

SUMMARY

[0004] In general, examples of the present disclosure provide a solution for Uplink Control Information (UCI) design.

[0004a] In an aspect, there is a method comprising determining (510), at a terminal device (120), a matrix $\widetilde{\mathbf{W}}_2$ comprising linear combination coefficients for a pre-coder matrix indicator, PMI, matrix, wherein:

the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size $2L$, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and represents components of a frequency domain orthogonal basis of size M , and matrix $\widetilde{\mathbf{W}}_2$ is a matrix of size $2L \times M$ and has rows and columns corresponding to spatial components and frequency components, respectively; and wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 ;

characterized by

determining a shifted matrix by shifting (520) the frequency components of matrix $\widetilde{\mathbf{W}}_2$ circularly, such that a maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$ is located in a frequency component with a predetermined index;

generating (530) a strongest coefficient indicator with $\lfloor \log_2 2L \rfloor$ bits, based on the index of the spatial component associated with the maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$; and

transmitting (540), to a network device (110), uplink control information comprising the strongest coefficient indicator and locations and values of non-zero coefficients of the shifted matrix, wherein the transmitted non-zero coefficients exclude the maximum coefficient.

[0004b] In an aspect, there is method comprising receiving (610), at a network device (110) and from a terminal device (120), uplink control information comprising a strongest coefficient indicator and locations and values of non-zero coefficients of a matrix $\widetilde{\mathbf{W}}_2$ for a pre-coder matrix indicator, PMI, matrix, wherein:

the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size $2L$, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and represents components of a frequency domain orthogonal basis of size M , matrix $\widetilde{\mathbf{W}}_2$ is a matrix of size $2L \times M$ and has rows and columns corresponding to spatial components and frequency components, respectively, wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 , and

wherein the received non-zero coefficients exclude a maximum coefficient;

characterized in that

the received strongest coefficient indicator with $\lfloor \log_2 2L \rfloor$ bits is based on the index of a spatial component associated with a maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$, and in that the method comprises:

determining (620) state information of the channel, wherein a coefficient of matrix

$\widetilde{\mathbf{W}}_2$, at a position with the spatial component indicated by the strongest coefficient indicator and with a frequency component determined by a predetermined index, assumes a preconfigured value obtained by applying a common scaling to the coefficients of the matrix $\widetilde{\mathbf{W}}_2$.

[0004c] In an aspect, there is a terminal device comprising at least one processor; and
at least one memory including computer program codes;

the at least one memory and the computer program codes are configured to, with the at least one processor, cause the terminal device at least to:

determine a matrix $\widetilde{\mathbf{W}}_2$ comprising linear combination coefficients, for a pre-coder matrix indicator, PMI, matrix, wherein:

the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size $2L$, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and represents components of a frequency domain orthogonal basis of size M , and the matrix $\widetilde{\mathbf{W}}_2$ is a matrix of size $2L \times M$ and has rows and columns corresponding to spatial components and frequency components, respectively; and wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 ;

characterized in that the terminal device is caused to

determine a shifted matrix by shifting the frequency components of matrix $\widetilde{\mathbf{W}}_2$ circularly, such that a maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$ is located in a frequency component with a predetermined index;

generate a strongest coefficient indicator with $\lceil \log_2 2L \rceil$ bits, based on the index of the spatial component associated with the maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$; and

transmit, to a network device (110), uplink control information comprising the strongest coefficient indicator and locations and values of non-zero coefficients of the shifted matrix, wherein the transmitted non-zero coefficients exclude the maximum coefficient.

[0004d] In an aspect, there is a network device comprising at least one processor; and
at least one memory including computer program codes;

the at least one memory and the computer program codes are configured to, with the at least one processor, cause the network device at least to:

receive, from a terminal device (120), uplink control information comprising a strongest coefficient indicator and locations and values of non-zero coefficients of a matrix $\widetilde{\mathbf{W}}_2$ for a pre-coder matrix indicator, PMI, matrix, wherein:

the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size $2L$, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and

represents components of a frequency domain orthogonal basis of size M, matrix $\widetilde{W}_2$ is a matrix of size $2L \times M$ and has rows and columns corresponding to spatial components and frequency components, respectively, wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 , and

wherein the received non-zero coefficients exclude a maximum coefficient;

characterized in that

the received strongest coefficient indicator with $\lceil \log_2 2L \rceil$ bits is based on the index of a spatial component associated with a maximum coefficient of matrix $\widetilde{W}_2$, and in that the device is caused to:

determine state information of the channel, wherein a coefficient of matrix $\widetilde{W}_2$ assumes a value of 1 at a position determined by the strongest coefficient indicator and a predetermined index of the matrix $\widetilde{W}_2$.

[0005] In an example, there is provided a method. The method comprises determining, at a terminal device, a matrix comprising a set of non-zero linear combination coefficients for quantizing a channel between the terminal device and a network device, the matrix having spatial components and frequency components; shifting the frequency components of the matrix circularly, such that a target coefficient of the set of non-zero linear combination coefficients is located in a frequency component with a predetermined index of the frequency components in a shifted matrix; generating a first indication indicating the spatial component associated with the target coefficient in the matrix; and transmitting, to the network device, uplink control information comprising the first indication.

[0006] In an example, there is provided a method. The method comprises receiving, at a network device and from a terminal device, uplink control information comprising a first indication, the first indication indicating spatial components associated with a target coefficient in a matrix comprising a set of non-zero linear combination coefficients for quantizing a channel between the terminal device and the network device, the matrix having the spatial components and frequency components; and determining state information of the channel based on the uplink control information.

[0007] In an example, there is provided a device. The device comprises at least one processor; and at least one memory including computer program codes; the at least one memory and the computer program codes are configured to, with the at least one processor, cause the device at least to determine, at a terminal device, a matrix comprising a set of non-zero linear combination coefficients for quantizing a channel between the terminal device and a network device, the matrix having spatial components and frequency components; shift the frequency components of the matrix circularly, such that a target coefficient of the set of non-

zero linear combination coefficients is located in a frequency component with a predetermined index of the frequency components in a shifted matrix; generate a first indication indicating the spatial component associated with the target coefficient in the matrix; and transmit, to the network device, uplink control information comprising the first indication.

[0008] In an example, there is provided a device. The device comprises at least one processor; and at least one memory including computer program codes; the at least one memory and the computer program codes are configured to, with the at least one processor, cause the device at least to receive, at a network device and from a terminal device, uplink control information comprising a first indication, the first indication indicating spatial components associated with a target coefficient in a matrix comprising a set of non-zero linear combination coefficients for quantizing a channel between the terminal device and the network device, the matrix having the spatial components and frequency components; and determine state information of the channel based on the uplink control information..

[0009] In an example, there is provided an apparatus comprises means for determining, at a terminal device, a matrix comprising a set of non-zero linear combination coefficients for quantizing a channel between the terminal device and a network device, the matrix having spatial components and frequency components; means for shifting the frequency components of the matrix circularly, such that a target coefficient of the set of non-zero linear combination coefficients is located in a frequency component with a predetermined index of the frequency components in a shifted matrix; means for generating a first indication indicating the spatial component associated with the target coefficient in the matrix; and means for transmitting, to the network device, uplink control information comprising the first indication.

[0010] In an example, there is provided an apparatus comprising means for receiving, at a network device and from a terminal device, uplink control information comprising a first indication, the first indication indicating spatial components associated with a target coefficient in a matrix comprising a set of non-zero linear combination coefficients for quantizing a channel between the terminal device and the network device, the matrix having the spatial components and frequency components; and means for determining state information of the channel based on the uplink control information.

[0011] In an example, there is provided a computer readable medium having a computer program stored thereon which, when executed by at least one processor of a device, causes the device to carry out the method according to the first aspect.

[0012] In an example, there is provided a computer readable medium having a computer program stored thereon which, when executed by at least one processor of a device, causes the device to carry out the method according to the second aspect.

WHAT IS CLAIMED IS:

1. A method, comprising:

Determining (510), at a terminal device (120), a matrix $\widetilde{\mathbf{W}}_2$ comprising linear combination coefficients for a pre-coder matrix indicator, PMI, matrix, wherein:

5 the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size $2L$, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and represents components of a frequency domain orthogonal basis of size M , and matrix $\widetilde{\mathbf{W}}_2$ is a matrix of size $2L \times M$ and has rows and columns corresponding to spatial components and frequency components, respectively; and wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 ;

characterized by

15 determining a shifted matrix by shifting (520) the frequency components of matrix $\widetilde{\mathbf{W}}_2$ circularly, such that a maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$ is located in a frequency component with a predetermined index;

generating (530) a strongest coefficient indicator with $\lceil \log_2 2L \rceil$ bits, based on the index of the spatial component associated with the maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$; and

20 transmitting (540), to a network device (110), uplink control information comprising the strongest coefficient indicator and locations and values of non-zero coefficients of the shifted matrix, wherein the transmitted non-zero coefficients exclude the maximum coefficient.

2. The method of claim 1, wherein determining the matrix $\widetilde{\mathbf{W}}_2$ comprises:

receiving downlink control information received from the network device;

25 obtaining a resource indication associated with the spatial components and the frequency components; and

determining the matrix based on the downlink control information and the resource indication.

30 3. The method of claim 1, wherein shifting the frequency components comprises:

determining indices of the frequency components;

determining a reference index from the indices of the frequency components, the

reference index indicating a frequency component associated with the maximum coefficient in the matrix; and

shifting the frequency components based on the indices of the frequency components, the predetermined index and the reference index.

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4. The method of claim 1, further comprising:

determining, based on the shifted matrix, a bitmap indicating the locations of non-zero linear combination coefficients in the shifted matrix; and

transmitting the uplink control information comprising the bitmap.

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5. The method of claim 1, further comprising:

generating, based on the predetermined index and the frequency components, a second indication indicating a frequency range associated with a subset of the frequency components;

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transmitting the uplink control information comprising the second indication.

6. The method of claim 5, wherein generating the second indication comprises:

determining, from the frequency components, a maximum frequency component associated with the predetermined index;

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selecting, from the frequency components, the subset of the frequency components excluding the maximum frequency component;

determining indices of the subset of the frequency components after the shifting; and

generating the second indication based on the indices of the subset of the frequency component.

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7. A method, comprising:

receiving (610), at a network device (110) and from a terminal device (120), uplink control information comprising a strongest coefficient indicator and locations and values of non-zero coefficients of a matrix $\widetilde{\mathbf{W}}_2$ for a pre-coder matrix indicator, PMI, matrix, wherein:

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the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size $2L$, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and represents components of a frequency domain orthogonal basis of size M , matrix $\widetilde{\mathbf{W}}_2$ is a matrix of size

2L x M and has rows and columns corresponding to spatial components and frequency components, respectively, wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 , and

wherein the received non-zero coefficients exclude a maximum coefficient;

5 characterized in that

the received strongest coefficient indicator with $\lceil \log_2 2L \rceil$ bits is based on the index of a spatial component associated with a maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$, and in that the method comprises:

determining (620) state information of the channel, wherein a coefficient of matrix $\widetilde{\mathbf{W}}_2$, at a position with the spatial component indicated by the strongest coefficient indicator and with a frequency component determined by a predetermined index, assumes a preconfigured value obtained by applying a common scaling to the coefficients of the matrix $\widetilde{\mathbf{W}}_2$.

15 8. A terminal device (120), comprising:

at least one processor; and

at least one memory including computer program codes;

the at least one memory and the computer program codes are configured to, with the at least one processor, cause the terminal device at least to:

20 determine a matrix $\widetilde{\mathbf{W}}_2$ comprising linear combination coefficients, for a pre-coder matrix indicator, PMI, matrix, wherein:

the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size 2L, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and represents components of a frequency domain orthogonal basis of size M, and the matrix $\widetilde{\mathbf{W}}_2$ is a matrix of size 2L x M and has rows and columns corresponding to spatial components and frequency components, respectively; and wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 ;

characterized in that the terminal device is caused to

30 determine a shifted matrix by shifting the frequency components of matrix $\widetilde{\mathbf{W}}_2$ circularly, such that a maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$ is located in a frequency component with a predetermined index;

generate a strongest coefficient indicator with $\lceil \log_2 2L \rceil$ bits, based on the

index of the spatial component associated with the maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$; and
transmit, to a network device (110), uplink control information comprising the
strongest coefficient indicator and locations and values of non-zero coefficients of the shifted
matrix, wherein the transmitted non-zero coefficients exclude the maximum coefficient.

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9. The terminal device of claim 8, the device is caused to determine the matrix $\widetilde{\mathbf{W}}_2$
by:

receiving downlink control information received from the network device;

obtaining a resource indication associated with the spatial components and the

10 frequency components; and

determining the matrix based on the downlink control information and the resource
indication.

10 10. The terminal device of claim 8, the device is caused to shift the frequency
components by:

determining indices of the frequency components;

determining a reference index from the indices of the frequency components, the
reference index indicating a frequency component associated with the maximum coefficient
in the matrix;

20 shifting the frequency components based on the indices of the frequency
components, the predetermined index and the reference index.

11. The terminal device of claim 8, the device is further caused to:

determine, based on the shifted matrix, a bitmap indicating the locations of non-zero

25 linear combination coefficients in the shifted matrix; and

transmit the uplink control information comprising the bitmap.

12. The terminal device of claim 8, the device is further caused to:

generate, based on the predetermined index and the frequency components, a second

30 indication indicating a frequency range associated with a subset of the frequency components;

transmit the uplink control information comprising the second indication.

13. The terminal device of claim 12, the device is caused to generate the second

indication by:

determining, from the frequency components, a maximum frequency component associated with the predetermined index;

selecting, from the frequency components, the subset of the frequency components

5 excluding the maximum frequency component;

determining indices of the subset of the frequency components after shifting; and

generating the second indication based on the indices of the subset of the frequency component.

10 14. A network device (110), comprising:

at least one processor; and

at least one memory including computer program codes;

the at least one memory and the computer program codes are configured to, with the at least one processor, cause the network device at least to:

15 receive, from a terminal device (120), uplink control information comprising a strongest coefficient indicator and locations and values of non-zero coefficients of a matrix $\widetilde{\mathbf{W}}_2$ for a pre-coder matrix indicator, PMI, matrix, wherein:

the PMI matrix is represented by $\mathbf{W} = \mathbf{W}_1 \widetilde{\mathbf{W}}_2 \mathbf{W}_f^H$,

20 matrix $\mathbf{W}_1$ is a matrix of size $2N_1N_2 \times 2L$ and represents components of a spatial domain orthogonal basis of size $2L$, matrix $\mathbf{W}_f$ is a matrix of size $N_3 \times M$ and represents components of a frequency domain orthogonal basis of size M , matrix $\widetilde{\mathbf{W}}_2$ is a matrix of size $2L \times M$ and has rows and columns corresponding to spatial components and frequency components, respectively, wherein $N_1 \times N_2$ is the number of antenna ports, N_3 is the number of configured PMI sub-bands and M is less than N_3 , and

25 wherein the received non-zero coefficients exclude a maximum coefficient; characterized in that

the received strongest coefficient indicator with $\lceil \log_2 2L \rceil$ bits is based on the index of a spatial component associated with a maximum coefficient of matrix $\widetilde{\mathbf{W}}_2$, and in that the device is caused to:

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determine state information of the channel, wherein a coefficient of matrix $\widetilde{\mathbf{W}}_2$ assumes a value of 1 at a position determined by the strongest coefficient indicator and a predetermined index of the matrix $\widetilde{\mathbf{W}}_2$.

15. A non-transitory computer readable medium comprising program instructions for causing an apparatus to perform at least the method of any of claims 1-6.

5 16. A non-transitory computer readable medium comprising program instructions for causing an apparatus to perform at least the method of claim 7.