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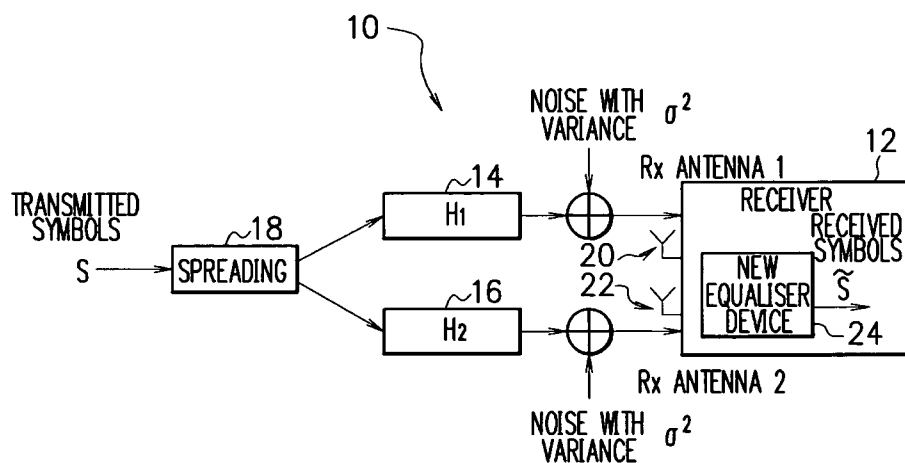
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(54) Title: DATA EQUALISATION IN A COMMUNICATION RECEIVER WITH RECEIVE DIVERSITY



(57) Abstract: A method of performing data equalization in a communication receiver forming part of a communication system with receive diversity is provided. The method comprises (a) for each i^{th} antenna, calculating a channel response matrix H_i from multi-path channel estimates, (b) calculating a channel gain matrix G from the channel response matrices H_i and a scalar noise factor β , (c) calculating the middle column c_0 of the inverse G^{-1} of the channel gain matrix G , (d) for each i -th antenna, calculating a filter coefficient vector w_i from the middle column c_0 of the inverse G^{-1} of the channel gain matrix G and the Hermitian transpose H_i^H of the corresponding channel response matrix H_i , (e) filtering input data r_i received at each i -th antenna with the corresponding filter coefficient vector w_i , (f) despreading the filtered input data from each i -th antenna, and (g) combining the despread data from all antennas to obtain received equalised data.

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DESCRIPTION

DATA EQUALISATION IN A COMMUNICATION RECEIVER WITH
RECEIVE DIVERSITY

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The present invention relates generally to spread spectrum receivers, and in particular to methods of optimising the equalisation in a communication receiver, with receive diversity, of a spread spectrum signal transmitted through multiple resolvable fading paths
10 channel. The invention is suitable for use in applications involving W-CDMA transmission techniques, and it will be convenient to describe the invention in relation to that exemplary application.

In W-CDMA communication systems, multicode signals at the transmitter are orthogonal to each other. However, this orthogonality
15 is lost as the signals propagate through a multi-path fading channel. A chip equaliser is employed in the W-CDMA receiver as a means to restore the orthogonality of the signal, and thereby improve the receiver performance.

Typically, implementations of chip equalisers include a finite
20 impulse response (FIR) filter. The chip equaliser tries to compensate for multi-path interference by inverting the channel. A known method for computing optimal chip equaliser filter coefficients uses a direct inversion matrix method involving estimation of the channel gain matrix G from the expression $G=H^H H+\beta I$, where $H^H H$ is the channel
25 correlation matrix, I is identity matrix, and β is a scalar noise factor in a W-CDMA system. Chip level equalisation based on the matrix inversion method requires extensive computation that involves matrix decomposition as well as backward and forward substitution.

In current 3rd generation partnership project (3GPP) standards,
30 receive diversity is used to improve receiver downlink performance.

Receive diversity uses multiple antennas at the receiver to enable stronger signal reception. This translates to higher data rates and increases system capacity. Current 3GPP standards specify requirements for receivers based on a least minimum mean-square error (LMMSE) chip level equaliser (CLE). Whilst implementation of the CLE is straightforward in the case of a communication system without transmit or receive diversity, implementation of the CLE in a communication receiver with receive diversity has yet to be implemented in a practical, computationally efficient manner.

10 There currently exists a need to provide a method of performing data equalisation in a communication receiver with receive diversity that ameliorates or overcomes one or more disadvantages of the prior art. There also exists a need to provide a method of performing data equalisation in a communication receiver with receive diversity that
15 optimizes the performance of a chip level equaliser in the communication receiver. There further exists a need to provide a method for performing data equalisation in a communication receiver which receive diversity that is simple, practical and computationally efficient to implement.

20 With this in mind, one aspect of the invention provides a method for performing data equalisation in a communication receiver forming part of a communication system with receive diversity, the method including the steps of:

25 (a) for each i -th antenna, calculating a channel response matrix H_i from multi-path channel estimates;

 (b) calculating a channel gain matrix G from the channel response matrices H_i and a scalar noise factor β ;

 (c) calculating the middle column c_0 of the inverse G^{-1} of the channel gain matrix G ;

30 (d) for each i -th antenna, calculating a filter coefficient vector w_i

from the middle column c_0 of the inverse G^{-1} of the channel gain matrix G and the Hermitian transpose H_i^H of the corresponding channel response matrix H_i ;

(e) filtering input data r_i received at each i -th antenna with the
5 corresponding filter coefficient vector w_i ;

(f) despreading the filtered input data from each i -th antenna;
and

(g) combining the despread data from all antennas to obtain
received equalised data.

10 Preferably, step (c) includes:

(h) performing a Cholesky decomposition of the channel gain
matrix G into a lower triangular matrix L and an upper triangular
matrix U ;

(i) performing forward substitution on the lower triangular
15 matrix L to calculate a column vector d ; and

(j) performing backward substitution on the column vector d and
the Hermitian transpose L^H of the lower triangular matrix L to
calculate the middle column c_0 of the inverse G^{-1} of the channel gain
matrix G .

20 Preferably, the channel gain matrix G to be inverted is calculated
from the expression

$$G = \sum_i \hat{H}_i^H \hat{H}_i + \tilde{\beta} I$$

where I is the identity matrix.

25 Another aspect of the invention provides a chip equaliser for use
in a communication receiver forming part of a communication system
with receive diversity, the chip equaliser including one or more
computational blocks for implementing the above described method.

The following description refers in more detail to various features
of the invention. To facilitate an understanding of the invention,

reference is made in the description to the accompanying drawings where the method for performing data equalisation and the chip equaliser are illustrated in preferred embodiments. It is to be understood that the invention is not limited to the preferred
5 embodiments as shown in the drawings.

In the drawings:

Figure 1 is a schematic diagram of a communication system including a communication receiver with receive diversity;

Figure 2 is a schematic diagram showing selected functional
10 blocks of an equaliser for use in the communications receiver forming part of the communication system of Figure 1;

Figure 3 is a flow chart showing a series of steps performed by a matrix inversion computational block for the equaliser shown in Figure 2; and

15 Figures 4 and 5 are graphical representations respectively of the forward and backward substitution steps of the filter coefficient calculation method carried out by the equaliser shown in Figure 2.

Referring now to Figure 1, there is shown generally a communication system 10 for transmission of data symbols S to a
20 communication receiver 12. The communication system 10 use a diversity scheme to improve the reliability of a message signal transmitted to the receiver 12 by using two or more communication channels with different characteristics. In the example illustrated in this figure, two communication channels 14 and 16 are illustrated.
25 Each of the communication channels 14 and 16 experience different levels of fading and interference.

Following signal spreading 18, the data symbols are effectively transferred to the communication receiver 12 over different propagation paths by the use of multiple antennas at the
30 communication receiver 12. In this example, two exemplary receiving

antennas 20 and 22 are illustrated, but in other embodiments of the invention any number of receiving antennas may be used.

During transmission of the data symbols to the communication receiver 12, noise characterised by variance σ^2 is effectively introduced into the dispersive channels 14 and 16. The communications receiver 12 includes an equaliser 24 designed to restore the transmitted data signals distorted by the dispersive channels 14 and 16 and the noise introduced into those dispersive channels.

Selected computational blocks of the equaliser 24 are illustrated in Figure 2. The equaliser 24 includes a channel response matrix calculation block 26, a direct gain matrix calculation block 28, a matrix inversion block 30, FIR filter blocks 32 and 34, despreader blocks 36 and 38 and a data symbol combining block 40. In use, the equaliser 24 receives samples r_i at each of the i receiver antennas, namely samples r_1 from the first reception antenna 20 and samples r_2 from the second reception antenna 22.

Channel estimates for the dispersive channel received at each i -th reception antenna are computed within the receiver 12 and provided as an input to the channel matrix calculation block 26. The channel estimates h_l^i , where $l=0,1,2,\dots,L-1$ are received by the channel matrix calculation block 26 for the L multiple resolvable fading paths of each transmission channel received by each i -th reception antenna.

The channel response matrix \hat{H}_i for each i -th receiver antenna is constructed from the received channel estimates by consecutively shifting a channel vector column by column, where the channel vector is formed by arranging the L channel estimates h_l^i in their multi-path position in the direction of the column. In the example shown in Figure 2, two such channel matrices are constructed.

A channel gain matrix G is then constructed based upon the estimate of the channel response matrices H_1 and H_2 together with an

estimate of the scale and noise factor in the communication system 10. The direct gain matrix G is calculated according to the following equation:

$$G = \hat{H}_1^H \hat{H}_1 + \hat{H}_2^H \hat{H}_2 + \tilde{\beta} I$$

5 where \hat{H}_1 and \hat{H}_2 are respectively the channel response matrices for the dispersive channels 14 and 16, \hat{H}_1^H and \hat{H}_2^H are respectively the hermitian transpose of those channel response matrices, $\tilde{\beta}$ is an estimate of the noise factor of the communication system 10 and I is the identity matrix. $\hat{H}_i^H \hat{H}_i$ is the channel correlation matrix for each i -
10 th dispersive channel in the communication system 10. The estimate $\hat{\beta}$ of the noise factor in the communication system 10 can be computed by the receiver 12 in the manner described in United States Patent Application 2006/0018367, filed 19 July 2005 in the name of NEC Corporation, the entire contents of which are incorporated herein by
15 reference.

The channel gain matrix G must then be inverted in the matrix inversion block 30. A computationally efficient series of steps performed by the matrix inversion block 30 are illustrated in the flow chart shown in Figure 3. At step 42, a Cholesky decomposition of the
20 channel gain matrix G is performed to obtain a lower triangular matrix L and an upper triangular matrix U .

At step 44, a forward substitution is then performed to solve the equation

$$Ld = e_{(N+1)/2} = [e_1, e_2, \dots, e_N]^T$$

$$\text{where } e_i = \begin{cases} 1 & i=(N+1)/2 \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

25 to obtain a column vector d . The lower triangular matrix L , the column vector d and the resultant column vector e are schematically represented in Figure 4. Preferably, only half of this vector (denoted as \hat{d} where $\hat{d} = d[(N-1)/2, \dots, N-1]$) needs to be inputted into the next

computational step.

At step 46, a backward substitution is then carried out to solve the equation

$$\hat{\mathbf{L}}^H \hat{\mathbf{c}}_0 = \hat{\mathbf{d}}$$

where

$$\hat{\mathbf{L}}^H[i, j] = \mathbf{L}^H[i + (N-1)/2, j + (N-1)/2]$$

$$\forall 0 \leq i, j \leq (N-1)/2$$

5 to obtain half of vector \mathbf{c}_0 (denoted as $\hat{\mathbf{c}}_0$) corresponding to the middle row of the matrix \mathbf{G}^{-1} . Figure 5 is a graphical illustration of the backward substitution step performed at this step. The full vector \mathbf{c}_0 can then be obtained noting that

$$\mathbf{c}_0[(N-1)/2+k] = \hat{\mathbf{c}}_0[k], \mathbf{c}_0[k] = \mathbf{c}_0[N-1-k], k = 0, \dots, (N-1)/2$$

10 At step 48, the vectors of filter coefficients \mathbf{w}_i for each of the FIR filters 32 and 34 can be obtained by computing $\mathbf{w}_i = \mathbf{c}_0^H \mathbf{H}_i^H$ for each i -th filter.

The input data r_i is periodically updated with filter coefficient vectors \mathbf{w}_i during operation of the receiver 12. Despreader blocks 36
15 and 38 perform despreading operations on the input data symbol estimates from the multiple resolvable fading paths received respectively by the reception antennas 20 and 22. Accordingly, each despreader block obtains estimated symbols corresponding to each i -th receive antenna (denoted as S_i).

20 The combining block 40 acts to combine the despread symbols from the receive antennas to obtain equalised data symbols $\{\tilde{S}(0), \tilde{S}(1), \tilde{S}(2), \dots\}$.

Since the linear equations solved in the forward substitution step 44 and backward substitution step 46 has N and $(N+1)/2$ unknowns,
25 solving them only requires calculation complexity of $O(N^2)$. This significantly reduced computational complexity and enables the use of the equaliser 24 in practical communication.

It will be appreciated from the foregoing that in a communication system, calculating the filter coefficients for an equaliser at the receiver using direct matrix inversion would normally require up to $O(N^3)$ complex multiplications for forward and backward substitutions processing, where N is dimension of the square channel matrix to be inverted. This high level of computational complexity is a prohibitive factor for this method to be used in practical communication device. The above-described equaliser uses an efficient method of calculation requiring only $O(N^2)$ complex multiplications for forward and backward substitutions processing to obtain exactly the same performance as normal equaliser employing direct matrix inversion. The simplified calculation is achievable by exploiting the special property (Hermitian and Positive Definite) of the channel response matrix G as well as the way filter coefficients are calculated in a particular realisation of the equaliser receiver.

Finally, it should be appreciated that modifications and/or additions may be made to the equaliser and method of calculating filter coefficients for an equaliser without departing from the spirit or ambit of the present invention described herein.

This application is based upon and claims the benefit of priority from Australian patent application No. 2006907316, filed on December 28, 2006, the disclosure of which is incorporated herein in its entirety by reference.

CLAIMS

1. A method for performing data equalisation in a communication receiver forming part of a communication system with receive diversity, the method including the steps of:
- 5 (a) for each i -th antenna, calculating a channel response matrix H_i from multi-path channel estimates;
- (b) calculating a channel gain matrix G from the channel response matrices H_i and a scalar noise factor β ;
- 10 (c) calculating the middle column c_0 of the inverse G^{-1} of the channel gain matrix G ;
- (d) for each i -th antenna, calculating a filter coefficient vector w_i from the middle column c_0 of the inverse G^{-1} of the channel gain matrix G and the Hermitian transpose H_i^H of the corresponding channel response matrix H_i ;
- 15 (e) filtering input data r_i received at each i -th antenna with the corresponding filter coefficient vector w_i ;
- (f) despreading the filtered input data from each i -th antenna; and
- 20 (g) combining the despread data from all antennas to obtain received equalised data.
2. A method according to claim 1, wherein step (c) includes:
- (h) performing a Cholesky decomposition of the channel gain matrix G into a lower triangular matrix L and an upper triangular matrix U ;
- 25 (i) performing forward substitution on the lower triangular matrix L to calculate a column vector d ; and
- (j) performing backward substitution on the column vector d and the Hermitian transpose L^H of the lower triangular matrix L to
- 30

calculate the middle column c_0 of the inverse G^{-1} of the channel gain matrix G .

3. A method according to either one of claims 1 or 2, wherein
5 the channel gain matrix G to be inverted is calculated from the expression

$$G = \sum_i \hat{H}_i^H \hat{H}_i + \tilde{\beta} I$$

where I is the identity matrix.

- 10 4. A chip equaliser for use in a communication receiver forming part of a communication system with receive diversity, the chip equaliser including one or more computational blocks for implementing a method according to any one of the preceding claims.

FIG. 1

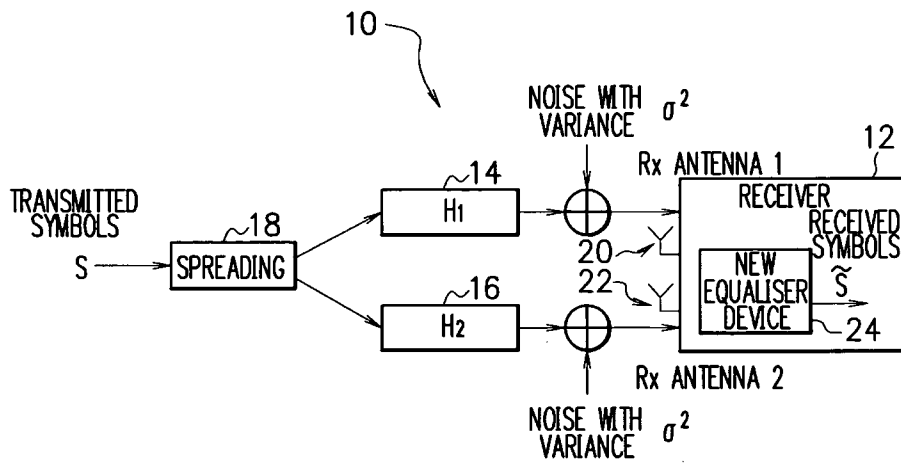


FIG. 2

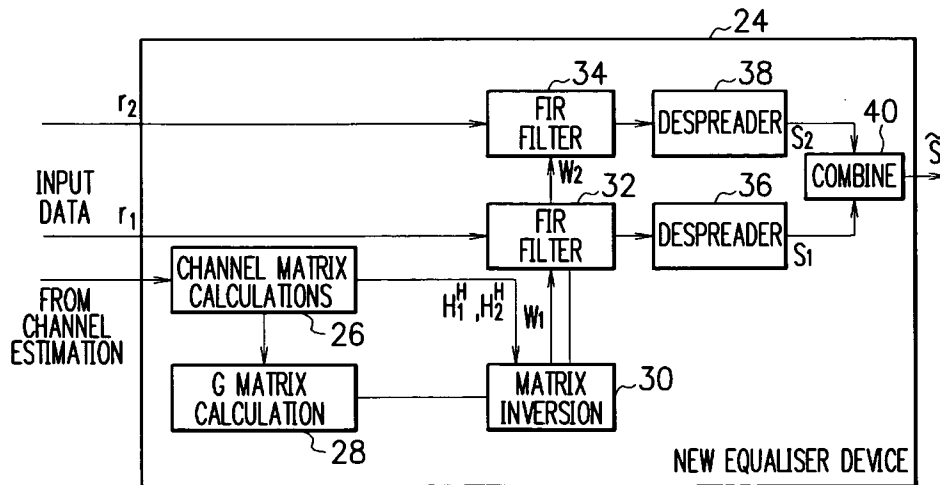


FIG. 3

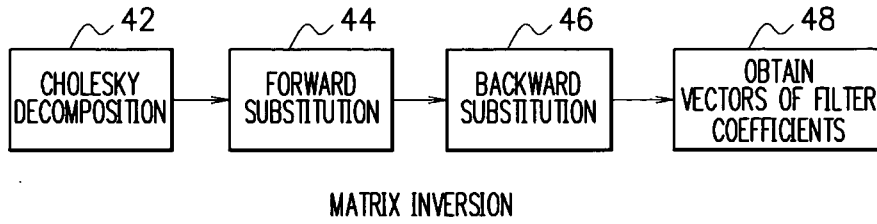


FIG. 4

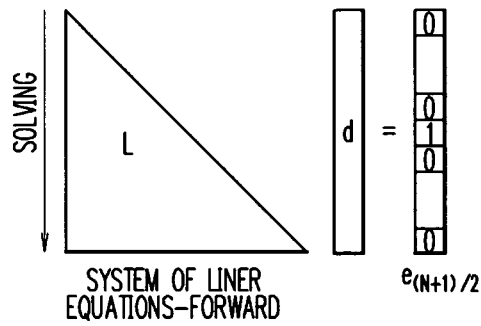
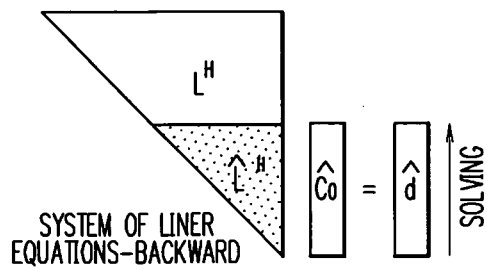


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

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A. CLASSIFICATION OF SUBJECT MATTER		
Int.Cl. H04B7/08 (2006.01) i, H04B7/005 (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)		
Int.Cl. H04B7/08, H04B7/005		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2008 Registered utility model specifications of Japan 1996-2008 Published registered utility model applications of Japan 1994-2008		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2006/016722 A1 (NEC CORPORATION) 2006.02.16, page 3, line 5 - page 5, line 2, Fig 3, Fig4 & EP 1776814 A1 & CN 1977504 A	1-4
Y	WO 2003/047032 A1 (INTERDIGITAL TECHNOLOGY CORPORATION) 2003.06.05, [0029]-[0030] & JP 2005-510928 A & EP 1449275 A1 & US 2007-121747 A1	1-4
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> 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		
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International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 97/41647 A1 (SIEMENS AG) 1997.11.06, page 17, line 4 - page 21, line 20, Fig 1 & JP 2000-509580 A & US 6307851 B1 & EP 895683 A1	1-4
A	WO 2002/060082 A2 (INTERDIGITAL TECHNOLOGY CORPORATION) 2002.08.01, [0022]-[0030] & JP 2004-531109 A & EP 1560347 A1 & US 2002-136188 A1	1-4
A	Karimi.H.R., EFFICIENT MULTI-RATE MULTI-USER DETECTION FOR THE ASYNCHRONOUS WCDMA UPLINK, 1999 IEEE 50TH VEHICULAR TECHNOLOGY CONFERENCE, 1999.09.22, Volume 1, Page(s):593 - 597	1-4