

CLAIMS

What is claimed is:

1. A method, comprising:
 - determining a precoding matrix indicator by a user equipment, comprising:
 - determining an intermediate set of vectors from a frequency-domain codebook;
 - forming a subset of the intermediate set of vectors;
 - mapping the subset of vectors to a combinatorial indicator; and
 - forming the precoding matrix indicator at least from the combinatorial indicator;
 - and
 - sending by the user equipment the precoding matrix indicator toward a wireless network.

2. The method of claim 1, wherein:
 - determining the intermediate set of vectors comprises:
 - selecting the intermediate set of vectors based on an initial value, $M_{initial}$, where $M_{initial}$ is selected from a set of nonpositive values $\{-2M + 1, -2M + 2, \dots, 0\}$, wherein there are $2M$ vectors in the intermediate set of vectors, wherein the indices of the intermediate set of vectors are defined as $IntS = \{(M_{initial} + i) \bmod N_3, i = 0, 1, \dots, 2M - 1\}$, where N_3 is a size of the frequency-domain codebook of vectors;
 - forming the subset of the intermediate set of vectors further comprises:
 - selecting the subset of M vectors from the intermediate set of $2M$ vectors;
 - mapping the subset of vectors to the combinatorial indicator comprises:
 - applying a first map to nonzero indices of the M vectors inside the intermediate set to obtain first intermediate indices defined between one and $2M-1$;
 - applying a second map to the first intermediate indices to obtain second intermediate indices defined between zero and $2M-2$;
 - using the second intermediate indices as an argument in a calculation of combinatorial coefficients to calculate the combinatorial indicator; and

forming the precoding matrix indicator at least from the combinatorial indicator further comprises:

forming the precoding matrix indicator from an index of the initial value $M_{initial}$, wherein vectors with nonzero indices are identified by the index of the initial value $M_{initial}$ and the combinatorial indicator.

3. The method of claim 2, wherein applying the first map comprises separating the nonzero indices of the M vectors inside the intermediate set into first and second groups depending on the initial value of the intermediate set and subtracting a first preconfigured quantity from the indices of the second group, according to the following function:

$$n_l^{(f)} = \begin{cases} n_{3,l}^{(f)} & n_{3,l}^{(f)} \leq M_{initial} + 2M - 1 \\ n_{3,l}^{(f)} - (N_3 - 2M) & n_{3,l}^{(f)} > M_{initial} + N_3 - 1 \end{cases},$$

wherein $n_{3,l}^{(f)}$ are the nonzero indices of the M vectors for layer l , for $f = 1, 2, \dots, M - 1$,

and where the nonzero values of $n_{3,l}^{(f)}$ are selected from a value set $\{1, 2, \dots, N_3 - 1\}$ associated to the vectors of the frequency-domain codebook.

4. The method of claim 2, wherein applying the second map comprises inverting a sign of the first intermediate indices and adding a second preconfigured quantity, according to the following function:

$$x_l^{(f)} = 2M - 1 - n_l^{(f)},$$

for first intermediate indices $n_l^{(f)}$ for $f = 1, 2, \dots, M - 1$ and for layer l .

5. The method of claim 2, wherein using the second intermediate indices as an argument in a calculation of combinatorial coefficients to calculate the combinatorial indicator comprises using the second intermediate indices as a first argument of combinatorial coefficients to calculate the combinatorial indicator associated with the vectors of nonzero index.

6. The method of any one of claims 2 to 5, wherein the initial value of the intermediate set is common for all reported layers, whereas the combinatorial indicator is specific for each reported layer.
7. The method of any one of the claims above, further comprising receiving by the user equipment and from the wireless network data that has had one or more codebook elements applied to the data based on the sent precoding matrix indicator.
8. A method, comprising:
receiving, at a base station, a precoding matrix indicator from a user equipment, the precoding matrix indicator comprising a combinatorial indicator that maps to a subset of vectors from a frequency-domain codebook; and
determining, using at least the received precoding matrix indicator, information from at least the frequency-domain codebook to apply to data for transmission toward the user equipment.
9. The method of claim 8, wherein the determining comprises:
obtaining first and second intermediate indices, wherein the second intermediate indices, $x_l^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , are obtained by performing an unranking procedure on the combinatorial indicator.
10. The method of claim 9, wherein:
the first intermediate indices, $n_l^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , are obtained from their respective second intermediate indices by inverting the following function:
$$x_l^{(f)} = 2M - 1 - n_l^{(f)}.$$
11. The method of any one of claims 9 or 10, wherein the precoding matrix indicator further comprises an index of an initial value, and wherein the determining comprises obtaining

nonzero indices of vectors $n_{3,l}^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , from their respective first intermediate indices by inverting the following function:

$$n_l^{(f)} = \begin{cases} n_{3,l}^{(f)} & n_{3,l}^{(f)} \leq M_{initial} + 2M - 1 \\ n_{3,l}^{(f)} - (N_3 - 2M) & n_{3,l}^{(f)} > M_{initial} + N_3 - 1 \end{cases},$$

where $M_{initial}$ is obtained from the index of the initial value, and where $n_{3,l}^{(f)}$ are associated to the vectors of the frequency-domain codebook.

12. The method of any one of claims 8 to 11 wherein the determining comprises obtaining at least from the vectors of the frequency-domain codebook corresponding to nonzero indices $n_{3,l}^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , precoding weights to apply to the data for transmission towards the user equipment.
13. The method of any one of claims 8 to 12, further comprising transmitting by the base station the data, having the information from at least the frequency-domain codebook applied, toward the user equipment.
14. A computer program, comprising code for performing the methods of any of claims 1 to 13, when the computer program is run on a computer.
15. The computer program according to claim 14, wherein the computer program is a computer program product comprising a computer-readable medium bearing computer program code embodied therein for use with the computer.
16. The computer program according to claim 14, wherein the computer program is directly loadable into an internal memory of the computer.
17. An apparatus, comprising means for performing:
determining a precoding matrix indicator by a user equipment, comprising:
determining an intermediate set of vectors from a frequency-domain codebook;

forming a subset of the intermediate set of vectors;
 mapping the subset of vectors to a combinatorial indicator; and
 forming the precoding matrix indicator at least from the combinatorial indicator;
 and
 sending by the user equipment the precoding matrix indicator toward a wireless network.

18. The apparatus of claim 17, wherein:

determining the intermediate set of vectors comprises:

selecting the intermediate set of vectors based on an initial value, $M_{initial}$, where
 $M_{initial}$ is selected from a set of nonpositive values $\{-2M + 1, -2M + 2, \dots, 0\}$, wherein there are $2M$ vectors in the intermediate set of vectors,
 wherein the indices of the intermediate set of vectors are defined as
 $IntS = \{(M_{initial} + i) \bmod N_3, i = 0, 1, \dots, 2M - 1\}$, where N_3 is a size
 of the frequency-domain codebook of vectors;

forming the subset of the intermediate set of vectors further comprises:

selecting the subset of M vectors from the intermediate set of $2M$ vectors;

mapping the subset of vectors to the combinatorial indicator comprises:

applying a first map to nonzero indices of the M vectors inside the intermediate
 set to obtain first intermediate indices defined between one and $2M-1$;

applying a second map to the first intermediate indices to obtain second
 intermediate indices defined between zero and $2M-2$;

using the second intermediate indices as an argument in a calculation of
 combinatorial coefficients to calculate the combinatorial indicator; and

forming the precoding matrix indicator at least from the combinatorial indicator further
 comprises:

forming the precoding matrix indicator from an index of the initial value $M_{initial}$,
 wherein vectors with nonzero indices are identified by the index of the
 initial value $M_{initial}$ and the combinatorial indicator.

19. The apparatus of claim 18, wherein applying the first map comprises separating the nonzero indices of the M vectors inside the intermediate set into first and second groups depending on the initial value of the intermediate set and subtracting a first preconfigured quantity from the indices of the second group, according to the following function:

$$n_l^{(f)} = \begin{cases} n_{3,l}^{(f)} & n_{3,l}^{(f)} \leq M_{\text{initial}} + 2M - 1 \\ n_{3,l}^{(f)} - (N_3 - 2M) & n_{3,l}^{(f)} > M_{\text{initial}} + N_3 - 1 \end{cases},$$

wherein $n_{3,l}^{(f)}$ are the nonzero indices of the M vectors for layer l , for $f = 1, 2, \dots, M - 1$,

and where the nonzero values of $n_{3,l}^{(f)}$ are selected from a value set $\{1, 2, \dots, N_3 - 1\}$ associated to the vectors of the frequency-domain codebook.

20. The apparatus of claim 18, wherein applying the second map comprises inverting a sign of the first intermediate indices and adding a second preconfigured quantity, according to the following function:

$$x_l^{(f)} = 2M - 1 - n_l^{(f)},$$

for first intermediate indices $n_l^{(f)}$ for $f = 1, 2, \dots, M - 1$ and for layer l .

21. The apparatus of claim 18, wherein using the second intermediate indices as an argument in a calculation of combinatorial coefficients to calculate the combinatorial indicator comprises using the second intermediate indices as a first argument of combinatorial coefficients to calculate the combinatorial indicator associated with the vectors of nonzero index.

22. The apparatus of any one of claims 18 to 21, wherein the initial value of the intermediate set is common for all reported layers, whereas the combinatorial indicator is specific for each reported layer.

23. The apparatus of any one of claims 17 to 22, further comprising means for receiving by the user equipment and from the wireless network data that has had one or more codebook elements applied to the data based on the sent precoding matrix indicator.
24. An apparatus, comprising means for performing:
receiving, at a base station, a precoding matrix indicator from a user equipment, the precoding matrix indicator comprising a combinatorial indicator that maps to a subset of vectors from a frequency-domain codebook; and
determining, using at least the received precoding matrix indicator, information from at least the frequency-domain codebook to apply to data for transmission toward the user equipment.
25. The apparatus of claim 24, wherein the determining comprises:
obtaining first and second intermediate indices, wherein the second intermediate indices, $x_l^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , are obtained by performing an unranking procedure on the combinatorial indicator.
26. The apparatus of claim 25, wherein:
the first intermediate indices, $n_l^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , are obtained from their respective second intermediate indices by inverting the following function:
$$x_l^{(f)} = 2M - 1 - n_l^{(f)}.$$
27. The apparatus of any one of claims 25 or 26, wherein the precoding matrix indicator further comprises an index of an initial value, and wherein the determining comprises obtaining nonzero indices of vectors $n_{3,l}^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , from their respective first intermediate indices by inverting the following function:

$$n_l^{(f)} = \begin{cases} n_{3,l}^{(f)} & n_{3,l}^{(f)} \leq M_{\text{initial}} + 2M - 1 \\ n_{3,l}^{(f)} - (N_3 - 2M) & n_{3,l}^{(f)} > M_{\text{initial}} + N_3 - 1 \end{cases},$$

where $M_{initial}$ is obtained from the index of the initial value, and where $n_{3,l}^{(f)}$ are associated to the vectors of the frequency-domain codebook.

28. The apparatus of any one of claims 24 to 27 wherein the determining comprises obtaining at least from the vectors of the frequency-domain codebook corresponding to nonzero indices $n_{3,l}^{(f)}$, for $f = 1, 2, \dots, M - 1$, and for layer l , precoding weights to apply to the data for transmission towards the user equipment.
29. The apparatus of any one of claims 24 to 28, further comprising means for transmitting by the base station the data, having the information from at least the frequency-domain codebook applied, toward the user equipment.
30. The apparatus of any of claims 17 to 29 wherein the means comprises:
at least one processor; and
at least one memory including computer program code, the at least one memory and computer program code configured to, with the at least one processor, cause the performance of the apparatus.
31. An apparatus, comprising:
one or more processors; and
one or more memories including computer program code,
wherein the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to perform operations comprising:
determining a precoding matrix indicator by a user equipment, comprising:
determining an intermediate set of vectors from a frequency-domain codebook;
forming a subset of the intermediate set of vectors;
mapping the subset of vectors to a combinatorial indicator; and

forming the precoding matrix indicator at least from the combinatorial indicator;
and
sending by the user equipment the precoding matrix indicator toward a wireless network.

32. An apparatus, comprising:
one or more processors; and
one or more memories including computer program code,
wherein the one or more memories and the computer program code are configured, with
the one or more processors, to cause the apparatus to perform operations
comprising:
receiving, at a base station, a precoding matrix indicator from a user equipment, the
precoding matrix indicator comprising a combinatorial indicator that maps to a
subset of vectors from a frequency-domain codebook; and
determining, using at least the received precoding matrix indicator, information from at
least the frequency-domain codebook to apply to data for transmission toward the
user equipment.