matrix

$$\mathbf{W} = \text{diag}(\mathbf{a})(\mathbf{1}_{M/4} \otimes \mathbf{H}_2 \otimes \mathbf{H}_2) \quad (10)$$

where $\mathbf{a}$ is a CAZAC sequence of length M , e.g., a Zadoff-Chu sequence, $\text{diag}(\mathbf{a})$ represents the diagonal matrix whose diagonal elements comprising the vector $\mathbf{a}$, $\mathbf{1}_{M/4}$ is a column vector

of length $M/4$ whose elements are all 1, $\otimes$ represents the Kronecker product, and $\mathbf{H}_2 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$ is the unitary 2×2 Hadamard matrix. Finally, the resulting $M \times 4$ STBC matrix $\mathbf{W}\mathbf{X}_d$ are transmitted from the M transmit antennas within 4 transmission intervals, either in the time or frequency domain.

The corresponding decoding procedure is as follows. Let $\mathbf{y}_d = [y_d(1), y_d(2), \dots, y_d(T_d)]^T$ be the received signal at the UE side within T_d transmission intervals. Since the actual modulation symbols in the codeword matrix $\mathbf{X}_d$ in (9) are s_1 and s_2 , the ML decoding of s_1 and s_2 can be expressed as

$$(\hat{s}_1, \hat{s}_2) = \arg \min_{s_1, s_2 \in e^{j \arctan(2)/2} S_{\text{QAM}}} \text{tr}((\mathbf{y}_d - \tilde{\mathbf{X}}_d \tilde{\mathbf{h}}^T)(\mathbf{y}_d - \tilde{\mathbf{X}}_d \tilde{\mathbf{h}}^T)) \quad (11)$$

where $\tilde{\mathbf{h}}$ can be obtained from (4) and

$$\tilde{\mathbf{X}}_d = \sqrt{2} \begin{bmatrix} (1+j)\Re(s_1) & (1+j)\Re(s_2) & 0 & 0 \\ (1-j)\Re(s_2) & -(1-j)\Re(s_1) & 0 & 0 \\ 0 & 0 & (1+j)\Im(s_1) & -(1+j)\Im(s_2) \\ 0 & 0 & (j-1)\Im(s_2) & -(1-j)\Im(s_1) \end{bmatrix}. \quad (12)$$

Example 3: The resulted binary bits b_l after channel encoding and interleaving are divided into groups. The bits in each group are mapped to N PSK symbols $x_1, x_2, \dots, x_N$, where $x_1, x_2, \dots, x_N \in S_{\text{PSK}}$. N can be an arbitrary even integer. $S_{\text{PSK}} = \{1, e^{j2\pi/L}, \dots, e^{j2\pi(L-1)/L}\}$ represents the PSK constellation and L is an even integer determining the modulation order in S_{PSK} . These N symbols are then used to construct the $K \times T_d$ STBC matrix $\mathbf{X}_d$ as follows.

Let $\mathbf{x}_d = [x_1, x_2, \dots, x_N]^T$. First, an $(N+K-1) \times K$ Toeplitz matrix $\mathbf{A}(\mathbf{x}_d, N, K)$ is constructed as

$$\mathbf{A}(\mathbf{x}_d, N, K) = \begin{bmatrix} x_1 & x_N & \cdots & x_{N-K+2} \\ x_2 & x_1 & \ddots & \vdots \\ \vdots & x_2 & \ddots & x_N \\ x_N & \vdots & \ddots & x_1 \\ -x_1 & x_N & \ddots & x_2 \\ \vdots & -x_1 & \ddots & \vdots \\ -x_{K-1} & \vdots & \ddots & x_N \end{bmatrix} \quad (13)$$

i.e.,

$$[\mathbf{A}(\mathbf{x}_d, N, K)]_{i,j} = \begin{cases} x_{i-j+1+L} & i < j \\ x_{i-j+1} & j \leq i < j+N \\ -x_{i-j+1-L} & i \geq j+N \end{cases} \quad (14)$$

Express the matrix $\mathbf{A}(\mathbf{x}_d, N, K)$ in (13) as

$$\mathbf{A}(\mathbf{x}_d, N, K) = [\mathbf{a}_1, \mathbf{a}_2, \dots, \mathbf{a}_K] \quad (15)$$

where $\mathbf{a}_n$ denotes the n th column of $\mathbf{A}(\mathbf{x}_d, N, K)$, an $(N+K-1) \times K$ matrix $\mathbf{B}(\mathbf{x}_d, N, K)$ is constructed as follows.

When N is odd, two matrices

$$\begin{aligned} \mathbf{A}_o(\mathbf{x}_d, N, K) &= [\mathbf{a}_1^*, \mathbf{a}_2, \mathbf{a}_3^*, \mathbf{a}_4, \dots, \mathbf{a}_{K-2}^*, \mathbf{a}_{K-1}, \mathbf{a}_K^*] \\ \mathbf{A}_e(\mathbf{x}_d, N, K) &= [\mathbf{a}_K, -\mathbf{a}_{K-1}^*, \mathbf{a}_{K-2}, \dots, -\mathbf{a}_4^*, \mathbf{a}_3, -\mathbf{a}_2^*, \mathbf{a}_1] \end{aligned} \quad (16)$$

and two vectors

$$\begin{aligned} \mathbf{x}_{d,o} &= [x_1, 0, x_3, 0, \dots, x_{N-1}, 0]^T \\ \mathbf{x}_{d,e} &= [0, x_2, 0, x_4, \dots, 0, x_{N-1}]^T \end{aligned} \quad (17)$$

are defined, respectively, where $\mathbf{x}_{d,o}$ keeps all the components of $\mathbf{x}_d$ with odd indices and replace the other components by zeros, and correspondingly $\mathbf{x}_{d,e}$ instead keeps all the components of $\mathbf{x}_d$ with even indices. Then an $(N+K-1) \times K$ matrix $\mathbf{B}(\mathbf{x}_d, N, K)$ is defined as

$$\mathbf{B}(\mathbf{x}_d, N, K) = \mathbf{A}_o(\mathbf{x}_{d,o}, N, K) + \mathbf{A}_e(\mathbf{x}_{d,e}, N, K), \quad (18)$$

Let $\mathbf{X}_d = (\mathbf{B}(\mathbf{x}_d, N, K))^T$. This yields the codeword design. In this case, $T_d = N + K - 1$.

When K is even, an $(N+K) \times (K+1)$ matrix $\mathbf{B}(\mathbf{x}_d, N, K+1)$ is first constructed from (18) since $K+1$ is odd. Then the first column, first row, and last row of $\mathbf{B}(\mathbf{x}_d, N, K+1)$ are deleted. Let $\mathbf{X}_d$ be the transpose of the resulting $(N+K-2) \times K$ matrix. This yields the codeword design. In this case, $T_d = N + K - 2$.

Next, the STBC matrix $\mathbf{X}_d$ obtained above is multiplied with the following $M \times K$ precoding matrix

$$\mathbf{W} = \text{diag}(\mathbf{a})(\mathbf{1}_{M/K} \otimes \mathbf{I}_K) \quad (19)$$

where $\mathbf{a}$ is a CAZAC sequence of length M , e.g., a Zadoff-Chu sequence, $\text{diag}(\mathbf{a})$ represents the diagonal matrix whose diagonal elements comprising the vector $\mathbf{a}$, $\mathbf{1}_{M/K}$ is a column vector of length M/K whose elements are all 1, $\otimes$ represents the Kronecker product. Finally, the resulting $M \times T_d$ STBC matrix $\mathbf{W}\mathbf{X}_d$ is transmitted from the M transmit antennas within T_d transmission intervals, either in the time or frequency domain.

The corresponding decoding procedure is as follows. With (2) we can rewrite the system model as

$$[y_d(1), y_d(2), \dots, y_d(T_d)] = \tilde{\mathbf{h}}^T \mathbf{X}_d + [z_d(1), z_d(2), \dots, z_d(T_d)]. \quad (20)$$

With the proposed encoding before, (20) have the following equivalent form

$$\mathbf{y}_d = \mathbf{H}\mathbf{x}_d + \mathbf{z}_d \quad (21)$$

where $\mathbf{x}_d = [x_1, x_2, \dots, x_N]^T$ and

$$\mathbf{y}_d = \begin{cases} [y_d^*(1), y_d(2), y_d^*(3), y_d(4), \dots, y_d^*(N+K-2), y_d(N+K-1)]^T & K \text{ is odd} \\ [y_d(1), y_d^*(2), y_d(3), y_d^*(4), \dots, y_d(N+K-3), y_d^*(N+K-2)]^T & K \text{ is even} \end{cases} \quad (22)$$

The dimension of $\mathbf{H}$ is $(N+K-1) \times N$ or $(N+K-2) \times N$ when K is odd or even, respectively. More specifically,

$$[\mathbf{H}]_{i,j} = \begin{cases} [\tilde{\mathbf{H}}]_{i,j} & j \leq i < K+j \\ -[\tilde{\mathbf{H}}]_{i-M,j} & i \geq K+j \\ [\tilde{\mathbf{H}}]_{i+M,j} & i \leq j-N+K-1 \\ 0 & \text{other} \end{cases} \quad (23)$$

where

$$\tilde{\mathbf{H}} = \begin{cases} \begin{bmatrix} \tilde{h}_1^* & \tilde{h}_2 & \tilde{h}_3^* & \cdots & \tilde{h}_K^* & 0 & \cdots & 0 & 0 \\ 0 & \tilde{h}_K & -\tilde{h}_{K-1}^* & \cdots & -\tilde{h}_2^* & \tilde{h}_1 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & \tilde{h}_1^* & \tilde{h}_2 & \cdots & \tilde{h}_K^* & 0 \\ 0 & 0 & 0 & \cdots & 0 & \tilde{h}_K & \cdots & -\tilde{h}_2^* & \tilde{h}_1 \end{bmatrix}^T & K \text{ is odd} \\ \begin{bmatrix} \tilde{h}_1 & \tilde{h}_2^* & \cdots & \tilde{h}_{K-2}^* & \tilde{h}_{K-1} & \tilde{h}_K^* & \cdots & 0 & 0 \\ \tilde{h}_K & -\tilde{h}_{K-1}^* & \cdots & -\tilde{h}_3^* & \tilde{h}_2 & -\tilde{h}_1^* & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & \tilde{h}_1 & \tilde{h}_2^* & \cdots & \tilde{h}_{K-1} & \tilde{h}_K^* \\ 0 & 0 & \cdots & 0 & \tilde{h}_K & -\tilde{h}_{K-1}^* & \cdots & \tilde{h}_2 & -\tilde{h}_1^* \end{bmatrix}^T & K \text{ is even} \end{cases} \quad (24)$$

$\tilde{h}_k$ denotes the k th element in $\tilde{\mathbf{h}}$. With (21), the estimation of the modulation symbols in $\mathbf{x}_d$ with zero-forcing (ZF) or minimum mean squared error (MMSE) receiver can be expressed as

$$\hat{\mathbf{x}}_d = \mathbf{G}\mathbf{y}_d \quad (25)$$

where

$$\mathbf{G} = \begin{cases} (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H & \text{ZF} \\ (\mathbf{H}^H \mathbf{H} + \sigma_n^2 \mathbf{I})^{-1} \mathbf{H}^H & \text{MMSE} \end{cases} \quad (26)$$

σ_n^2 denotes the noise variance.

While various embodiments of the invention have been described above, it should be understood that they have been presented by way of example only, and not by way of limitation. Likewise, the various diagrams may depict an example architectural or other configuration for the disclosure, which is done to aid in understanding the features and functionality that can be included in the disclosure. The disclosure is not restricted to the illustrated example architectures or configurations, but can be implemented using a variety of alternative architectures and configurations. Additionally, although the disclosure is described above in terms of various

exemplary embodiments and implementations, it should be understood that the various features and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described. They instead can be applied alone or in some combination, to one or more of the other embodiments of the disclosure, whether or not such embodiments are described, and whether or not such features are presented as being a part of a described embodiment. Thus the breadth and scope of the present disclosure should not be limited by any of the above-described exemplary embodiments.

It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processors or domains may be used without detracting from the invention. For example, functionality illustrated to be performed by separate processors or controllers may be performed by the same processor or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

Terms and phrases used in this document, and variations thereof, unless otherwise expressly stated, should be construed as open ended as opposed to limiting. As examples of the foregoing: the term “including” should be read as meaning “including, without limitation” or the like; the term “example” is used to provide exemplary instances of the item in discussion, not an exhaustive or limiting list thereof; and adjectives such as “conventional,” “traditional,” “normal,” “standard,” “known”, and terms of similar meaning, should not be construed as limiting the item described to a given time period, or to an item available as of a given time. But instead these terms should be read to encompass conventional, traditional, normal, or standard technologies that may be available, known now, or at any time in the future. Likewise, a group of items linked with the conjunction “and” should not be read as requiring that each and every one of those items be present in the grouping, but rather should be read as “and/or” unless expressly stated otherwise. Similarly, a group of items linked with the conjunction “or” should not be read as requiring mutual exclusivity among that group, but rather should also be read as “and/or” unless expressly stated otherwise. Furthermore, although items, elements or components of the disclosure may be described or claimed in the singular, the plural is contemplated to be within the scope thereof

unless limitation to the singular is explicitly stated. The presence of broadening words and phrases such as “one or more,” “at least,” “but not limited to”, or other like phrases in some instances shall not be read to mean that the narrower case is intended or required in instances where such broadening phrases may be absent.

Additionally, memory or other storage, as well as communication components, may be employed in embodiments of the invention. It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processing logic elements or domains may be used without detracting from the invention. For example, functionality illustrated to be performed by separate processing logic elements, or controllers, may be performed by the same processing logic element, or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

Furthermore, although individually listed, a plurality of means, elements or method steps may be implemented by, for example, a single unit or processing logic element. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined. The inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather the feature may be equally applicable to other claim categories, as appropriate.

WHAT IS CLAIMED IS:

1. A method for omnidirectional space-time block coding in massive MIMO systems, comprising: generating one $K \times T_d$ data block via space-time encoding; inserting one $K \times T_p$ pilot block to generate one $K \times (T_d + T_p)$ signal block; applying an $M \times K$ precoding matrix to said $K \times (T_d + T_p)$ signal block to generate one $M \times (T_d + T_p)$ signal block; and transmitting said $M \times (T_d + T_p)$ signal block over M transmit antennas in a base station (BS) of said massive MIMO system within $T_d + T_p$ transmission intervals.
2. The method of claim 1, further comprising: said $M \times K$ precoding matrix and the space-time encoding scheme to generate said $K \times T_d$ data block need to be jointly designed.
3. The method of claim 1, further comprising: K is much smaller than M .
4. The method of claim 1, further comprising: the decoding procedure at the user equipment (UE) side does not need to know the actual M -dimensional channel between the BS and the UE, but just needs to know the equivalent K -dimensional channel, which is composed by the actual M -dimensional channel and said $M \times K$ precoding matrix.
5. The method of claim 1, further comprising: in the said $K \times T_p$ pilot block, it should be satisfied that $T_p \geq K$.
6. The method of claim 1, 4 and 5, further comprising: assuming that the UE has single antenna, let

$$\begin{aligned} \mathbf{h} &= [h_1, h_2, \dots, h_M]^T \\ \tilde{\mathbf{h}} &= \mathbf{W}^T \mathbf{h} \end{aligned} \quad (27)$$

be the actual M -dimensional channel vector between the BS and the UE, and the equivalent K -dimensional channel vector, respectively, where $\mathbf{W}$ is said $M \times K$ precoding matrix. Moreover, let

$$\begin{aligned} \mathbf{X}_p &= [\mathbf{x}_p(1), \mathbf{x}_p(2), \dots, \mathbf{x}_p(T_p)] \\ \mathbf{y}_p &= [y_p(1), y_p(2), \dots, y_p(T_p)]^T \end{aligned} \quad (28)$$

be the transmitted pilot signals at the BS and the received pilot signals at the UE within T_p transmission intervals, respectively. The estimation of the equivalent channel can be obtained by

$$\hat{\mathbf{h}} = (\mathbf{X}_p^* \mathbf{X}_p^T)^{-1} \mathbf{X}_p^* \mathbf{y}_p. \quad (29)$$

$(\cdot)^T$, $(\cdot)^*$ and $(\cdot)^{-1}$ denote transpose, conjugate and inverse, respectively.

7. The method of claim 1, further comprising processing a binary bit stream to generate one or more symbol streams, wherein said symbol streams are encoded with said space-time encoding scheme to generate said $K \times T_d$ data block.

8. The method of claim 1, wherein the number of transmit antennas equipped in said BS is M , wherein M is of or over the level of tens.

9. The method of claim 1, wherein signals transmitted from said BS in all spatial directions have the same signal power.

10. The method of claim 1, wherein signals transmitted from all antenna units equipped in said BS have the same transmission power.

11. The method of claim 1, wherein said space-time coding scheme provides a first degree of diversity, said method providing a second degree of diversity that is as much as said first degree of diversity.

12. The method of claim 1, 2, and 7, wherein said $K \times T_d$ data block and $M \times K$ precoding matrix can have the following design. The binary bit stream are divided into groups. The binary bits in each group are mapped to four PSK symbols x_1, x_2, x_3, x_4 , where $x_1, x_2 \in \mathcal{S}_{\text{PSK}}$ and $x_3, x_4 \in e^{j\pi/L} \mathcal{S}_{\text{PSK}}$. $\mathcal{S}_{\text{PSK}} = \{1, e^{j2\pi/L}, \dots, e^{j2\pi(L-1)/L}\}$ denotes the PSK constellation and L in $\mathcal{S}_{\text{PSK}}$ is an even integer determining the modulation order. For example, $L=2$ and $L=4$ correspond to BPSK and QPSK, respectively. Then these four modulation symbols x_1, x_2, x_3, x_4 are used to construct said 4×4 (corresponding to $K = T_d = 4$) data block

$$\mathbf{X}_d = \begin{bmatrix} x_1 & x_2^* & x_3 & x_4^* \\ x_2 & -x_1^* & x_4 & -x_3^* \\ x_3 & x_4^* & x_1 & x_2^* \\ x_4 & -x_3^* & x_2 & -x_1^* \end{bmatrix}. \quad (30)$$

Said $M \times 4$ (corresponding to $K = 4$) precoding matrix has the structure

$$\mathbf{W} = \text{diag}(\mathbf{a})(\mathbf{1}_{M/4} \otimes \mathbf{I}_4), \quad (31)$$

where $\mathbf{a}$ is a CAZAC sequence of length M , e.g., a Zadoff-Chu sequence, $\text{diag}(\mathbf{a})$ represents the diagonal matrix whose diagonal elements comprising the vector $\mathbf{a}$, $\mathbf{1}_{M/4}$ is a column vector of length $M/4$ whose elements are all 1, $\otimes$ represents the Kronecker product.

13. The method of claim 12, has the following decoding procedure. Assuming the UE has single antenna, let $\mathbf{y}_d = [y_d(1), y_d(2), \dots, y_d(T_d)]^T$ be the received signal at the UE side within T_d transmission intervals. The maximum likelihood (ML) decoding of the four modulation symbols x_1, x_2, x_3, x_4 can be expressed as

$$(\hat{x}_1, \hat{x}_2, \hat{x}_3, \hat{x}_4) = \arg \min_{\substack{x_1, x_2 \in \mathcal{S}_{\text{PSK}} \\ x_3, x_4 \in e^{j\pi/L} \mathcal{S}_{\text{PSK}}}} \text{tr}((\mathbf{y}_d - \mathbf{X}_d^T \tilde{\mathbf{h}})(\mathbf{y}_d - \mathbf{X}_d^T \tilde{\mathbf{h}})) \quad (32)$$

where $\mathbf{X}_d$ is as in (30) and $\tilde{\mathbf{h}}$ is as in (27). $\text{tr}(\cdot)$ denotes trace.

14. The method of claim 1, 2, and 7, wherein said $K \times T_d$ data block and $M \times K$ precoding matrix can have the following design. The binary bit stream are divided into groups. The binary bits in each group are mapped to two rotated-QAM symbols s_1 and s_2 , where $s_1, s_2 \in e^{j\arctan(2)/2} \mathcal{S}_{\text{QAM}}$. $\mathcal{S}_{\text{QAM}} = d \cdot \{\pm 1 \pm j, \pm 3 \pm j3, \dots, \pm(2L-1) \pm j(2L-1)\}$ denotes the QAM constellation. d and L in $\mathcal{S}_{\text{QAM}}$ are used to normalize the mean energy and determine the modulation order, respectively. For example, $d = 1/\sqrt{10}$ and $L = 2$ correspond to 16QAM while $d = 1/\sqrt{42}$ and $L = 4$ correspond to 64QAM. Then these two modulation symbols are used to generate four modulation symbols x_1, x_2, x_3, x_4 with the following scheme

$$\begin{cases} x_1 = \sqrt{2}(1+j)\Re(s_1) \\ x_2 = \sqrt{2}(1-j)\Re(s_2) \\ x_3 = \sqrt{2}(1+j)\Im(s_1) \\ x_4 = \sqrt{2}(j-1)\Im(s_2) \end{cases} \quad (33)$$

where $\Re(\cdot)$ and $\Im(\cdot)$ denote the real part and the imaginary part, respectively. Then, these four modulation symbols are used to construct said 4×4 (corresponding to $K = T_d = 4$) data block

$$\mathbf{X}_d = \begin{bmatrix} x_1 & x_2^* & 0 & 0 \\ x_2 & -x_1^* & 0 & 0 \\ 0 & 0 & x_3 & x_4^* \\ 0 & 0 & x_4 & -x_3^* \end{bmatrix}. \quad (34)$$

Said $M \times 4$ (corresponding to $K = 4$) precoding matrix has the structure

$$\mathbf{W} = \text{diag}(\mathbf{a})(\mathbf{1}_{M/4} \otimes \mathbf{H}_2 \otimes \mathbf{H}_2) \quad (35)$$

where $\mathbf{a}$ is a CAZAC sequence of length M , e.g., a Zadoff-Chu sequence, $\text{diag}(\mathbf{a})$ represents the diagonal matrix whose diagonal elements comprising the vector $\mathbf{a}$, $\mathbf{1}_{M/4}$ is a column vector of length $M/4$ whose elements are all 1, $\otimes$ represents the Kronecker product, and $\mathbf{H}_2 = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$ is the unitary 2×2 Hadamard matrix.

15. The method of claim 14, has the following decoding procedure. Assuming the UE has single antenna, let $\mathbf{y}_d = [y_d(1), y_d(2), \dots, y_d(T_d)]^T$ be the received signal at the UE side within T_d transmission intervals. The ML decoding of s_1 and s_2 can be expressed as

$$(\hat{s}_1, \hat{s}_2) = \arg \min_{s_1, s_2 \in e^{j\arctan(2)/2} \mathcal{S}_{\text{QAM}}} \text{tr}((\mathbf{y}_d - \tilde{\mathbf{X}}_d \tilde{\mathbf{h}}^T)(\mathbf{y}_d - \tilde{\mathbf{X}}_d \tilde{\mathbf{h}}^T)) \quad (36)$$

where

$$\tilde{\mathbf{X}}_d = \sqrt{2} \begin{bmatrix} (1+j)\Re(s_1) & (1+j)\Re(s_2) & 0 & 0 \\ (1-j)\Re(s_2) & -(1-j)\Re(s_1) & 0 & 0 \\ 0 & 0 & (1+j)\Im(s_1) & -(1+j)\Im(s_2) \\ 0 & 0 & (j-1)\Im(s_2) & -(1-j)\Im(s_1) \end{bmatrix}. \quad (37)$$

and $\tilde{\mathbf{h}}$ is as in (27).

16. The method of claim 1, 2, and 7, wherein said $K \times T_d$ data block and $M \times K$ precoding matrix have the following design. The binary bit stream are divided into groups. The binary bits in each group are mapped to N PSK symbols $x_1, x_2, \dots, x_N$, where $x_1, x_2, \dots, x_N \in \mathcal{S}_{\text{PSK}}$. N can be an arbitrary even integer. $\mathcal{S}_{\text{PSK}} = \{1, e^{j2\pi/L}, \dots, e^{j2\pi(L-1)/L}\}$ represents the PSK constellation and L is an even integer determining the modulation order in $\mathcal{S}_{\text{PSK}}$. These N symbols are then used to construct said $K \times T_d$ data block $\mathbf{X}_d$ as follows.

Let $\mathbf{x}_d = [x_1, x_2, \dots, x_N]^T$. First, an $(N+K-1) \times K$ Toeplitz matrix $\mathbf{A}(\mathbf{x}_d, N, K)$ is constructed as

$$\mathbf{A}(\mathbf{x}_d, N, K) = \begin{bmatrix} x_1 & x_N & \cdots & x_{N-K+2} \\ x_2 & x_1 & \ddots & \vdots \\ \vdots & x_2 & \ddots & x_N \\ x_N & \vdots & \ddots & x_1 \\ -x_1 & x_N & \ddots & x_2 \\ \vdots & -x_1 & \ddots & \vdots \\ -x_{K-1} & \vdots & \ddots & x_N \end{bmatrix} \quad (38)$$

i.e.,

$$[\mathbf{A}(\mathbf{x}_d, N, K)]_{i,j} = \begin{cases} x_{i-j+1+L} & i < j \\ x_{i-j+1} & j \leq i < j+N \\ -x_{i-j+1-L} & i \geq j+N \end{cases} \quad (39)$$

Express the matrix $\mathbf{A}(\mathbf{x}_d, N, K)$ in (38) as

$$\mathbf{A}(\mathbf{x}_d, N, K) = [\mathbf{a}_1, \mathbf{a}_2, \dots, \mathbf{a}_K] \quad (40)$$

where $\mathbf{a}_n$ denotes the n th column of $\mathbf{A}(\mathbf{x}_d, N, K)$, an $(N+K-1) \times K$ matrix $\mathbf{B}(\mathbf{x}_d, N, K)$ is constructed as follows.

When N is odd, two matrices

$$\begin{aligned} \mathbf{A}_o(\mathbf{x}_d, N, K) &= [\mathbf{a}_1^*, \mathbf{a}_2, \mathbf{a}_3^*, \mathbf{a}_4, \dots, \mathbf{a}_{K-2}^*, \mathbf{a}_{K-1}, \mathbf{a}_K^*] \\ \mathbf{A}_e(\mathbf{x}_d, N, K) &= [\mathbf{a}_K, -\mathbf{a}_{K-1}^*, \mathbf{a}_{K-2}, \dots, -\mathbf{a}_4^*, \mathbf{a}_3, -\mathbf{a}_2^*, \mathbf{a}_1] \end{aligned} \quad (41)$$

and two vectors

$$\begin{aligned}\mathbf{x}_{d,o} &= [x_1, 0, x_3, 0, \dots, x_{N-1}, 0]^T \\ \mathbf{x}_{d,e} &= [0, x_2, 0, x_4, \dots, 0, x_{N-1}]^T\end{aligned}\quad (42)$$

are defined, respectively, where $\mathbf{x}_{d,o}$ keeps all the components of $\mathbf{x}_d$ with odd indices and replace the other components by zeros, and correspondingly $\mathbf{x}_{d,e}$ instead keeps all the components of $\mathbf{x}_d$ with even indices. Then an $(N+K-1) \times K$ matrix $\mathbf{B}(\mathbf{x}_d, N, K)$ is defined as

$$\mathbf{B}(\mathbf{x}_d, N, K) = \mathbf{A}_o(\mathbf{x}_{d,o}, N, K) + \mathbf{A}_e(\mathbf{x}_{d,e}, N, K), \quad (43)$$

Let $\mathbf{X}_d = (\mathbf{B}(\mathbf{x}_d, N, K))^T$ just yields said $K \times T_d$ data block. In this case, $T_d = N + K - 1$.

When K is even, an $(N+K) \times (K+1)$ matrix $\mathbf{B}(\mathbf{x}_d, N, K+1)$ is first constructed from (43) since $K+1$ is odd. Then the first column, first row, and last row of $\mathbf{B}(\mathbf{x}_d, N, K+1)$ are deleted. Let $\mathbf{X}_d$ be the transpose of this resulted $(N+K-2) \times K$ matrix just yields said $K \times T_d$ data block. In this case, $T_d = N + K - 2$.

Said $M \times K$ precoding matrix has the structure

$$\mathbf{W} = \text{diag}(\mathbf{a})(\mathbf{1}_{M/K} \otimes \mathbf{I}_K) \quad (44)$$

where $\mathbf{a}$ is a CAZAC sequence of length M , e.g., a Zadoff-Chu sequence, $\text{diag}(\mathbf{a})$ represents the diagonal matrix whose diagonal elements comprising the vector $\mathbf{a}$, $\mathbf{1}_{M/K}$ is a column vector of length M/K whose elements are all 1, $\otimes$ represents the Kronecker product.

17. The method of claim 16, has the following decoding procedure. Assuming the UE has single antenna, let $\{y_d(1), y_d(2), \dots, y_d(T_d)\}$ be the received data signal at the UE side within T_d transmission intervals. The estimation of the modulation symbols $\mathbf{x}_d = [x_1, x_2, \dots, x_N]^T$ with zero-forcing (ZF) or minimum mean squared error (MMSE) receiver can be expressed as

$$\hat{\mathbf{x}}_d = \mathbf{G}\mathbf{y}_d \quad (45)$$

where

$$\mathbf{y}_d = \begin{cases} [y_d^*(1), y_d(2), y_d^*(3), y_d(4), \dots, y_d^*(N+K-2), y_d(N+K-1)]^T & K \text{ is odd} \\ [y_d(1), y_d^*(2), y_d(3), y_d^*(4), \dots, y_d(N+K-3), y_d^*(N+K-2)]^T & K \text{ is even} \end{cases} \quad (46)$$

and

$$\mathbf{G} = \begin{cases} (\mathbf{H}^H \mathbf{H})^{-1} \mathbf{H}^H & \text{ZF} \\ (\mathbf{H}^H \mathbf{H} + \sigma_n^2 \mathbf{I})^{-1} \mathbf{H}^H & \text{MMSE} \end{cases} \quad (47)$$

while σ_n^2 denotes the noise variance. The dimension of $\mathbf{H}$ is $(N+K-1) \times N$ or $(N+K-2) \times N$ when K is odd or even, respectively. More specifically,

$$[\mathbf{H}]_{i,j} = \begin{cases} [\tilde{\mathbf{H}}]_{i,j} & j \leq i < K+j \\ -[\tilde{\mathbf{H}}]_{i-M,j} & i \geq K+j \\ [\tilde{\mathbf{H}}]_{i+M,j} & i \leq j-N+K-1 \\ 0 & \text{other} \end{cases}, \quad (48)$$

where $[\mathbf{H}]_{i,j}$ denotes the (i, j) th element of $\mathbf{H}$ and

$$\tilde{\mathbf{H}} = \begin{cases} \begin{bmatrix} \tilde{h}_1^* & \tilde{h}_2 & \tilde{h}_3^* & \dots & \tilde{h}_K^* & 0 & \dots & 0 & 0 \\ 0 & \tilde{h}_K & -\tilde{h}_{K-1}^* & \dots & -\tilde{h}_2^* & \tilde{h}_1 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & \tilde{h}_1^* & \tilde{h}_2 & \dots & \tilde{h}_K^* & 0 \\ 0 & 0 & 0 & \dots & 0 & \tilde{h}_K & \dots & -\tilde{h}_2^* & \tilde{h}_1 \end{bmatrix}^T & K \text{ is odd} \\ \begin{bmatrix} \tilde{h}_1 & \tilde{h}_2^* & \dots & \tilde{h}_{K-2}^* & \tilde{h}_{K-1} & \tilde{h}_K^* & \dots & 0 & 0 \\ \tilde{h}_K & -\tilde{h}_{K-1}^* & \dots & -\tilde{h}_3^* & \tilde{h}_2 & -\tilde{h}_1^* & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \dots & 0 & \tilde{h}_1 & \tilde{h}_2^* & \dots & \tilde{h}_{K-1} & \tilde{h}_K^* \\ 0 & 0 & \dots & 0 & \tilde{h}_K & -\tilde{h}_{K-1}^* & \dots & \tilde{h}_2 & -\tilde{h}_1^* \end{bmatrix}^T & K \text{ is even.} \end{cases} \quad (49)$$

$\tilde{h}_k$ in (49) denotes the k th element of $\tilde{\mathbf{h}}$ as in (27).

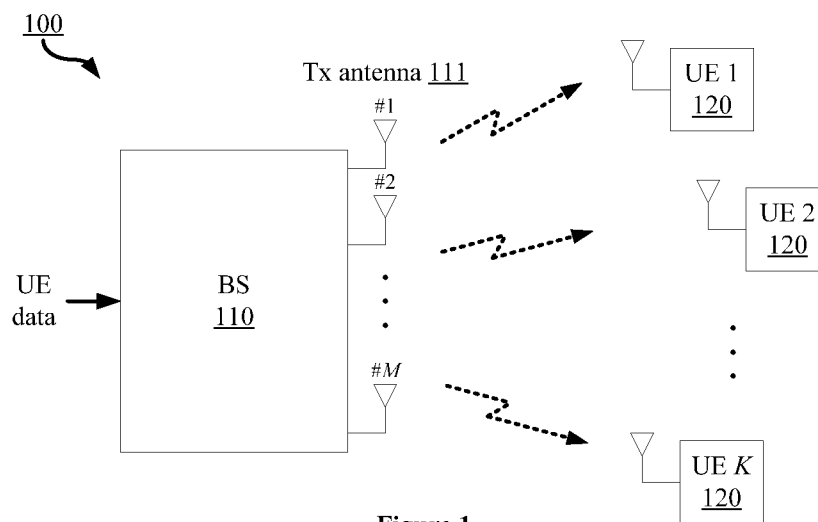


Figure 1

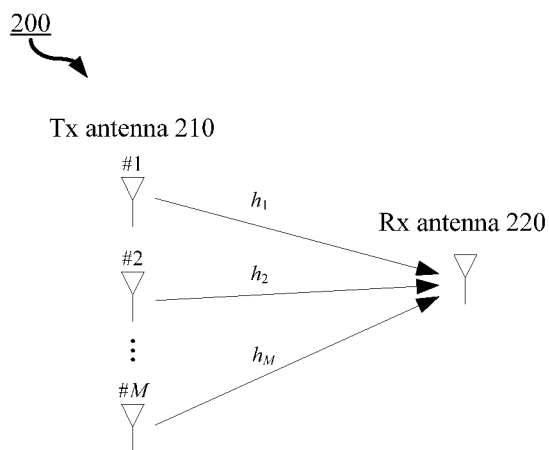


Figure 2

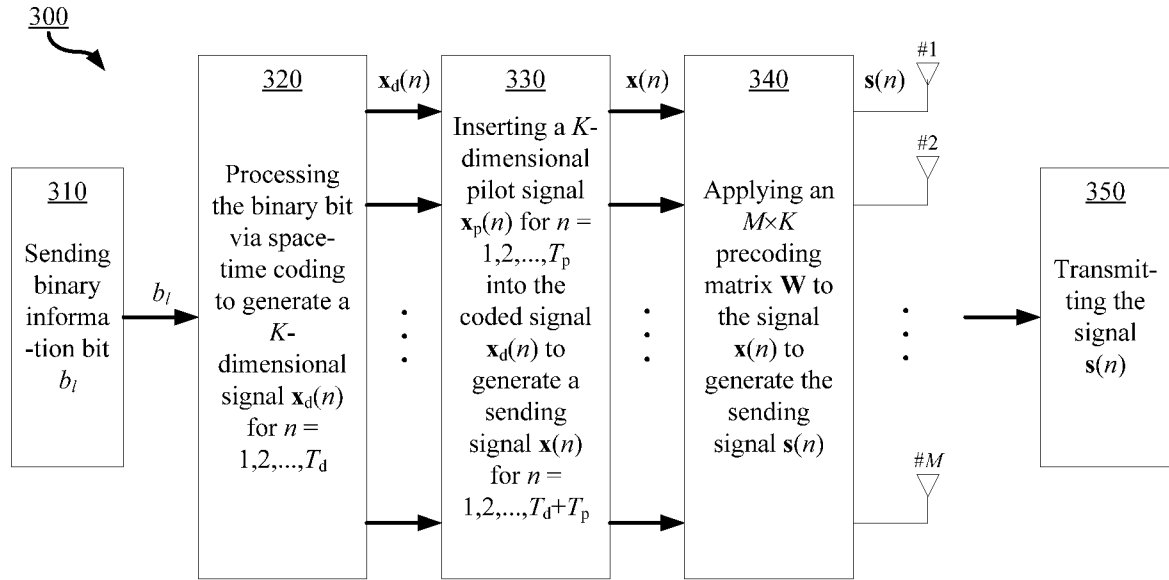


Figure 3

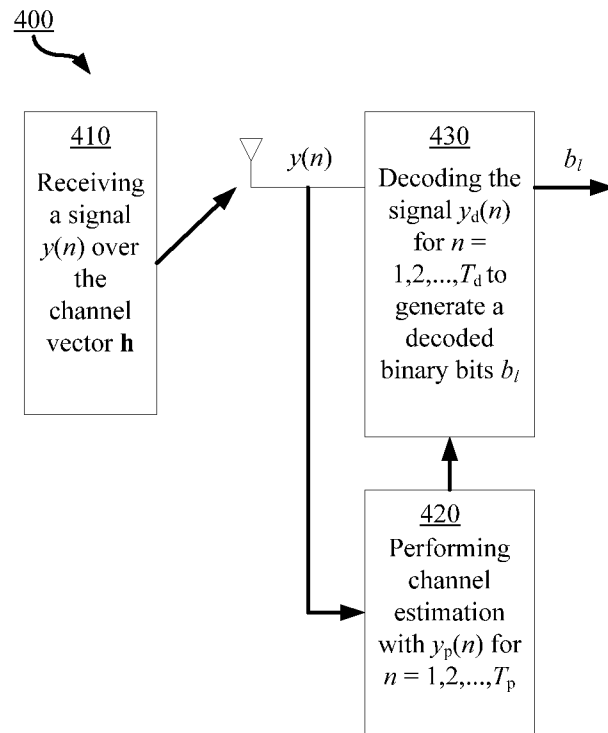


Figure 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2015/082292**A. CLASSIFICATION OF SUBJECT MATTER**

H04L 25/00(2006.01)i

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)

H04L H04B H04J

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 practicable, search terms used)

CNABS,CNTXT,VEN: MIMO,code,encode,space,time,pilot,precode,matrix,antenna

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014307702 A1 (BROADCOM CORPORATION) 16 October 2014 (2014-10-16) the whole document	1-17
A	CN 103944702 A (UNIVERSITY QINGHUA) 23 July 2014 (2014-07-23) the whole document	1-17
A	CN 103856422 A (UNIVERSITY QINGHUA) 11 June 2014 (2014-06-11) the whole document	1-17



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

“E” earlier application or patent but published on or after the international filing date

“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search

10 March 2016

Date of mailing of the international search report

17 March 2016

Name and mailing address of the ISA/CN

**STATE INTELLECTUAL PROPERTY OFFICE OF THE
P.R.CHINA**
**6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing
100088, China**

Authorized officer

CHEN,Junru

Facsimile No. (86-10)62019451

Telephone No. (86-10)62089549

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2015/082292

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
US	2014307702	A1	16 October 2014	None	
CN	103944702	A	23 July 2014	None	
CN	103856422	A	11 June 2014	None	