(12) UK Patent Application (19) GB (11) 2467145 (13) A

(43) Date of A Publication 28.07.2010

(21) Application No: **0901089.3**

(22) Date of Filing: **22.01.2009**

(71) Applicant(s):
**Toshiba Research Europe Limited**
**(Incorporated in the United Kingdom)**
**32 Queen Square, BRISTOL, BS1 4ND, United Kingdom**

(72) Inventor(s):
**Henning Vetter**

(74) Agent and/or Address for Service:
**Marks & Clerk LLP**
**90 Long Acre, LONDON, WC2E 9RA, United Kingdom**

(51) INT CL:
***H04B 7/04*** (2006.01) ***H04B 7/06*** (2006.01)

(56) Documents Cited:
**WO 2008/054178 A2** **US 7317764 B2**
**Wee Seng Chua; Chau Yuen; Chin, F., "A Continuous Vector Perturbation for Multi-Antenna Multi-User Communication," Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th , vol., no., pp.1806-1810, 22-25 April 2007**
**KR 10-2007-0074023 (SAMSUNG)**

(58) Field of Search:
INT CL **H04B, H04L**
Other: **Online: WPI, EPODOC, TXTE, INSPEC**

(54) Title of the Invention: **Wireless communications methods and apparatus**
Abstract Title: **MIMO precoding method which uses a perturbation vector determined using a diagonal matrix representing plural modulo shift parameters**

(57) The invention concerns a multiple input multiple output (MIMO) system employing precoding. Information for transmission is represented by a data vector comprising corresponding data for each of the multi-antennae. A perturbation vector is applied to the data vector in order to generate a perturbed data vector. The perturbation vector is formed by multiplying together a diagonal matrix of positive real numbers and a complex integer vector. Each non-zero element of the diagonal matrix comprises a constellation shift parameter for a respective spatial stream. Conventional methods do not support different modulo shift parameters for different spatial streams — they use a scalar rather than a diagonal matrix. The perturbation vector is selected by solving an integer least squares problem such that a normalisation factor is minimised; this involves applying a scaling factor to the integer least squares problem.

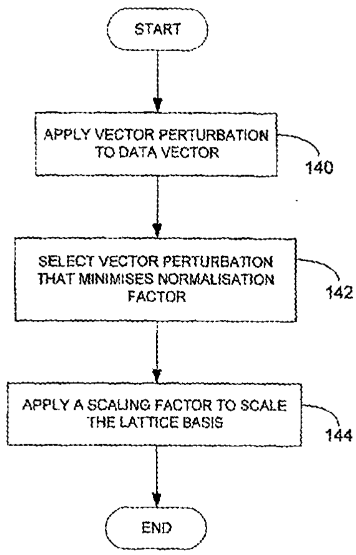


FIGURE 4

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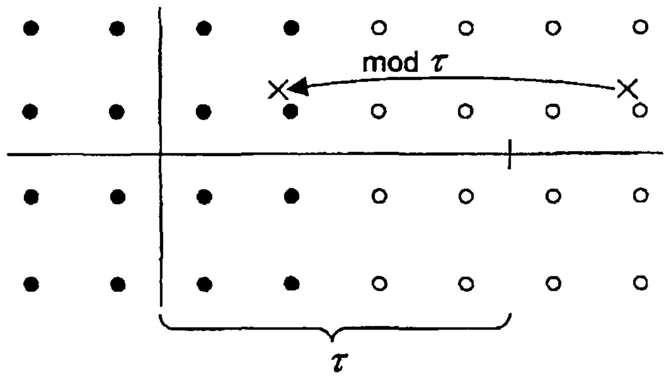



FIGURE 1

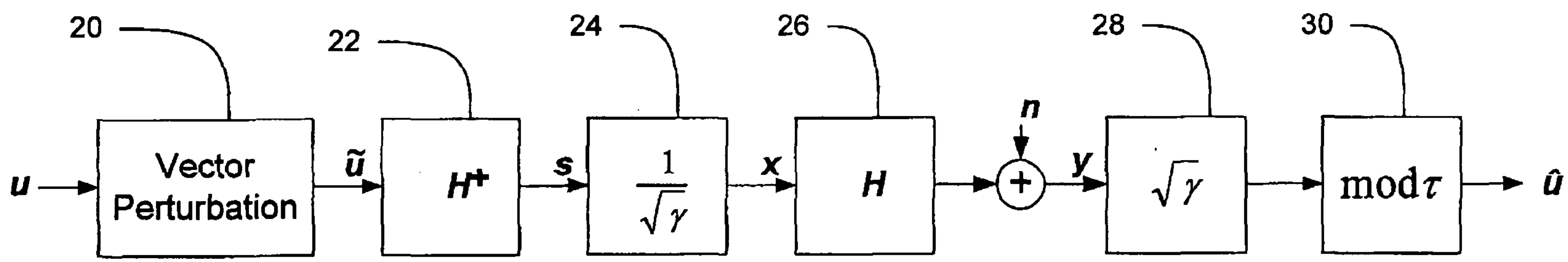



FIGURE 2

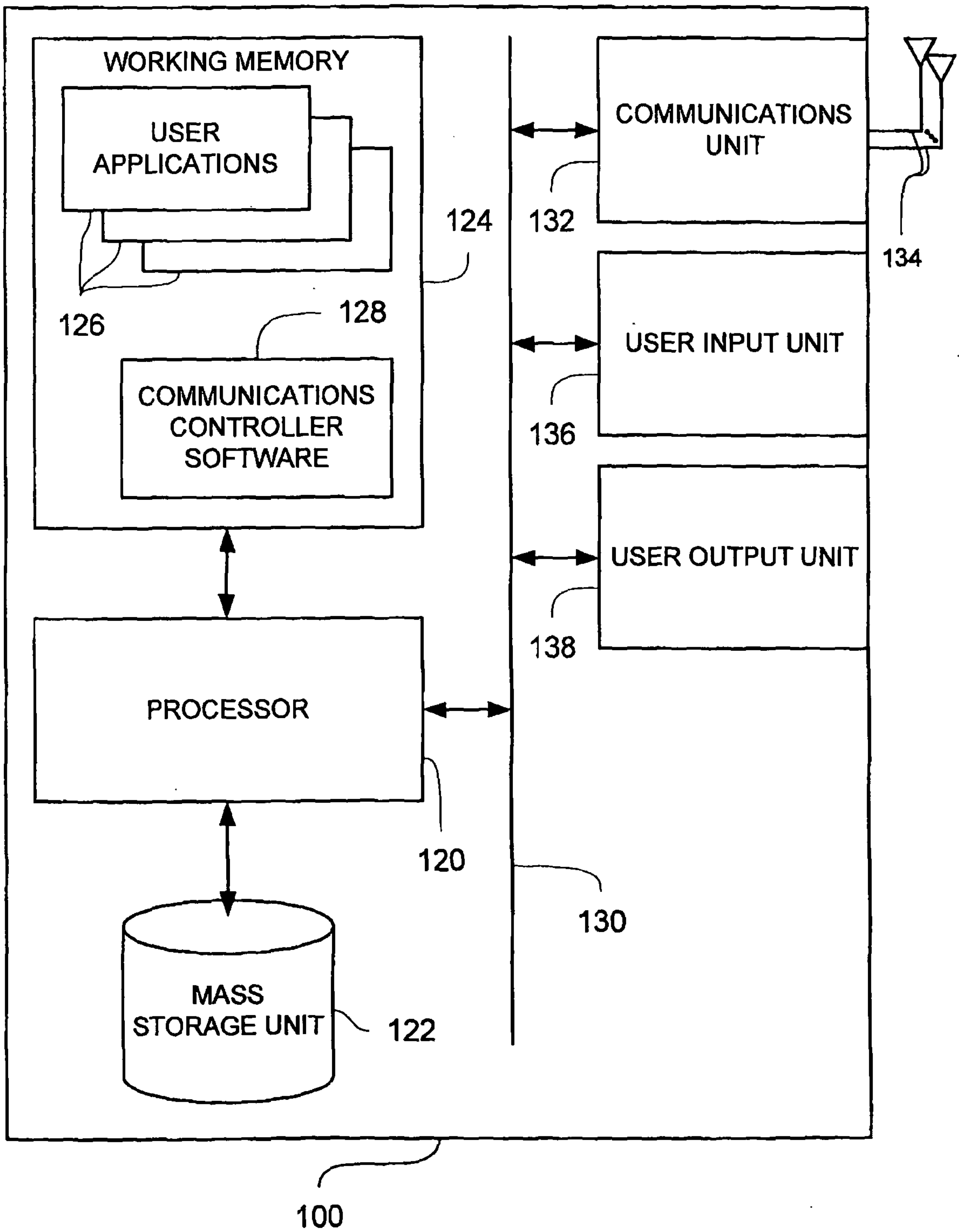

WORKING MEMORY
USER APPLICATIONS
126
128
COMMUNICATIONS CONTROLLER SOFTWARE
124
132
COMMUNICATIONS UNIT
134
USER INPUT UNIT
136
USER OUTPUT UNIT
138
PROCESSOR
120
130
MASS STORAGE UNIT
122
100

FIGURE 3

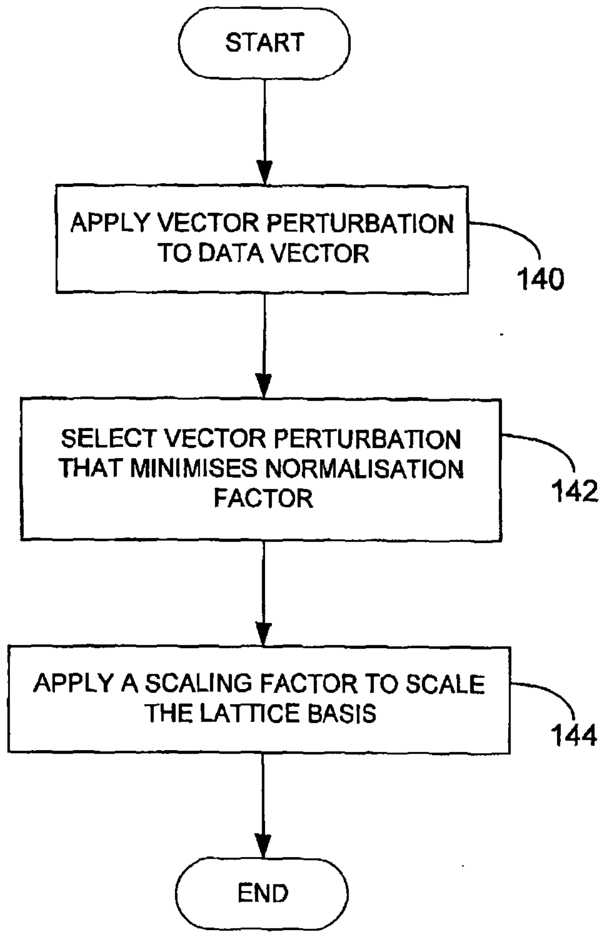
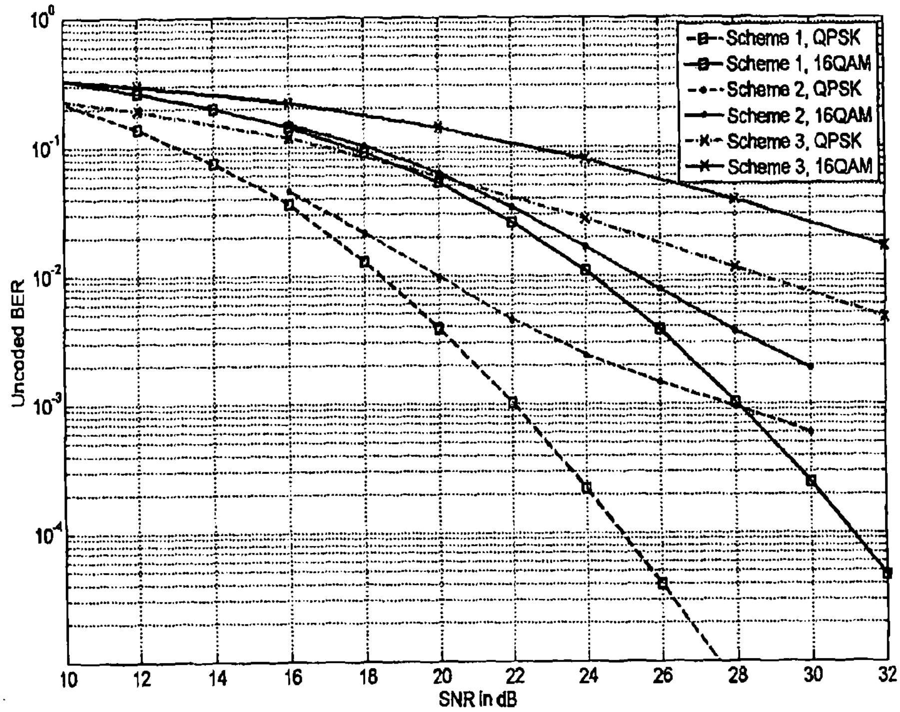

START
APPLY VECTOR PERTURBATION TO DATA VECTOR
140
SELECT VECTOR PERTURBATION THAT MINIMISES NORMALISATION FACTOR
142
APPLY A SCALING FACTOR TO SCALE THE LATTICE BASIS
144
END

FIGURE 4



Scheme 1, QPSK
Scheme 1, 16QAM
Scheme 2, QPSK
Scheme 2, 16QAM
Scheme 3, QPSK
Scheme 3, 16QAM
Uncoded BER
SNR in dB


FIGURE 5

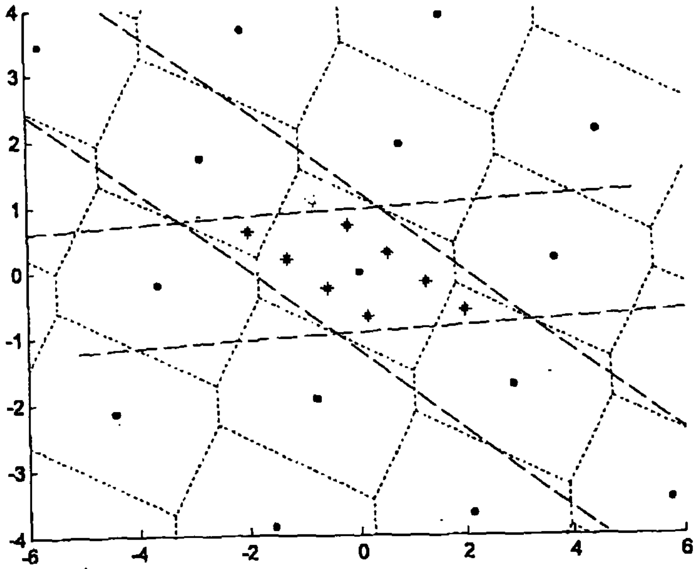



FIGURE 6

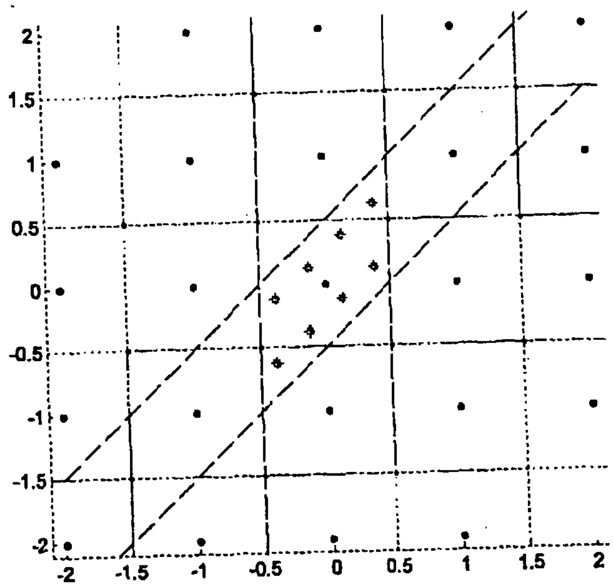



FIGURE 7

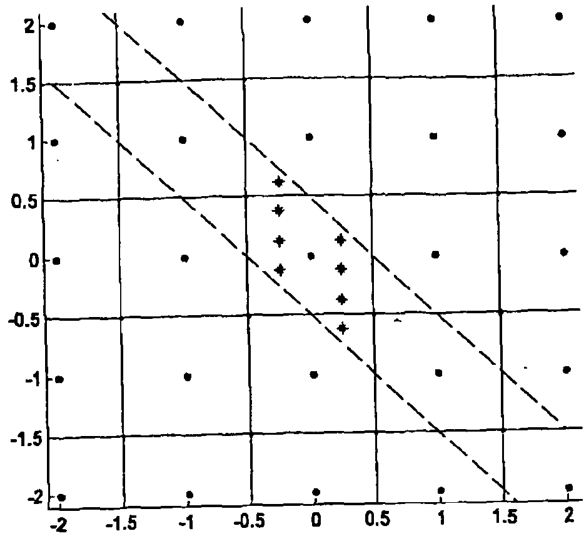



FIGURE 8

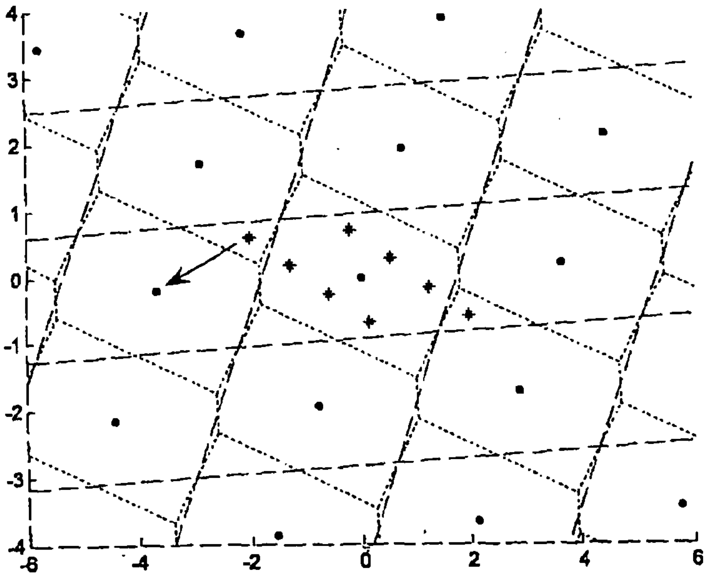



FIGURE 9

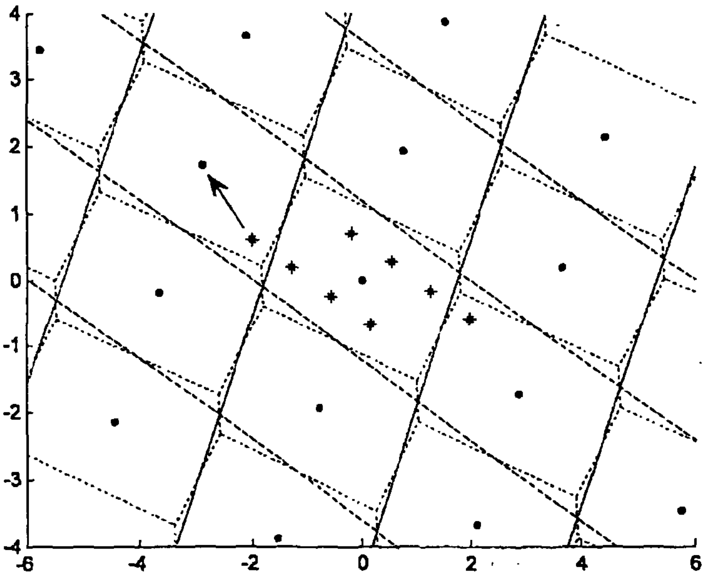



FIGURE 10

# WIRELESS COMMUNICATIONS METHODS AND APPARATUS

## Field of the Invention

The present invention is in the field of wireless communication and particularly, though not exclusively, the field of multiple input, multiple output (MIMO) communications.

## Background of the Invention

In multiple input multiple output (MIMO) systems employing precoding, channel knowledge is used at the transmitter in order to enhance link quality.

A conventional MIMO system, with $n_T$ transmit and $n_R$ receive antennas, can be modelled mathematically in the complex narrowband notation as:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n} \tag{1}$$

where $\mathbf{H}$ is the $n_R \times n_T$ channel matrix, $\mathbf{x}$ is the $n_T \times 1$ transmit vector of complex symbols with an imposed transmit power constraint, for instance $\|\mathbf{x}\|^2 = 1$ without loss of generality, $\mathbf{y}$ is the $n_R \times 1$ receive vector, and $\mathbf{n}$ is an $n_R \times 1$ zero-mean white Gaussian distributed noise vector with variance $\sigma_n^2$.

Precoding can be also employed in OFDM systems. In such a system, it can be applied, for example, for each subcarrier separately or for a group of subcarriers. For example, an OFDM system having 512 subcarriers can have a joint transmit power constraint of 512, or an average transmit power constraint $\|\mathbf{x}\|^2 = 1$ without loss of generality.

Precoding can be achieved in several ways. For example, the Moore-Penrose pseudoinverse $\mathbf{P} = \mathbf{H}^+ = \mathbf{H}^H\left(\mathbf{H}\mathbf{H}^H\right)^{-1}$ can be applied at the transmitter side, which, in one network configuration, can be at a base station. If $n_T = n_R$, **P** becomes simply $\mathbf{P} = \mathbf{H}^{-1}$. This precoding step is necessary for instance in multi-user MIMO systems, wherein each element of **y** will be assigned to an independent user terminal (UT), and therefore no cooperation will be possible between the UTs. In such a case, the precoding matrix **P** will suppress the inter-user interference; nevertheless the above technique may also be employed in a single-user MIMO system or a multi-user multi-antenna MIMO system, where one or more UTs have more than one receive antenna.

A further example of precoding is the regularised pseudoinverse $\mathbf{P} = \mathbf{H}^H\left(\mathbf{H}\mathbf{H}^H + \alpha\mathbf{I}\right)^{-1}$, as set out in "A vector-perturbation technique for near-capacity multiantenna multiuser communication – part I: channel inversion and regularization," (C. B. Peel, B. M. Hochwald, and A. L. Swindlehurst, *IEEE Trans. on Commun.*, vol. 53, no. 1, pp. 195-202, Jan. 2005), hereinafter referred to as "Peel et al." , where $\alpha = K\sigma_n^2$ is defined, and $K$ is the number of spatial streams.

However, a drawback of precoding by means of the pseudoinverse channel matrix, or regularised pseudoinverse channel matrix (or in general any non-unitary matrix) is that it can lead to an increase in transmitted power. This is addressed in "A vector-perturbation technique for near-capacity multiantenna multiuser communication---part II: perturbation," (B. M. Hochwald, C. B. Peel, and A. L. Swindlehurst, *IEEE Trans. on Commun.*, vol. 53, no. 3, pp. 537-544, March 2005) hereinafter referred to as "Hochwald et al.". Variations in transmitted power are undesirable, particularly as they may violate performance constraints for a device. They may also lead to increased power consumption, which is an important factor in the design of a handheld or otherwise portable communications device.

To illustrate problems faced and identified in the prior art, an example will now be given. In this example, **u** denotes the symbols, prior to precoding, to be transmitted. The vector is precoded by means of a precoding matrix **P**, which is chosen to be the Moore-Penrose pseudoinverse $\mathbf{P} = \mathbf{H}^+$, as

$$\mathbf{s} = \mathbf{P}\mathbf{u} \qquad (2)$$

The Moore-Penrose pseudoinverse is well known, but is particularly referenced in "On the reciprocal of the general algebraic matrix" (E. H. Moore; Bulletin of the American Mathematical Society 26: 394-395) and "A generalized inverse for matrices" (R. Penrose; Proceedings of the Cambridge Philosophical Society 51: 406-413).

Prior to transmission, the precoded signal **s** has to be scaled in order to fulfil the power restriction $\|\mathbf{x}\|^2 = 1$, such that

$$\mathbf{x} = \frac{\mathbf{s}}{\sqrt{\gamma}} \qquad (3)$$

where $\gamma = \|\mathbf{s}\|^2 = \|\mathbf{Pu}\|^2$ as set out in Peel et al.. This approach assumes perfect knowledge of $\gamma$ at the receiver side.

The normalisation factor is often very large because of the large singular values of the precoding matrix **P**, i.e., of the pseudoinverse of the channel matrix **H** (such as noted in papers by Hochwald et al. and by Peel et al., cited above). This can cause noise amplification at the receiver side since the receive symbol vector $\mathbf{y} = \sqrt{\gamma}(\mathbf{Hx} + \mathbf{n})$, or equivalently, $\frac{\mathbf{y}}{\sqrt{\gamma}} = (\mathbf{Hx} + \mathbf{n})$, is impaired by a scaled Gaussian noise vector $\sqrt{\gamma}\mathbf{n}$. In a MIMO OFDM system, the instantaneous normalisation factor of a transmission can be determined for each subcarrier or the average normalisation factor can be determined as a mean value for all the subcarriers, or any other grouping of resources to resource blocks and the like. This may be, for example in an Orthogonal frequency-division multiple access (OFDMA) MIMO system, where different subcarriers are assigned to different groups of terminals, thus representing multiple multi-user MIMO configurations.

Hochwald et al. suggests that one way of overcoming this noise amplification is to ensure that the transmitted data **u** does not lie along the singular values of $\mathbf{H}^{-1}$ (or $\mathbf{H}^{+}$, as the case may be). This approach is also described in US7317764. The idea is to allow **u** to be perturbed by a complex vector. The perturbed data vector is then:

$$\hat{\mathbf{u}} = \mathbf{u} + \tau\mathbf{l} \tag{4}$$

where $\tau$ is a positive real number and $\mathbf{l}$ is a complex integer vector. The scalar $\tau$ is selected to be sufficiently large that the receiver may apply element-wise a modulo function to $\mathbf{y}$

$$\hat{u}_i = f_\tau(y_i) = y_i - \left\lfloor \frac{y_i + \tau/2}{\tau} \right\rfloor \tau \tag{5}$$

to obtain $\hat{\mathbf{u}}$, where $\lfloor\ \rfloor$ rounds towards the nearest integer closest to zero. It will be noted that $f_\tau(y_i)$ is applied to real and imaginary parts separately. It should be recognised by the reader that $\hat{\mathbf{u}}$ is not quantised and therefore contains additive noise.

Hochwald et al. also suggests that the constellation shift parameter $\tau$ should be

$$\tau = 2\left(|c|_{max} + \frac{\Delta}{2}\right) \tag{6}$$

where $|c|_{max}$ is the absolute value of the real or imaginary part of the constellation symbol with greatest magnitude, and $\Delta$ is the smallest distance between two constellation symbols. It will be understood that the foregoing is set out for M-QAM constellations; non-square constellations such as PSK (Phase shift keying) or other, such as hexagonal constellations, may have a constellation shift parameter $\tau$ that is essentially the distance between the centres of repeated equidistantly shifted constellations.

Figure 1 illustrates the modulo operation at the receiver side for a 16-QAM constellation. The received symbol, marked with an 'x', is shifted from the extended constellation (unfilled points) back to the original constellation (filled points), in which the symbol detection stage will be done. As will be appreciated by the reader, the average number of neighbouring points will be increased, as points of the original constellation which were previously considered to be at the edge of the constellation now have a complete set of neighbours. This has an impact on the error protection of the outer symbols. The shift parameter $\tau$, as the distance between the centres of the respective constellations, can lower this impact if it is chosen to be greater than defined in Equation 6.

In accordance with the above, for a given $\tau$, $\mathbf{l}$ can be selected in order to minimise $\gamma = \|\mathbf{s}\|^2$, such that:

$$\mathbf{l} = arg\ min_{\mathbf{l}'} \|\mathbf{P}(\mathbf{u} + \tau\mathbf{l}')\|^2 \tag{7}$$

This is an integer least squares problem in the dimension of **u**, for the solution of which there exist a large number of algorithms. For instance, the reader is directed to "Closest point search in lattices" (E. Agrell, T. Eriksson, A. Vardy, and K. Zeger, *IEEE Transactions on Information Theory*, vol. 48, no. 8, pp. 2201-2214, Aug. 2002) and to the references noted in Hochwald et al., especially the Fincke-Pohst algorithm, which is used for space-time demodulation in "Lattice code decoder for space-time codes," (M. O. Damen, A. Chkeif, and J.-C. Belfiore, *IEEE Commun. Letters*, vol. 4, pp. 161-163, May 2000), where it is called a sphere decoder. Because this algorithm can be used for encoding the data vector **u**, it is called a "*sphere encoder*".

If G is defined as the set:

$$G = \{a + ib \mid a, b \in \mathbf{Z}\}, \quad \text{with} \quad i^2 = -1,$$

that is, the set of complex-valued integers, then an approximation of $\mathbf{l}$ can be calculated, and the perturbation vector is then given as

$$\mathbf{l}_{\text{approx}} = -\mathbf{T}Q_{\tau G^K}\{\mathbf{T}^{-1}\mathbf{u}\},$$

where the quantisation function $Q_{\tau G^K}\{\cdot\}$ rounds the $K$-dimensional vector towards the nearest complex-valued point of the K-dimensional integer lattice, scaled with τ (depicted by $\tau G^K$), where $K$ is the number of spatial streams, i.e., the dimension of the vector **u**.

A practical implementation as an integer rounding function, indicated by G, can be

$$\mathbf{l}_{\text{approx}} = -\mathbf{T} Q_{G^K}\left\{\frac{\mathbf{T}^{-1}\mathbf{u}}{\tau}\right\}. \quad (8)$$

Due to the denominator τ, the complex-integer-rounding function operates in a scaled integer lattice.

This is as set out in "Lattice-reduction-aided broadcast precoding," (C. Windpassinger, R. F. H. Fischer, and J. B. Huber, *IEEE Trans. on Commun.*, vol. 52, no. 12, pp. 2057-2060, Dec. 2004 – "Windpassinger et al.").

A number of lattice reduction algorithms exist. Any one of them can be used to calculate a transformation matrix, **T**, such that a reduced basis, $\tilde{\mathbf{P}}$, is given by $\mathbf{PT}$. The matrix **T** contains only complex integer entries and its determinant is $|\det(\mathbf{T})| = 1$ and thus is called a unimodular matrix.

The unimodular matrix **T** is given by means of a lattice reduction of the precoding matrix **P** with the LLL algorithm "Factoring Polynomials with Rational Coefficients" (A. Lenstra, H. Lenstra and L. Lovasz, *Math Ann.*, Vol. 261, pp. 515-534, 1982.), but any other algorithm for reducing a lattice basis is also applicable.

The normalisation factor $\gamma$ is then determined, by means of a closest point approximation, as:

$$\gamma = \|\mathbf{s}\|^2 = \|\mathbf{P}(\mathbf{u} + \tau\mathbf{l}_{\text{approx}})\|^2 \quad (9)$$

The complete transmission employing non-linear precoding can thus be formulated as

$$\mathbf{y} = \sqrt{\gamma}\left(\mathbf{H}\left(\frac{\mathbf{P}(\mathbf{u}+\tau\mathbf{l})}{\sqrt{\gamma}}\right) + \mathbf{n}\right) \quad (10)$$

with $\mathbf{y}$ being the receive signal of a single user or a plurality of users, each receiving one or more elements $y_i$ of the vector $\mathbf{y}$.

A block diagram of a transmission train employing data perturbation is shown in Figure 2. As illustrated in Figure 2, vector perturbation is carried out on the transmitted data **u** in a vector perturbation unit 20. The perturbed data is passed to be multiplied by the pseudo inverse $\mathbf{H}^{+}$ in block 22, which is equivalent to equation 2 set out above. The next block 24 represents division by $\sqrt{\gamma}$, which is a normalisation step. The resultant vector **x** is re-multiplied by the channel matrix **H** (in block 26), to which is added a noise vector **n**. In block 28, the resultant vector **y** is re-multiplied by the square root of the normalisation factor $\gamma$ and then modulo $\tau$ is applied to arrive at the perturbed data vector $\hat{\mathbf{u}}$.

Finding the perturbation vector **l** can be done in several ways. For instance, the solution of

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \|\mathbf{P}(\mathbf{u} + \tau\mathbf{l}')\|^2 \quad (11)$$

is an integer least squares problem for which there exist a large number of solution methods, such as that disclosed in Agrell et al. and also as disclosed in references contained in Hochwald et al. Moreover, "On the expected complexity of integer least-squares problems," (B. Hassibi and H. Vikalo, Proc. *IEEE International Conference on Acoustics, Speech, and Signal Processing, 2002 (ICASSP '02)*, vol. 2, pp. 1497-1500) describes complexity in the context of sphere decoding.

Further, approximation by means of lattice reduction is introduced in Windpassinger et al.

As set out in "Communications over MIMO broadcast channels using lattice-basis reduction," (M. Taherzadeh, A. Mobasher, and A. K. Khandani, *IEEE Trans. On Information Theory*, vol. 53, no. 12, pp. 4567-4582, 2007 – hereinafter referred to as Taherzadeh et al.), an appropriate supporting region for transmission is determined by reducing the average transmit energy in the reduced lattice. However, Taherzadeh et al. does not address the "closest lattice point" problem as set out in Equation 7 above. Instead, the approach according to Taherzadeh et al. is to determine an appropriate supporting region for the transmission by reducing the average transmitted energy in the reduced lattice.

As identified in the above paragraphs, conventional methods such as those described in Windpassinger et al. and Taherzadeh et al. do not support different modulo shift values $\tau$ for different spatial streams sharing one frequency resource. This problem will now be illustrated by way of an example.

In this example, $\mathbf{\Omega}$ represents a matrix containing the constellation shift parameters $\tau_{1 \cdots K}$ for $K$ spatial streams:

$$\mathbf{\Omega} = \begin{bmatrix} \tau_1 & 0 & \cdots & 0 \\ 0 & \tau_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \tau_K \end{bmatrix} \tag{12}$$

Accordingly, equation (7) is expressed as:

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \mathbf{P}(\mathbf{u} + \boldsymbol{\Omega}\,\mathbf{l}') \right\|^2 \tag{13}$$

Hence the lattice reduction aided closest point approximation $\mathbf{l}$ can be calculated, and the perturbation vector is then given as

$$\mathbf{l}_{\text{approx}} = -\mathbf{T} Q_{\boldsymbol{\Omega}\,\mathrm{G}^K} \left\{ \mathbf{T}^{-1}\mathbf{u} \right\} \tag{14}$$

However, when a lattice reduction algorithm, for instance a LLL algorithm, is applied to the basis P to calculate the transformation matrix, **T**, it is evident that the transformation matrix, **T**, does not correspond to the quantisation function $Q_{\boldsymbol{\Omega}\,\mathrm{G}^K}\{\ \}$, which operates in a different lattice.

Although this problem can be resolved by implementing a simple integer rounding function such that equation (14) can be expressed as:

$$\mathbf{l}_{\text{approx}} = -\mathbf{T} Q_{\mathrm{G}^K} \left\{ \mathbf{T}^{-1}\boldsymbol{\Omega}^{-1}\mathbf{u} \right\} \tag{15}$$

It will, however, be understood that this approach does not address the fundamental problem of having the incorrect lattice transformation matrix **T**. An example will be provided below to further illustrate this problem.

Since the modulo shift parameters $\tau_i$ are dependent on the constellations used in the different spatial streams, the conventional methods are therefore currently restricted to using the same constellation for all spatial streams sharing one frequency resource when vector perturbation precoding is applied. It is noted that this can have a significant impact on the quality of the transmission as a result of imperfect user selection, for example the modulation and coding scheme (MCS) cannot be selected according to the transmission quality of the transmission link quality.

Summary of the Invention

In a first aspect of the present invention, there is provided a method of processing information prior to emission thereof on a multi-antenna emission, said information being a data vector comprising corresponding data for each antenna of said multi-antenna emission, the method comprising applying a perturbation to said data vector in order to generate a perturbed data vector, said perturbation being expressible as a perturbation vector comprising a diagonal matrix of positive real numbers and a complex integer vector, said perturbation vector being selected by solving a integer least squares problem such that a normalisation factor is minimised, wherein said solving the integer least squares problem includes applying a scaling factor to the integer least squares problem.

The integer least squares problem may be expressible in the form $\mathbf{l} = \arg\min_{\mathbf{l}'} \|\mathbf{P}(\mathbf{u} + \mathbf{\Omega}\,\mathbf{l}')\|^2$, where $\mathbf{u} + \mathbf{\Omega l}'$ is a perturbed data vector, $\mathbf{u}$ is a data vector, $\mathbf{\Omega}$ is a diagonal matrix of positive real numbers, $\mathbf{l}'$ is a complex integer vector, and P is a precoding matrix.

The scaling factor may be applied to the integer least squares problem such that said integer least squares problem may be expressible in the form $\mathbf{l} = \arg\min_{\mathbf{l}'} \left\|\hat{\mathbf{P}}(\mathbf{\Omega}^{-1}\mathbf{u} + \mathbf{l}')\right\|^2$, where $\hat{\mathbf{P}} = \mathbf{P\Omega}$ .

In an embodiment of the above aspect, the method may further comprise the step of determining a solution for solving said integer least squares problem.

In one example described herein, the solution may be a lattice reduction closest point approximation expressible in the form

$$\mathbf{l}_{\text{approx}} = -\hat{\mathbf{T}} Q_{G^K} \left\{\hat{\mathbf{T}}^{-1}\mathbf{\Omega}^{-1}\mathbf{u}\right\}$$

where $\hat{\mathbf{T}}$ is a lattice reduction transformation matrix.

The lattice reduction transformation matrix may be determined by applying a LLL algorithm, and is expressible in the form

$\hat{\mathbf{T}} = LLL(\hat{\mathbf{P}})$

where $\hat{\mathbf{P}} = \mathbf{P}\boldsymbol{\Omega}$ .

The positive real numbers may be a plurality of constellation shift parameter.

The plurality of constellation shift parameter may be distinct from each other.

In a second aspect of the present invention there is provided a signal processing apparatus for processing information for a multi-antenna wireless communication apparatus, said information being a data vector comprising corresponding data for each antenna of said multi-antenna emission, the signal processing apparatus comprising a precoder for precoding said data vector, the precoder comprising perturbation means for applying a perturbation to said data vector in order to generate a perturbed data vector, said perturbation being expressible as a perturbation vector comprising a diagonal matrix of positive real numbers and a complex integer vector, the perturbation means being operable to select said perturbation vector by solving an integer least squares problem such that a normalisation factor is minimised, wherein said solving the integer least squares problem includes applying a scaling factor to the integer least squares problem.

Brief description of the drawings

Further aspects, features and advantages of the invention will become apparent from the following description of specific embodiments thereof, with reference to the accompanying drawings, in which:

Figure 1 illustrates a 16 QAM constellation having a modulo operation applied thereto;

Figure 2 illustrates a block diagram of a transmission train employing data perturbation;

Figure 3 illustrates an exemplary wireless communications device incorporating a specific embodiment of the invention;

Figure 4 illustrates a flow diagram of a precoding method in accordance with the specific embodiment of the invention;

Figure 5 illustrates a comparison simulation result obtained using the method in accordance with the present invention, and the method in accordance with the prior art;

Figure 6 illustrates an example of the closest point approximation in accordance with the prior art;

Figure 7 illustrates an example of the lattice-reduction-aided closest-point approximation in accordance with the prior art;

Figure 8 illustrates an example of the lattice-reduction-aided closest point approximation in accordance with an embodiment of the present invention;

Figure 9 illustrates an example of applying a transformation matrix in accordance with the prior art; and

Figure 10 illustrates an example of applying a transformation matrix in accordance with an embodiment of the present invention.

Detailed Description

Specific embodiments of the present invention will be described in further detail on the basis of the attached diagrams. It will be appreciated that this is by way of example only, and should not be viewed as presenting any limitation on the scope of protection sought.

The present invention will now be described with reference to an implementation of a wireless communication device. Figure 3 illustrates such a device 100.

The wireless communication device 100 illustrated in Figure 3 is generally capable of being used in a MIMO context, to establish a MIMO communications channel with one or more other devices and, in accordance with a specific embodiment of the invention, to take account of channel information so as to derive a pre-coding scheme appropriate to the quality of the channel. The reader will appreciate that the actual implementation of the wireless communication device is non-specific, in that it could be a base station or a user terminal.

Figure 3 illustrates schematically hardware operably configured (by means of software or application specific hardware components) as a wireless communication device 100. The receiver device 100 comprises a processor 120 operable to execute machine code instructions stored in a working memory 124 and/or retrievable from a mass storage device 122. By means of a general purpose bus 130, user operable input devices 136 are capable of communication with the processor 120. The user operable input devices 136 comprise, in this example, a keyboard and a mouse though it will be appreciated that any other input devices could also or alternatively be provided, such as another type of pointing device, a writing tablet, speech recognition means, or any other means by which a user input action can be interpreted and converted into data signals.

Audio/video output hardware devices 138 are further connected to the general purpose bus 130, for the output of information to a user. Audio/video output hardware devices 138 can include a visual display unit, a speaker or any other device capable of presenting information to a user.

Communications hardware devices 132, connected to the general purpose bus 130, are connected to antennas 134. In the illustrated embodiment in Figure 3, the working memory 124 stores user applications 126 which, when executed by the processor 120, cause the establishment of a user interface to enable communication of data to and from a user. The applications in this embodiment establish general purpose or specific computer implemented utilities that might habitually be used by a user.

Communications facilities 128 in accordance with the specific embodiment are also stored in the working memory 124, for establishing a communications protocol to enable data generated in the execution of one of the applications 126 to be processed and then passed to the communications hardware devices 132 for transmission and communication with another communications device. It will be understood that the software defining the applications 126 and the communications facilities 128 may be partly stored in the working memory 124 and the mass storage device 122, for convenience. A memory manager could optionally be provided to enable this to be managed effectively, to take account of the possible different speeds of access to data stored in the working memory 124 and the mass storage device 122.

On execution by the processor 120 of processor executable instructions corresponding with the communications facilities 128, the processor 120 is operable to establish communication with another device in accordance with a recognised communications protocol.

The specific embodiment performs a method to enable efficient employment of different constellations for different spatial streams by scaling the lattice basis according to different constellation shift parameters $\tau$.

Figure 4 illustrates the steps of precoding a data vector in accordance with the specific embodiment of the invention. In the first step (step 140) of the method, the data vector $\mathbf{u}$ is perturbed by applying a perturbation vector to the data vector as follows:

$$\hat{\mathbf{u}} = \mathbf{u} + \boldsymbol{\Omega}\,\mathbf{l} \qquad (16)$$

where $\boldsymbol{\Omega}$ represents a matrix containing $\tau_{1 \ldots K}$ for $K$ spatial streams:

$$\boldsymbol{\Omega} = \begin{bmatrix} \tau_1 & 0 & \cdots & 0 \\ 0 & \tau_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \tau_K \end{bmatrix} \qquad (17)$$

and $\mathbf{l}$ is a complex integer vector. In step 142, $\boldsymbol{\Omega}$ and $\mathbf{l}$ can be selected in order to minimise normalisation factor $\gamma = \|\mathbf{s}\|^2$, such that:

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \mathbf{P}(\mathbf{u} + \boldsymbol{\Omega}\,\mathbf{l}') \right\|^2 \tag{18}$$

In step 144, scaling factor $\boldsymbol{\Omega}\boldsymbol{\Omega}^{-1}$ is applied to equation 18:

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \mathbf{P}\boldsymbol{\Omega}\,\boldsymbol{\Omega}^{-1}(\mathbf{u} + \boldsymbol{\Omega}\,\mathbf{l}') \right\|^2 \tag{19}$$

where $\boldsymbol{\Omega}$ is as expressed in equation 17. Accordingly, the minimisation problem of equation 19 can be expressed as:

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \hat{\mathbf{P}}(\boldsymbol{\Omega}^{-1}\mathbf{u} + \mathbf{l}') \right\|^2 \tag{20}$$

where $\hat{\mathbf{P}} = \mathbf{P}\boldsymbol{\Omega}$ , and it will be appreciated that the closest point can be determined to the lattice point $\boldsymbol{\Omega}^{-1}\mathbf{u}$ .

There are a large number of solution methods that can be employed to solve the problem of equation 20. For instance, a sphere encoder can be used to find the solution of the minimisation problem.

It can also be demonstrated that the minimisation problem of equation 20 can also be solved by lattice reduction aided closest point approximation as follows:

$$\mathbf{l}_{\text{approx}} = -\hat{\mathbf{T}} Q_{\boldsymbol{\Omega}\,\mathrm{G}^{K}} \left\{ \hat{\mathbf{T}}^{-1}\mathbf{u} \right\} \tag{21}$$

where

$$\hat{\mathbf{T}} = LLL(\hat{\mathbf{P}}) \tag{22}$$

In this example, $\hat{\mathbf{T}}$ is the lattice reduction transformation matrix obtained by a lattice reduction by means of the LLL algorithm applied to $\hat{\mathbf{P}} = \mathbf{P}\boldsymbol{\Omega}$ . However, it will be appreciated that any other lattice reduction algorithm can also be employed.

The quantisation function as a simpler element-wise complex-valued rounding to the nearest Gaussian integer as

$$\mathbf{l}_{\text{approx}} = -\hat{\mathbf{T}} Q_{\mathrm{G}^K} \left\{ \hat{\mathbf{T}}^{-1} \mathbf{\Omega}^{-1} \mathbf{u} \right\} \tag{23}$$

In a further example, the minimisation problem of equation 20 can also be solved by a method employing lattice reduction which has the capability of providing performance closer to an optimal solution previously described in UK patent application 0805306.8.

The present invention can be applied to a technique named "LLL THP" or as described in Windpassinger et al. as "nearest-plane approximation". For example, let $\hat{\mathbf{W}}$ be the reduced-lattice precoding matrix, $\hat{\mathbf{W}} = \hat{\mathbf{P}} \hat{\mathbf{T}}$, then it is defined that

$$\hat{\mathbf{F}} \hat{\mathbf{W}} \hat{\mathbf{V}} = \hat{\mathbf{B}} \tag{24}$$

where $\hat{\mathbf{B}}$ is a lower triangular with unit diagonal elements, $\hat{\mathbf{F}}$ is a unitary matrix, and $\hat{\mathbf{V}}$ is a permutation matrix according to the V-BLAST criteria applied to $\hat{\mathbf{W}}$. The feedback stage of THP is initialised as

$$\hat{\mathbf{q}} = -\hat{\mathbf{F}} \hat{\mathbf{P}} \mathbf{\Omega}^{-1} \mathbf{u} = -\hat{\mathbf{F}} \mathbf{P} \mathbf{u} \tag{25}$$

where $\mathbf{\Omega}^{-1}\mathbf{u}$ is the transmit vector in the scaled lattice coordinates of $\hat{\mathbf{P}} = \mathbf{P\Omega}$, and $\hat{\hat{q}}_1 = \hat{q}_1$. The feedback loop calculates for $k = 2, \ldots, K$, where $K$ is the number of spatial streams,

$$\hat{\hat{q}}_k = Q_{\mathrm{G}^K} \left\{ \hat{q}_k - \sum_{l=1}^{k-1} \hat{b}_{kl} \hat{\hat{q}}_l \right\}. \tag{26}$$

$Q_{G^K}\{\ \}$ is the rounding operation towards the nearest complex integer vector. The perturbation vector is computed as

$$\mathbf{l}_{\text{approx}} = \hat{\mathbf{T}}\hat{\mathbf{V}}\hat{\hat{\mathbf{q}}}, \tag{27}$$

which is then applied to the vector perturbation step of the transmit symbol vector as per

$$\hat{\mathbf{u}} = \mathbf{u} + \boldsymbol{\Omega}\,\mathbf{l}_{\text{approx}}. \tag{28}$$

It will be appreciated that the THP Feedback Loop in equation (26) has been changed, as the rounding is now done to complex integers, and not to the scaled integer lattice by "A", as demonstrated in Windpassinger et al.

By way of a numerical example, the performance of the method described above for the present invention will be now compared with that of the conventional method described in the prior art.

Firstly, the channel **H** is set as,

$$\mathbf{H} = \begin{bmatrix} 1.0457 - 0.0253i & 1.3469 + 0.2466i & -0.8098 + 0.8257i & 0.8027 - 0.7540i \\ -0.0082 - 1.4889i & 2.0122 + 0.4893i & 1.0708 - 1.6798i & 0.0260 + 0.9390i \\ -0.9108 + 1.1089i & 1.1823 - 1.0528i & -1.6645 - 1.0167i & 0.0959 - 0.7873i \\ -1.5254 + 0.3394i & -0.2364 + 0.6440i & 1.7713 + 0.2965i & -0.8815 - 1.6437i \end{bmatrix}$$

Accordingly, the precoding matrix, $\mathbf{P}=\mathbf{H}^{-1}$ is

$$\mathbf{P} = \begin{bmatrix} 0.3962 - 1.0942i & -1.3030 + 0.2683i & -0.1889 + 1.4390i & -0.9139 - 0.6860i \\ 0.4827 + 0.6900i & 0.9877 - 0.5657i & -0.3591 - 1.0571i & 0.7582 + 0.0428i \\ 1.1477 - 0.2373i & -0.6009 - 1.3282i & -1.7991 + 0.4727i & 0.4595 - 1.0758i \\ 1.2164 - 0.1456i & -0.8905 - 1.3030i & -1.6147 + 0.8140i & 0.1313 - 0.8744i \end{bmatrix}$$

In this example, the transmit vector is given as,

$$\mathbf{u} = \left[\text{-0.7071 - 0.7071i}, \quad \text{0.7071 - 0.7071i}, \quad 0.3162 + 0.9487\text{i}, \quad \text{-0.9487 - 0.9487i}\right]^T$$

wherein the first two elements are drawn from a QPSK constellation, and the last two elements are drawn from a 16-QAM constellation. Accordingly, the matrix containing the constellation perturbation distances is as follows

$$\Omega = \begin{bmatrix} \tau_{\text{QPSK}} & 0 & 0 & 0 \\ 0 & \tau_{\text{QPSK}} & 0 & 0 \\ 0 & 0 & \tau_{\text{16QAM}} & 0 \\ 0 & 0 & 0 & \tau_{\text{16QAM}} \end{bmatrix} = \begin{bmatrix} 2.8284 & 0 & 0 & 0 \\ 0 & 2.8284 & 0 & 0 \\ 0 & 0 & 2.5298 & 0 \\ 0 & 0 & 0 & 2.5298 \end{bmatrix}$$

which leads to a minimisation problem of $\mathbf{l} = \arg\min_{\mathbf{l}'} \left\|\mathbf{P}(\mathbf{u} + \boldsymbol{\Omega}\,\mathbf{l}')\right\|^2$.

As described in the foregoing paragraphs, the minimisation problem can be solved by a number of solution methods, for example the lattice-reduction-aided closest point approximation method can be applied, such that the lattice reduction transformation matrix **T** can be computed by the LLL algorithm as **T**=*LLL*(**P**),

$$T = \begin{bmatrix} 0 & -i & 1 & i \\ 1 & i & -1 & i \\ 0 & 1 & 1+i & 1 \\ -1+i & -1+i & 0 & 1 \end{bmatrix}$$

By applying the approximation according to the prior art, that is equation 15, the following can be obtained,

$$\mathbf{l}_{\text{approx}} = -\mathbf{T}Q_{\mathrm{G}^K}\left\{\mathbf{T}^{-1}\boldsymbol{\Omega}^{-1}\mathbf{u}\right\}$$

$$\mathbf{l}_{\text{approx}} = \begin{bmatrix} -i \\ 0 \\ 1 \\ 0 \end{bmatrix}$$

and by applying the method as described above according to the present invention, the lattice reduction matrix is obtained as $\hat{\mathbf{T}} = LLL(\mathbf{P}\boldsymbol{\Omega})$,

$$\hat{\mathbf{T}} = \begin{bmatrix} 0 & 0 & i & i \\ i & 1 & -1-i & 1+i \\ 1 & 0 & -1+i & 1-i \\ 0 & -1+i & 1-i & 1 \end{bmatrix}$$

Accordingly, equation 21 can be applied as follows,

$$\hat{\mathbf{l}}_{\text{approx}} = -\hat{\mathbf{T}}Q_{\mathrm{G}^K}\left\{\hat{\mathbf{T}}^{-1}\boldsymbol{\Omega}^{-1}\mathbf{u}\right\}$$

$$\hat{\mathbf{l}}_{\text{approx}} = \begin{bmatrix} 0 \\ 0 \\ i \\ -1-i \end{bmatrix}$$

Finally, by applying equation 9, the approximation using the conventional method is obtained as $\gamma_{\text{approx}} = 2.0065$, while the approximation using the method according to the present invention is obtained as $\hat{\gamma}_{\text{approx}} = 1.4383$. Hence, this example illustrates the method of the present invention clearly provides a better approximation of the solution of the minimisation of $\gamma$ than the conventional method.

The performance of the present invention will now be compared using three different schemes as summarised in Table 1 below.

<table>
<tr><th>#</th><th>Constellations</th><th>Precoding</th><th>Parameter $\tau$</th><th>LLL input matrix</th></tr>
<tr><td>1</td><td>QPSK, 16QAM</td><td rowspan="2">Pseudo-inverse and non-linear LLL Vector Perturbation precoding</td><td>$\tau_{\mathrm{QPSK}}, \tau_{16\mathrm{QAM}}$ with invention</td><td>$\hat{\mathbf{P}} = \mathbf{P}\boldsymbol{\Omega}$</td></tr>
<tr><td>2</td><td>QPSK, 16QAM</td><td>$\tau_{\mathrm{QPSK}}, \tau_{16\mathrm{QAM}}$ without invention</td><td>$\mathbf{P}$</td></tr>
<tr><td>3</td><td>QPSK, 16QAM</td><td>Pseudo-inverse</td><td>no $\tau$ required (linear precoding)</td><td>none</td></tr>
</table>

**Table 1: Schemes used for performance comparison**

Scheme 1 employs the method as described above in accordance with the present invention, that is the scaling of the LLL input matrix by the different modulo shift values. Different $\tau$ are used for the spatial streams.

Scheme 2 is similar to Scheme 1, but it applies different modulo shift parameters according to the constellation of the spatial streams, without using the method of the present invention.

Scheme 3 employs linear precoding by means of the channel pseudoinverse.
The results of the simulations for the three schemes are displayed in Figure 5. The results clearly show that scheme 1 which employs the method of the present invention performs better that Scheme 2.

The performance of the method described above for the present invention will now be further illustrated by way of a graphical example.

In this example, the precoding matrix is set as

$$\mathbf{P} = \begin{bmatrix} 1.1380 & -1.2919 \\ -0.6841 & -0.0729 \end{bmatrix}$$

The transmit symbol vector is expressed as

$$\mathbf{u} = [u_1, u_2]^T$$

where is $u_1$ a 16-QAM alphabet expressible in the form $u_1 \in \{-0.9487,\ -0.3162,\ 0.3162,\ 0.9487\}$, and $u_2$ is a QPSK alphabet expressible in the form $u_2 \in \{-0.7071, 0.7071\}$.

Accordingly, the matrix of perturbation distances is

$$\mathbf{\Omega} = \begin{bmatrix} \tau_{\text{16-QAM}} & 0 \\ 0 & \tau_{\text{QPSK}} \end{bmatrix} = \begin{bmatrix} 2.5298 & 0 \\ 0 & 2.8284 \end{bmatrix}$$

An example of a closest-lattice search is illustrated in Figure 6. In Figure 6, the stars (*) represent all the possible unperturbed transmit vectors, $\mathbf{Pu}$. The dashed lines represent the border of the constellation in the precoded space. The Voronoi regions as indicated by the dotted lines contain all the closest points to the centres of the regions, and the dots (•) in the centre of these regions represents all the possible perturbation vectors, $\mathbf{P\Omega l}$. The person skilled in the art will appreciate that the left most star and the right most star will result in a perturbation of the transmit vector as these points are located in different decision regions.

According to the equations above, the lattice reduction matrices can be determined as

$$\mathbf{T} = \begin{bmatrix} 1 & 0 \\ 1 & -1 \end{bmatrix}$$

and

$$\hat{\mathbf{T}} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}$$

where $\mathbf{T} = LLL(\mathbf{P})$, and $\hat{\mathbf{T}} = LLL(\mathbf{P\Omega})$

Lattice-reduction-aided closest point approximation is dependent on $\mathbf{PT}$ being close to orthogonal, such that

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \mathbf{PT}\left(\mathbf{T}^{-1}\mathbf{u} + \mathbf{T}^{-1}\mathbf{\Omega}\,\mathbf{l}'\right) \right\|^2 \approx \arg\min_{\mathbf{l}'} \left\| \mathbf{T}^{-1}\mathbf{u} + \mathbf{T}^{-1}\mathbf{\Omega}\,\mathbf{l}' \right\|^2 .$$

However, it is noted that a rounding-off error will result if $\mathbf{PT}$ is not unitary. Firstly, the closest point approximation of the reduced lattice, **PT**, is determined as shown in figure 7. In this example, the perturbation vectors are represented as integers. In figure 7, the closest point in the integer lattice is determined by simple element-wise rounding which leads to the Voronoi regions represented by the solid lines. The stars represent all the possible unperturbed transmit symbols $\mathbf{T}^{-1}\mathbf{u}$. In summary, the minimisation problem as shown in figure 7 operates in a orthogonal lattice and it can be solved by the rounding function. Accordingly, the minimisation problem is solved by: $\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \mathbf{T}^{-1}\mathbf{\Omega}^{-1}\mathbf{u} + \mathbf{T}^{-1}\mathbf{l}' \right\|^2$ (normalised to an integer rounding function).

Similarly, the same operation is carried out in figure 8, except in this example the transformation matrix, $\hat{\mathbf{T}}$, is applied. The normalised points $\hat{\mathbf{T}}^{-1}\mathbf{u}$ is displayed and the closest point of the lattice, $\hat{\mathbf{T}}^{-1}\mathbf{l}$, is determined accordingly. Again, the minimisation problem as shown in figure 8 operates in a orthogonal lattice and it can be solved by the rounding function. Accordingly, the minimisation problem is solved by:

$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \hat{\mathbf{T}}^{-1}\mathbf{\Omega}^{-1}\mathbf{u} + \mathbf{T}^{-1}\mathbf{l}' \right\|^2$, or $\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \hat{\mathbf{T}}^{-1}\mathbf{\Omega}^{-1}\mathbf{u} + \hat{\mathbf{T}}^{-1}\mathbf{l}' \right\|^2$ (normalised to an integer rounding function).

In the following examples, the rounding-off error caused by the above methods will be illustrated.

As shown in the figure 9, the Voronoi regions of the closest point search are represented in dotted lines. In the figure, the dots represent possible perturbation vectors, and the stars represent all the possible transmit symbols, $\mathbf{Pu}$, for all possible combinations of $u_1$ and $u_2$. The decision regions used by the approximation in the prior art are indicated by solid lines. As clearly indicated by the arrow in the figure 9, the left most symbol is wrongly mapped onto the perturbation vector.

In figure 10 the Voronoi regions of the closest point search is represented by dotted lines, and the decision regions used by the approximation using the method as described above in accordance with the present invention are indicated by solid lines. In this case, it is clearly shown in figure 10 that the left most symbol is correctly mapped onto the perturbation vector, as indicated by the arrow in the figure.

While the foregoing specific description of an embodiment of the invention has been provided for the benefit of the skilled reader, it will be understood that it should not be read as mandating any restriction on the scope of the invention. The invention should be considered as characterised by the claims appended hereto, as interpreted with reference to, but not bound by, the supporting description.

**CLAIMS:**

1. A method of processing information prior to emission thereof on a multi-antenna emission, said information being a data vector comprising corresponding data for each antenna of said multi-antenna emission, the method comprising applying a perturbation to said data vector in order to generate a perturbed data vector, said perturbation being expressible as a perturbation vector comprising a diagonal matrix of positive real numbers and a complex integer vector, said perturbation vector is selected by solving an integer least squares problem such that a normalisation factor is minimised, wherein said solving of the integer least squares problem includes applying a scaling factor to the integer least squares problem.

2. A method according to claim 1 wherein the integer least squares problem is expressible in the form

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \mathbf{P}(\mathbf{u} + \mathbf{\Omega}\,\mathbf{l}') \right\|^2,$$

where $\mathbf{u} + \mathbf{\Omega l}'$ is a perturbed data vector, $\mathbf{u}$ is a data vector, $\mathbf{\Omega}$ is a diagonal matrix of positive real numbers, $\mathbf{l}'$ is a complex integer vector, and $\mathbf{P}$ is a precoding matrix.

3. A method according to claim 2 wherein the scaling factor is applied to the integer least squares problem such that said integer least squares problem is expressible in the form

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \hat{\mathbf{P}}(\mathbf{\Omega}^{-1}\mathbf{u} + \mathbf{l}') \right\|^2,$$

where $\hat{\mathbf{P}} = \mathbf{P\Omega}$ .

4. A method according to claim 3 further comprising the step of determining a solution for solving said integer least squares problem.

5. A method according to claim 4 wherein said solution is a lattice reduction closest point approximation expressible in the form

$$\mathbf{l}_{\text{approx}} = -\hat{\mathbf{T}} Q_{\mathrm{G}^K} \left\{ \hat{\mathbf{T}}^{-1} \mathbf{\Omega}^{-1} \mathbf{u} \right\}$$

where $\hat{\mathbf{T}}$ is a lattice reduction transformation matrix.

6. A method according to claim 5 wherein the lattice reduction transformation matrix is determined by applying a LLL algorithm, and is expressible in the form

$$\hat{\mathbf{T}} = LLL(\hat{\mathbf{P}})$$

where $\hat{\mathbf{P}} = \mathbf{P}\boldsymbol{\Omega}$ .

7. A method according to any one of the preceding claims wherein the positive real numbers of the diagonal matrix comprise a plurality of constellation shift parameters.

8. A method according to claim 7 wherein the constellation shift parameters are distinct from each other.

9. A signal processing apparatus for processing information for a multi-antenna wireless communication apparatus, said information being a data vector comprising corresponding data for each antenna of said multi-antenna emission, the signal processing apparatus comprising a precoder for precoding said data vector, the precoder comprising perturbation means for applying a perturbation to said data vector in order to generate a perturbed data vector, said perturbation being expressible as a perturbation vector comprising a diagonal matrix of positive real numbers and a complex integer vector, the perturbation means being operable to select said perturbation vector by solving a integer least squares problem such that a normalisation factor is minimised, wherein said solving the integer least squares problem includes applying a scaling factor to the integer least squares problem.

10. A signal processing apparatus according to claim 9 wherein the integer least squares problem is expressible in the form

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \mathbf{P}(\mathbf{u} + \boldsymbol{\Omega}\,\mathbf{l}') \right\|^2 ,$$

where $\mathbf{u} + \boldsymbol{\Omega}\mathbf{l}'$ is a perturbed data vector, $\mathbf{u}$ is a data vector, $\boldsymbol{\Omega}$ is a diagonal matrix of positive real numbers, $\mathbf{l}'$ is a complex integer vector, and $\mathbf{P}$ is a precoding matrix.

11. A signal processor according to claim 10 wherein the perturbation means is operable to apply the scaling factor to the integer least squares problem such that said integer least squares problem is expressible in the form

$$\mathbf{l} = \arg\min_{\mathbf{l}'} \left\| \hat{\mathbf{P}}(\mathbf{\Omega}^{-1}\mathbf{u} + \mathbf{l}') \right\|^2,$$

where $\hat{\mathbf{P}} = \mathbf{P\Omega}$ .

12. A signal processor according to claim 11 is further operable to determine a solution for solving said integer least squares problem.

13. A signal processor according to claim 12 wherein said solution is a lattice reduction closest point approximation expressible in the form

$$\mathbf{l}_{\text{approx}} = -\hat{\mathbf{T}} Q_{G^K} \left\{ \hat{\mathbf{T}}^{-1} \mathbf{\Omega}^{-1} \mathbf{u} \right\}$$

where $\hat{\mathbf{T}}$ is a lattice reduction transformation matrix.

14. A signal processor according to claim 13 wherein the lattice reduction transformation matrix is determined by applying a LLL algorithm, and is expressible in the form

$$\hat{\mathbf{T}} = LLL(\hat{\mathbf{P}})$$

where $\hat{\mathbf{P}} = \mathbf{P\Omega}$ .

15. A signal processor according to any one of claims 9 to 14 wherein the positive real numbers of the diagonal matrix comprise a plurality of constellation shift parameters.

16. A signal processor according to claim 15 wherein the constellation shift parameters are distinct from each other.

17. A storage medium storing computer executable instructions which, when executed on general purpose computer controlled communications apparatus, cause the apparatus to become configured to perform the method of any of claims 1 to 8.

18. A signal carrying computer receivable information, the information defining computer executable instructions which, when executed on general purpose computer controlled communications apparatus, cause the apparatus to become configured to perform the method of any of claims 1 to 8.

19. A signal processor substantially as herein described with reference to Figure 3 of the accompanying drawings.

20. A method substantially as herein described with reference to any of Figures 1 to 10 of the accompanying drawings.

**Application No:** GB0901089.3 **Examiner:** Dr John Cullen

**Claims searched:** 1-20 **Date of search:** 15 May 2009

## Patents Act 1977: Search Report under Section 17

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular relevance |
|---|---|---|
| X | --- | KR 10-2007-0074023 (SAMSUNG) See page 4 |
| A | --- | US7317764 B2 (HOCHWALD) See line 20 of col. 5. |
| A | --- | WO2008/054178 A2 (LG) See Formula 12 |
| A | --- | Wee Seng Chua; Chau Yuen; Chin, F., "A Continuous Vector Perturbation for Multi-Antenna Multi-User Communication," Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th , vol., no., pp.1806-1810, 22-25 April 2007 |

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Worldwide search of patent documents classified in the following areas of the IPC

H04B; H04L

The following online and other databases have been used in the preparation of this search report

Online: WPI, EPODOC, TXTE, INSPEC

**International Classification:**

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| H04B | 0007/04 | 01/01/2006 |

| Subclass | Subgroup | Valid From |
| --- | --- | --- |
| H04B | 0007/06 | 01/01/2006 |