

first zero-forcing solution s_1 and a second zero-forcing solution s_2 , wherein modified channel gain matrix $(H'H)^{-1}H'$ is calculated from a product of an inverse of a product of a conjugate transpose of the channel gain matrix H' and the channel gain matrix H , and a conjugate transpose of the channel gain matrix H' ;

for a second QAM constellation point vector c_2 having a n number of constellation points therein, obtaining a n number of soft estimates $c_{1\text{soft}}$ based at least on the upper triangular matrix R , the first zero-forcing solution s_1 and the second QAM constellation point vector c_2 ;

slicing the n number of soft estimates $c_{1\text{soft}}$ to produce a n number of hard decision results $c_{1\text{chol}}$ corresponding to the second QAM constellation point vector c_2 ; and

calculating a plurality of distance metrics D , which comprises:

for each constellation point from at least some of the n number of constellation points comprised in the second QAM constellation point vector c_2 , calculating a distance metric based at least on

the upper triangular matrix R ,

the second zero-forcing solution s_2 ,

the each constellation point comprised in the second QAM constellation point vector c_2 ,

a corresponding hard decision result from the n number of hard decision result $c_{1\text{chol}}$, and

the noise variance σ^2 .

With reference to the first aspect, in a first possible implementation manner of the first aspect, the method further comprises:

identifying a minimum distance metric $D_{\min}$ from the plurality of distance metrics D ;

using the identified minimum distance metric $D_{\min}$, identifying a corresponding QAM constellation point from the second QAM constellation point vector c_2 as an estimated transmitted signal x_2 .

apply a modified channel gain matrix $(H'H)^{-1}H'$ to the received signal vector y to produce a zero-forcing solution vector s which at least comprises a first zero-forcing solution s_1 and a second zero-forcing solution s_2 , wherein modified channel gain matrix $(H'H)^{-1}H'$ is calculated from a product of an inverse of a product of a conjugate transpose of the channel gain matrix H' and the channel gain matrix H , and a conjugate transpose of the channel gain matrix H' ;
a distance calculation and signal estimation module configured to:

for a second QAM constellation point vector c_2 having a n number of constellation points therein, obtain a n number of soft estimates $c_{1\text{soft}}$ based at least on the upper triangular matrix R , the first zero-forcing solution s_1 and the second QAM constellation point vector c_2 ;

slice the n number of soft estimates $c_{1\text{soft}}$ to produce a n number of hard decision results $c_{1\text{chol}}$ corresponding to the second QAM constellation point vector c_2 ; and

calculate a plurality of distance metrics D , which comprises:

for each constellation point from at least some of the n number of constellation points comprised in the second QAM constellation point vector c_2 , calculate a distance metric based at least on the upper triangular matrix R , the second zero-forcing solution s_2 , the each constellation point comprised in the second QAM constellation point vector c_2 , a corresponding hard decision result from the n number of hard decision result $c_{1\text{chol}}$, and the noise variance σ^2 .

According to a third aspect of the invention, an equalizer for implementing maximum likelihood detection in a wireless MIMO channel having a transmitted signal vector x and a received signal vector y is provided. The equalizer comprises:

a processor and a storage medium communicably coupled thereto, wherein the storage medium is configured to store instructions to be executed by the processor, wherein the processor is configured to: perform the steps described in relation to the first aspect of the invention.

In block 112, the n number of soft estimates $c_{1\text{soft}}$ is sliced to produce a n number of hard decision results $c_{1\text{chol}}$ corresponding to the second QAM constellation point vector c_2 . The n number of hard decision results $c_{1\text{chol}}$ are calculated by Equation 8. After this slicing step, a unique hard decision result, i.e. slicer $\{c_1\}$, is obtained for each constellation point of the second QAM constellation point vector c_2 , without compromising the search for the minimum distance metrics.

In block 114, a plurality of distance metrics D are ascertained or calculated by the following step(s): for each constellation point comprised in the second QAM constellation point vector c_2 , calculating a distance metric based at least on: the upper triangular matrix R , the second zero-forcing solution s_2 , the each constellation point comprised in the second QAM constellation point vector c_2 , a corresponding hard decision result from the n number of hard decision result $c_{1\text{chol}}$, and the noise variance σ^2 . The distance metrics D are calculated by Equation 6.

From Equation 6, each combination of c_2 has a unique corresponding c_1 . Therefore the total number of D is equal to the number of constellation points, e.g. 64 for 64QAM.

In block 116, a minimum distance metric $D_{\min}$ is identified from the plurality of distance metrics D is identified.

In block 118, using the identified minimum distance metric from block 116, a corresponding QAM constellation point from the second QAM constellation point vector c_2 as an estimated transmitted signal x_2 is identified.

It is to be appreciated that some of the above sequence may be interchanged or modified, for example, block 106 may take place prior to blocks 102 and 104.

It is to be appreciated that the identified minimum metrics $D_{\min}$ (from block 116) may be applied in two ways: either as hard decision solution to x , or as soft decision solution to x . Hard decision solution to x is the corresponding $[c_1 \ c_2]$ to $D_{\min}$. Soft decision solution to x is computed from $D_{\min}$ from known techniques in the art.

It is to be appreciated that a smaller set of distance metrics may be ascertained or calculated in block 114 to reduce complexity. To this purpose, using the result of zero-forcing from block 108, i.e. second zero-forcing solution s_2 , a first constellation point corresponding to the second zero-forcing solution s_2 and a

Claims

1. An equalization method for maximum likelihood detection in a wireless MIMO channel having a transmitted signal vector x and a received signal vector y , the method comprising:

obtaining a channel gain matrix H and a noise variance σ^2 ;

obtaining an upper triangular matrix R and a constant beta value β by applying Cholesky decomposition to a product of the channel gain matrix H and a conjugate transpose of the channel gain matrix H' ;

obtaining the received signal vector y which comprises received signals from the MIMO channel;

applying a modified channel gain matrix $(H'H)^{-1}H'$ to the received signal vector y to produce a zero-forcing solution vector s which at least comprises a first zero-forcing solution s_1 and a second zero-forcing solution s_2 , wherein modified channel gain matrix $(H'H)^{-1}H'$ is calculated from a product of an inverse of a product of a conjugate transpose of the channel gain matrix H' and the channel gain matrix H , and a conjugate transpose of the channel gain matrix H' ;

for a second QAM constellation point vector c_2 having a n number of constellation points therein, obtaining a n number of soft estimates $c_{1\text{soft}}$ based at least on the upper triangular matrix R , the first zero-forcing solution s_1 and the second QAM constellation point vector c_2 ;

slicing the n number of soft estimates $c_{1\text{soft}}$ to produce a n number of hard decision results $c_{1\text{chol}}$ corresponding to the second QAM constellation point vector c_2 ; and

calculating a plurality of distance metrics D , which comprises:

for each constellation point from at least some of the n number of constellation points comprised in the second QAM constellation point vector c_2 , calculating a distance metric based at least on the upper triangular matrix R , the second zero-forcing solution s_2 , the each constellation point comprised in the second QAM constellation point vector c_2 , a corresponding hard decision result from the n number of hard decision result $c_{1\text{chol}}$, and the noise variance σ^2 .

obtain the received signal vector y which comprises received signals from the MIMO channel;

a zero-forcing module configured to:

5 apply a modified channel gain matrix $(H'H)^{-1}H'$ to the received signal vector y to produce a zero-forcing solution vector s which at least comprises a first zero-forcing solution s_1 and a second zero-forcing solution s_2 , wherein modified channel gain matrix $(H'H)^{-1}H'$ is calculated from a product of an inverse of a product of a conjugate transpose of the channel gain matrix H' and the channel gain matrix H , and a conjugate transpose of the channel gain matrix H' ;

a distance calculation and signal estimation module configured to:

15 for a second QAM constellation point vector c_2 having a n number of constellation points therein, obtain a n number of soft estimates $c_{1\text{soft}}$ based at least on the upper triangular matrix R , the first zero-forcing solution s_1 and the second QAM constellation point vector c_2 ;

slice the n number of soft estimates $c_{1\text{soft}}$ to produce a n number of hard decision results $c_{1\text{chol}}$ corresponding to the second QAM constellation point vector c_2 ; and

20 calculate a plurality of distance metrics D , which comprises:

25 for each constellation point from at least some of the n number of constellation points comprised in the second QAM constellation point vector c_2 , calculate a distance metric based at least on the upper triangular matrix R , the second zero-forcing solution s_2 , the each constellation point comprised in the second QAM constellation point vector c_2 , a corresponding hard decision result from the n number of hard decision result $c_{1\text{chol}}$, and the noise variance σ^2 .

7. The equalizer of claim 6, wherein the distance calculation and signal estimation module is further configured to:

30 identify a minimum distance metric D_{min} from the plurality of distance metrics D ;

apply a modified channel gain matrix $(H'H)^{-1}H'$ to the received signal vector y to produce a zero-forcing solution vector s which at least comprises a first zero-forcing solution s_1 and a second zero-forcing solution s_2 , wherein modified channel gain matrix $(H'H)^{-1}H'$ is calculated from a product of an inverse of a product of a conjugate transpose of the channel gain matrix H' and the channel gain matrix H , and a conjugate transpose of the channel gain matrix H' ;

for a second QAM constellation point vector c_2 having a n number of constellation points therein, obtain a n number of soft estimates $c_{1\text{soft}}$ based at least on the upper triangular matrix R , the first zero-forcing solution s_1 and the second QAM constellation point vector c_2 ;

slice the n number of soft estimates $c_{1\text{soft}}$ to produce a n number of hard decision results $c_{1\text{chol}}$ corresponding to the second QAM constellation point vector c_2 ; and

calculate a plurality of distance metrics D , which comprises:

for each constellation point from at least some of the n number of constellation points comprised in the second QAM constellation point vector c_2 , calculate a distance metric based at least on the upper triangular matrix R , the second zero-forcing solution s_2 , the each constellation point comprised in the second QAM constellation point vector c_2 , a corresponding hard decision result from the n number of hard decision result $c_{1\text{chol}}$, and the noise variance σ^2 .

12. The equalizer of claim 11, wherein the processor is further configured to:

identify a minimum distance metric $D_{\min}$ from the plurality of distance metrics D ;

using the identified minimum distance metric $D_{\min}$, identify a corresponding QAM constellation point from the second QAM constellation point vector c_2 as an estimated transmitted signal x_2 .

13. The equalizer of claim 11 or 12, wherein the at least some of the n number of constellation points include a first constellation point corresponding to the second