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, wherein there are 2M vectors in the intermediate set of vectors;

mapping the subset of vectors to a combinatorial indicator of order $M - 1$ and number $2M - 1$; 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 the indices of the intermediate set of vectors are defined as $IntS = \{(M_{initial} + i)\ mod\ N_3, i = 0,1, \dots, 2M - 1\}$, 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; and

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 claim 2, 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 claim 1, 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. 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:
determine 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, wherein there are 2M vectors in the intermediate set of vectors;
mapping the subset of vectors to a combinatorial indicator of order $M - 1$ and number $2M - 1$; and
forming the precoding matrix indicator at least from the combinatorial indicator; and
send by the user equipment the precoding matrix indicator toward a wireless network.

9. The apparatus of claim 8, wherein:
when determining the intermediate set of vectors, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to:

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

when forming the subset of the intermediate set of vectors, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to:

select the subset of M vectors from the intermediate set of 2M vectors;

when mapping the subset of vectors to the combinatorial indicator, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to:

apply 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;

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

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

when forming the precoding matrix indicator at least from the combinatorial indicator, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to:

form 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.

10. The apparatus of claim 9, wherein when applying the first map, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to separate 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 subtract 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 $f = 1,2, \ldots, M-1$, and where the nonzero values of $n_{3,l}^{(f)}$ are selected from a value set $\{1,2, \ldots, N_3 - 1\}$ associated to the vectors of the frequency-domain codebook.

11. The apparatus of claim 9, wherein when applying the second map, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to invert a sign of the first intermediate indices and add 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 $f = 1,2, \ldots M-1$ and for layer l.

12. The apparatus of claim 9, wherein when using the second intermediate indices as an argument in a calculation of combinatorial coefficients to calculate the combinatorial indicator, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to use the second intermediate indices as a first argument of combinatorial coefficients to calculate the combinatorial indicator associated with the vectors of nonzero index.

13. The apparatus of claim 9, wherein the initial value of the intermediate set is common for all reported layers, whereas the combinatorial indicator is specific for each reported layer.

14. The apparatus of claim 8, wherein the one or more memories and the computer program code are further configured, with the one or more processors, to cause the apparatus to:

receive 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.

15. 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:

receive, 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, wherein the combinatorial indicator is of order $M-1$ and number $2M-1$; and

determine, 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.

16. The apparatus of claim 15, wherein when determining, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to:

obtain first and second intermediate indices, wherein the second intermediate indices, $x_l^{(f)}$, for $f = 1,2, \ldots M-1$, and for layer l, are obtained by performing an unranking procedure on the combinatorial indicator.

17. The apparatus of claim 16, wherein:

the first intermediate indices, $n_l^{(f)}$, for $f = 1,2, \ldots M-1$, and for layer l, are obtained from their respective second intermediate indices by inverting the following function:

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

18. The apparatus of claim 16, wherein the precoding matrix indicator further comprises an index of an initial value, and wherein when determining, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to obtain nonzero indices of vectors $n_{3,l}^{(f)}$, for $f = 1,2, \ldots M-1$, 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.

19. The apparatus of claim 15, wherein when determining, the one or more memories and the computer program code are configured, with the one or more processors, to cause the apparatus to obtain at least from the vectors of the frequency-domain codebook corresponding to nonzero indices $n_{3,l}^{(f)}$, for $f = 1,2, \ldots M-1$, and for layer l, precoding weights to apply to the data for transmission towards the user equipment.

20. The apparatus of claim 15, wherein the one or more memories and the computer program code are further configured, with the one or more processors, to cause the apparatus to: transmit by the base station the data, having the information from at least the frequency-domain codebook applied, toward the user equipment.

21. A computer program product comprising a computer-readable storage medium bearing computer program code embodied therein for use with a computer, the computer program code comprising:

code for 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, wherein there are 2M vectors in the intermediate set of vectors;

mapping the subset of vectors to a combinatorial indicator of order $M - 1$ and number $2M - 1$; and

forming the precoding matrix indicator at least from the combinatorial indicator; and

code for sending by the user equipment the precoding matrix indicator toward a wireless network.