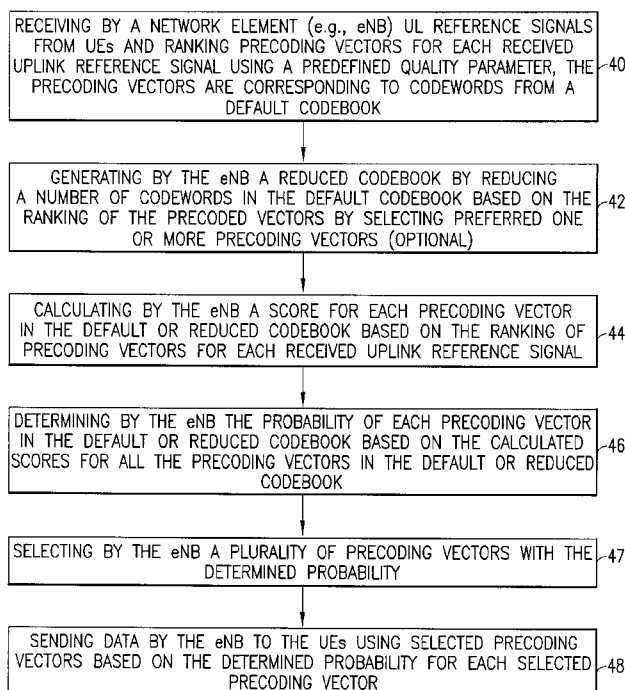




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[Continued on next page]

(54) **Title:** RANDOM PRECODER SELECTION

REPEAT STEPS 40-48

FIG.4

(57) **Abstract:** The specification and drawings present a new method, apparatus and software related product for precoding vector selection (e.g., in LTE wireless systems). Instead of cycling through all available precoding vectors, a network element such as eNB may select precoding vectors based on a prioritized distribution of precoding vectors within the cell using initialization with a default codebook. This ensures that preferred precoding vectors are selected more often than other precoding vectors. The method is of low-complexity and intended to ensure a reliable performance of devices in LTE networks.



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RANDOM PRECODER SELECTION

Technical Field

The exemplary and non-limiting embodiments of this invention relate generally to wireless
 5 communications and more specifically to precoder vector selection (e.g., in LTE systems).

Background Art

The following abbreviations that may be found in the specification and/or the drawing
 figures are defined as follows:

10

3GPP	third generation partnership project
CQI	channel quality indicator
CRS	common (cell-specific) reference signal
CSI	channel state information
15 CSI-RS	channel state information reference signal
DL	downlink
DMRS	demodulation reference signal (user specific)
E-UTRA	evolved universal terrestrial radio access
eNB, eNodeB	evolved node B /base station in an E-UTRAN system
20 ePDCCH	enhanced physical downlink control channel
eREG	eResource element group
E-UTRAN	evolved UTRAN (LTE)
LTE	long term evolution
LTE-A	long term evolution advanced
25 NCT	new carrier type
PDSCH	physical downlink shared channel
PUCCH	physical uplink control channel
PUSCH	physical uplink shared channel
PMI	precoding matrix index
30 PRB	physical resource block
RAN	radio access network
SCH	synchronization channel
SFBC	space-frequency block code
SNR	signal-to-noise ratio

	SINR	signal to interference plus noise ratio
	SRS	sounding reference signal
	UE	user equipment
	UL	uplink
5	ULA	uniform linear array
	UTRAN	universal terrestrial radio access network
	WG	working group

In LTE 3GPP Release-11, ePDCCH is supported using UE-specific demodulation reference signals (DMRS) instead of common reference signals (CRS), e.g., see 3GPP-RAN WG1 Meeting #68, R1-120109, Link level evaluation on E-PDCCH transmission schemes, CATT, February 6-10, 2012, Germany, and 3GPP-RAN WG1 Meeting #68, R1-120628, DM-RS Utilization of Diversity and Beamforming Schemes for ePDCCH, MediaTek Inc., February 6-10, 2012, Germany. In addition, in an upcoming 3GPP LTE Release 12, a new carrier type (NCT) will be introduced that will exclusively use DMRS for PDSCH demodulation. In both cases, it is assumed that the DMRS will be beamformed for each individual UE.

Summary

According to a first aspect of the invention, a method comprising: selecting, by a network element using a statistical predefined criterion, a plurality of precoding vectors with a probability determined for each selected precoding vector; and signaling by the network element to the user equipments using the selected precoding vectors based on the determined probability for each selected precoding vector.

According to a second aspect of the invention, an apparatus comprising: a processing system comprising at least one processor and a memory storing a set of computer instructions, in which the processing system is arranged to cause the apparatus to: selecting, using a statistical predefined criterion, a plurality of precoding vectors with a probability determined for each selected precoding vector; and signaling by the network element to the user equipments using the selected precoding vectors based on the determined probability for each selected precoding vector.

According to a third aspect of the invention, a computer program product comprising a computer readable medium bearing computer program code embodied herein for use with a computer, the computer program code comprising: code for selecting, by a network element

using a statistical predefined criterion, a plurality of precoding vectors with a probability using signals received from user equipments, determined for each selected precoding vector; and code for signaling by the network element to the user equipments using the selected precoding vectors based on the determined probability for each selected precoding vector.

5

Brief Description of the Drawings:

For a better understanding of the nature and objects of embodiments of the invention, reference is made to the following detailed description taken in conjunction with the following drawings, in which:

10 Figure 1 is a diagram demonstrating a cell with a non-uniform user distribution (e.g., with hot-spots);

Figure 2 is an example of a preferred precoding vector distribution for 4 transceivers with ULA antennas, according to an exemplary embodiment of the invention;

15 Figure 3 is an example of a preferred precoding vector distribution for 4 transceivers with 2 pairs of cross-pole antennas, according to an exemplary embodiment of the invention;

Figure 4 is a flow chart demonstrating an exemplary embodiment of the invention performed by an eNB;

Figure 5 is another flow chart demonstrating an exemplary embodiment of the invention performed by an eNB; and

20 Figure 6 is a block diagram of wireless devices for practicing exemplary embodiments of the invention.

Detailed Description

To support beamforming of the DMRS and associated control and data channels, two
25 approaches may be considered. First, the network can obtain knowledge of the propagation channels either explicitly (e.g., using a sounding reference signal SRS) or through an appropriate feedback (e.g., using a covariance matrix). Alternately, a UE can directly feedback a preferred precoding matrix indicator (PMI) to be used by the network. In certain situations, however, this is not possible (e.g., during initial attachment of the UE to a cell). Furthermore,
30 the channel estimates or feedback may be of poor quality in some cases and therefore unusable for beamforming. Therefore, a fallback mode is desirable. In previous 3GPP LTE releases, SFBC was used as the fallback mode, but this is not possible to support the beamforming of the DMRS due to the absence of the CRS.

One potential fallback mode may involve precoder cycling (i.e., random beamforming).

In this method, several predefined precoding vectors could be available (for example, 4 precoding vectors) and the network may cycle through the available precoding vectors (e.g., 0, 1, 2, 3, 0, 1, 2, 3,...). For instance, each precoding vector may be applied to one physical resource block or one eREG (eResource Element Group) depending on how the transmission is structured. This method then may be transparent to the UE and under exclusive implementation control of the eNB. It will not require any change to 3GPP specifications. However, simply cycling through all available precoding vectors may not be an optimal solution. This is because certain precoding vectors may be preferred over others. That can be due to, for example, cell deployments, user distribution, directional coverage, antenna configuration and other factors.

Figure 1 shows an example of different concentrations of UEs in a macro-cell 10 with eNB 11 where UEs in geographical areas 12 and 14 have high concentration, so that the UEs in the area 12 may select one preferred precoding vector, the UEs in the area 14 may select another preferred precoding vector, and the preferred precoding vectors for the UEs in the area 12 and 14 may be different than for other UEs, in the cell 10.

A new method, apparatus, and software related product (e.g., a computer readable memory) are presented for precoding vector selection (e.g., in LTE wireless systems). Instead of cycling through all available precoding vectors, a network element such as eNB may select precoding vectors based on a prioritized distribution of precoding vectors within the cell using initialization with a default codebook. This ensures that preferred precoding vectors are selected more often than other precoding vectors. The method is of low-complexity and intended to ensure a reliable performance of devices in LTE networks. The embodiments described herein are implementation-specific and are done exclusively at the network element (access point) such as eNB. According to embodiments of the invention, the network element may select, using a statistical predefined criterion, a plurality of precoding vectors with a determined probability based on information received from UEs, where the probability is determined for each selected precoding vector. Then the network element may send data/control signals to the UEs using selected plurality of the precoding vectors based on the determined probability for each selected precoding vector.

Figures 2 and 3 illustrate a preferred precoding vector distribution in a cell with different antenna configurations: for 4 transceivers with ULA antennas in Figure 2 and for 4 transceivers with two pairs of cross-pole antennas in Figure 3. The precoding vectors are selected from the 3GPP codebook for four transmit antennas.

From Figures 2 and 3, it can be ascertained that only a few vectors are preferred. For example, from Figure 2 it is seen that precoding vectors with indices 0, 1, 4, 5, 7, 8 are

preferred. Furthermore, a precoding vector with the index 1 is by far the most preferred precoding vector by users in the cell. Conversely, some precoding vectors are rarely selected. Similarly, in Figure 3 the precoding vector with the index 1 is also the most preferred precoding vector by users in the cell. Therefore, a simple cycling through all available precoding vectors is not an optimal way to select precoding vectors and can result in suboptimal performance, so that embodiments described herein can offer a better solution.

According to a **first embodiment**, the preferred precoding vectors may be determined/selected based on channel information knowledge. The network element (eNB) can start with a default codebook and collect statistics regarding the preferred precoding vectors within the codebook (the precoding vectors corresponds to codewords from the default codebook) using, for example, sounding reference signals (SRS) from the UEs in the cell. This can be done at the eNB once channel information is known (e.g., by selecting the precoding vector that will maximize SNR, SINR or throughput, etc.). In other words, the eNB may determine/rank, using the collected statistics from the UEs, a first preferred precoding vector with rank1p, a second preferred precoding vector with rank2p (i.e., next preferred if the first is not available), a third preferred precoding vector with rank3p, etc. for each SRS from the UE (see Table 1 for details as discussed below). This ranking may be performed by the eNB using a predefined quality parameter, e.g., by computing SNR, SINR or throughput for all available precoding vectors in the SRS.

Further, the eNB may determine/calculate a score of a given precoding vector based on collected statistics including, for example, how many times this precoding vector was the first, second, third, etc. vector. This score can be calculated using the following equation:

$$s_i = \sum_k w_k n_{k,i} \quad (1),$$

where s_i is a score for a vector i , w_k is a weight for k -th preferred vector and $n_{k,i}$ is a preferred vector count for the vector i . The Equation 1 may be further refined as a function time t . For example, if a weighted histogram is used, more weight may be assigned for recent subframes and less weight may be assigned for subframes in the past. Then the Equation 1 may be further modified, e.g., using a time scaling factor α , as follows:

$$s_i = \sum_k e^{-\alpha t} w_k n_{k,i} \quad (2).$$

Moreover, the eNB may determine/calculate a probability p_i of selecting a given precoding vector based on the determined vector scores as follows:

$$p_i = \frac{s_i}{\sum_l s_l} \quad (3).$$

Then based on the calculated probability, the eNB may use any given precoding vector i with the probability p_i for DL transmission (data and/or control) to the UEs. Note that according a further embodiment, the eNB may remove some precoding vectors from the codebook if their selection probabilities are zeros or below a predefined threshold. In LTE, these precoding vectors can be applied to DL channels such as PDSCH, ePDCCH, and SCH. The precoding vectors may be applied to the entire transmission or to a part of the transmission. For example, if a UE is given an assignment of 10 PRBs in the PDSCH, for each PRB, a different precoding vector can be applied. Thus for each PRB, the network can pick a precoding vector to be applied based on the probability. In another example, for the ePDCCH, a different precoding vector can be applied for each eREG.

Thus according to **the first embodiment**, as described herein, the network element (eNB) may receive UL reference signals (e.g., SRSs) from the UEs and rank precoding vectors for each received uplink reference signal using a predefined quality parameter such as SINR, calculate a score for each precoding vector based on the ranking of each precoding vector for each received uplink reference signal, and determine the probability of each precoding vector based on the calculated scores for all precoding vectors.

An example illustrating the **first embodiment** is shown in Table 1 below where 10 UEs are in the system/cell periodically send sounding reference signals (SRS) to the eNB. The eNB calculates preferred precoding vectors after every SRS transmission. After 11 SRS transmissions, the eNB calculates the distribution as shown below. In Table 1, the eNB calculates the preferred precoding vectors as v_i, v_j where v_i is a first preferred precoding vector (with assigned probability of 0.8), and v_j is a second preferred precoding vector (with assigned probability of 0.2) for each SRS transmission.

Table 1. Statistics collected by the eNB according to the first embodiment.

UE	SRS transmission instance										
	1	2	3	4	5	6	7	8	9	10	11
1	v_1	v_3	v_3	v_2	v_2	v_6	v_2	v_2	v_2	v_2	v_2
	v_2	v_1	v_1	v_3	v_3	v_2	v_3	v_3	v_3	v_3	v_3
2	v_2	v_3	v_2	v_2	v_1	v_2	v_2	v_1	v_3	v_2	v_2
	v_1	v_1	v_1	v_3	v_2	v_3	v_3	v_2	v_2	v_3	v_3

3	v ₂ , v ₁	v ₃ , v ₁	v ₂ , v ₁	v ₃ , v ₂	v ₆ , v ₂	v ₂ , v ₃	v ₃ , v ₂	v ₃ , v ₂	v ₃ , v ₂	v ₂ , v ₃	v ₂ , v ₃
4	v ₂ , v ₁	v ₁ , v ₂	v ₂ , v ₁	v ₁ , v ₂	v ₂ , v ₃	v ₆ , v ₂	v ₃ , v ₂	v ₂ , v ₂	v ₂ , v ₃	v ₂ , v ₃	v ₂ , v ₃
5	v ₂ , v ₁	v ₆ , v ₁	v ₂ , v ₁	v ₆ , v ₂	v ₂ , v ₃	v ₁ , v ₂	v ₂ , v ₃	v ₂ , v ₂	v ₂ , v ₃	v ₂ , v ₃	v ₂ , v ₃
6	v ₂ , v ₁	v ₂ , v ₁	v ₂ , v ₁	v ₇ , v ₂	v ₂ , v ₃	v ₂ , v ₃	v ₂ , v ₃	v ₂ , v ₂	v ₂ , v ₃	v ₂ , v ₃	v ₂ , v ₃
7	v ₂ , v ₁	v ₂ , v ₁	v ₆ , v ₁	v ₃ , v ₂	v ₂ , v ₃	v ₂ , v ₃	v ₃ , v ₂	v ₁ , v ₂	v ₂ , v ₃	v ₁ , v ₂	v ₂ , v ₃
8	v ₂ , v ₁	v ₂ , v ₁	v ₃ , v ₁	v ₃ , v ₂	v ₂ , v ₃	v ₂ , v ₃	v ₃ , v ₂	v ₃ , v ₂	v ₃ , v ₂	v ₃ , v ₂	v ₂ , v ₃
9	v ₃ , v ₁	v ₆ , v ₁	v ₃ , v ₁	v ₃ , v ₂	v ₁ , v ₂	v ₃ , v ₂	v ₃ , v ₂	v ₂ , v ₃	v ₃ , v ₂	v ₁ , v ₂	v ₂ , v ₃
10	v ₃ , v ₁	v ₅ , v ₁	v ₃ , v ₁	v ₇ , v ₁	v ₃ , v ₂	v ₃ , v ₂	v ₂ , v ₃	v ₂ , v ₃	v ₃ , v ₂	v ₃ , v ₂	v ₂ , v ₃

The calculation may be performed using Equations 1 and 3 as follows.

Assuming $w_0=0.8$ and $w_1=0.2$ and using Equation 1, it can be found that $s_0=0$,
 5 $s_1=0.8*10+0.2*29$, $s_2=0.8*50+0.2*39$, $s_{43}=0.8*30+0.2*42$, $s_4=0$, $s_5=0.8*1$, $s_6=0.8*7$,
 $s_7=0.8*2$.

Thus, $s_0=0$, $s_1=13.8$, $s_2=47.8$, $s_3=32.4$, $s_4=0$, $s_5=0.8$, $s_6=5.6$, $s_7=1.6$.

Then corresponding probabilities calculated using Equation 3 are: $p_0=0.000$, $p_1=0.135$,
 $p_2=0.468$, $p_3=0.318$, $p_4=0.000$, $p_5=0.008$, $p_6=0.055$, $p_7=0.016$. Thus the corresponding
 10 probabilities of using precoding vectors are the following: for v_0 it is 0%, for v_1 it is 13.5%, for
 v_2 it is 46.8%, for v_3 it is 31.8%, for v_4 it is 0%, for v_5 it is 0.8%, for v_6 it is 5.5%, for v_7 it is
 1.6%. Then if we use 1% as a threshold probability for using the precoding vectors, the eNB
 may remove precoding vectors v_0 , v_4 , v_5 from the codebook.

According to a **second embodiment**, the preferred precoding vectors may be
 15 determined/selected based on a PMI feedback from the UEs. The network element (eNB) can
 start with a default codebook and collect statistics regarding the preferred PMI reported by the
 UEs. Note that in one option only statistics about the first preferred precoding vector can be

obtained from the PMI feedback signal from the UE, but in general it could be more than one preferred precoding vectors as further discussed herein.

Next, the eNB may determine/calculate a score of a given precoding vector based on collected statistics including, for example, how many times a particular vector was in the reported feedback (PMIs) by the UEs. This score for the statistics collected about the first preferred precoding vector can be calculated using the following equation:

$$s_i = \sum_k n_{k,i} \quad (4),$$

where s_i is a score for a vector i and $n_{k,i}$ is a precoding vector count reported by the UEs for the vector i . The Equation 4 may be further refined as a function time t . For example, if a weighted histogram is used, more weight may be assigned for recent subframes and less weight may be assigned for subframes in the past. Then the Equation 4 may be further modified, e.g., using a time scaling factor α , as follows:

$$s_i = \sum_k e^{-\alpha t} n_{k,i} \quad (5).$$

Moreover, the eNB may determine/calculate a probability p_i of selecting a given precoding vector based on the determined vector scores using Equation 3 as in the first embodiment.

Then, based on the calculated probability, the eNB may use any given precoding vector i with the probability p_i for DL transmission (data and/or control) to the UEs. Note the eNB may remove some precoding vectors from the codebook if their selection probabilities are zeros or below a threshold as in the first embodiment.

Thus according to **the second embodiment**, as described herein, the network element (eNB) may receive UL feedback signals (e.g., PMI signals) from the UEs, each feedback signal comprising information on one or more preferred precoding vectors, calculate a score for each precoding vector comprised in a default codebook using the received information, and determine the probability of each precoding vector based on the calculated scores for all precoding vectors.

An example illustrating the **second embodiment** is shown in Table 2 below where 10 UEs are in the system/cell periodically send PMI signals (e.g., as a part of a CSI feedback report) to the eNB and using only first preferred precoding vector in the PMI report by the UEs. After 11 PMI transmissions, the eNB calculates the distribution as shown below.

Table 2. Statistics collected by the eNB according to the second embodiment.

UE	Reporting Instance										
	1	2	3	4	5	6	7	8	9	10	11
1	v ₁	v ₃	v ₃	v ₂	v ₂	v ₆	v ₂	v ₂	v ₂	v ₂	v ₂
2	v ₂	v ₃	v ₂	v ₂	v ₁	v ₂	v ₂	v ₁	v ₃	v ₂	v ₂
3	v ₂	v ₃	v ₂	v ₃	v ₆	v ₂	v ₃	v ₃	v ₃	v ₂	v ₂
4	v ₂	v ₁	v ₂	v ₁	v ₂	v ₆	v ₃	v ₂	v ₂	v ₂	v ₂
5	v ₂	v ₆	v ₂	v ₆	v ₂	v ₁	v ₂	v ₂	v ₂	v ₂	v ₂
6	v ₂	v ₂	v ₂	v ₇	v ₂	v ₂	v ₂	v ₂	v ₂	v ₂	v ₂
7	v ₂	v ₂	v ₆	v ₃	v ₂	v ₂	v ₃	v ₁	v ₂	v ₁	v ₂
8	v ₂	v ₂	v ₃	v ₃	v ₂	v ₂	v ₃	v ₃	v ₃	v ₃	v ₂
9	v ₃	v ₆	v ₃	v ₃	v ₁	v ₃	v ₃	v ₂	v ₃	v ₁	v ₂
10	v ₃	v ₅	v ₃	v ₇	v ₃	v ₃	v ₂	v ₂	v ₃	v ₃	v ₂

5

The calculation may be performed using Equations 4 and 3 as follows.

Using Equation 1, it can be found that $s_0=0$, $s_1=10$, $s_2=60$, $s_3=30$, $s_4=0$, $s_5=1$, $s_6=7$, $s_7=2$.

Then corresponding probabilities calculated using Equation 3 are: $p_0=0.000$, $p_1=0.091$, $p_2=0.545$, $p_3=0.273$, $p_4=0.000$, $p_5=0.009$, $p_6=0.064$, $p_7=0.018$. Thus the corresponding probabilities of using the precoding vectors are the following: for v_0 it is 0%, for v_1 it is 9.1%, for v_2 it is 54.5%, for v_3 it is 27.3%, for v_4 it is 0%, for v_5 it is 0.9%, for v_6 it is 6.4%, for v_7 it is 1.8%. Then if we use 1% as a threshold probability for using precoding vectors, the eNB may remove precoding vectors v_0 , v_4 , v_5 from the codebook.

As it is noted herein, in general more than one preferred precoding vectors may be obtained from the PMI feedback signal from one UE. For example, if the UE in the CSI feedback may report two or more corresponding preferred precoding vectors, the eNB may use Equation 1 with assigned weights w_k as explained in the first embodiment and Table 1. Alternatively the w_k information for each preferred precoding vector can be asserted based on CQI information for each preferred precoding vector which can be contained in the CSI feedback report.

Furthermore, in the 3GPP LTE Releases 8-11 precoders have the nested structure

where a high rank precoder is composed from low rank precoders.

In case the PMI feedback from a UE is for a desired precoder with rank >1 , then the rank=1 precoders forming the desired precoder with the rank >1 are considered desirable for statistics accumulation.

5 For example, the eNB may have 4 antenna ports so that the UE can feedback a rank 3 PMI, which means that the preferred precoder is a 4×3 matrix $[v_1 \ v_2 \ v_3]$. In LTE, each column vector of a precoder matrix at rank >1 is actually a rank 1 precoder in the codebook. Then the indices for precoders v_1 , v_2 and v_3 may be included in the statistics (e.g., see Table 2). In this example, v_1 , v_2 and v_3 are 3 rank 1 (4×1 vectors) precoders in the codebook. As the
10 UE prefers a rank 3 precoder (a matrix), and the random precoders used for control channel are rank 1 precoders, the question may be "which rank 1 precoder(s) will the UE prefer?". In this case, the answer may be that each vector may be assigned an equal weight with a score of $1/3$.

In the future (e.g., 3GPP LTE Release 12/13), if codebook design includes non-nested codewords, then subspace-fitting can be used to approximate the desired precoder. For
15 example, the desired high rank precoder is $[v_1, v_2, v_3]$, but v_1, v_2, v_3 themselves are not included in the codebook. Then three rank1 vectors from the codebook w_1, w_2, w_3 may be searched so the subspace spanned by $[v_1, v_2, v_3]$ can be found to be close to the subspace spanned by $[w_1, w_2, w_3]$ as further explained below.

As stated above, there is no guarantee that in the future the codebook still has the
20 property so that a column vector of a high rank precoder is actually a legitimate codeword in the (default) codebook. For example, even though the matrix $V = [v_1, v_2, v_3]$ is in the codebook $CB = \{w_1, w_2, w_3, w_4, \dots, A, B, \dots, V, \dots\}$ which may include rank 1 precoders, rank 2 precoders, rank 3 precoders, etc., yet v_1, v_2 and v_3 are not in the codebook CB. Then we can find some rank 1 precoders in the codebook CB such as w_1, w_2 and w_3 which may be close to
25 forming the matrix V. For example, one can examine the projection of w_i into V : $\|w_i^H V\|$, where $\|\cdot\|$ is a Frobenius norm, and H stands for a conjugate transpose; a large value of this projection may suggest that w_i is really covered by V . But our real goal is not to find a rank precoder well covered by V , rather we are interested in finding a couple of rank 1 precoders to cover V . In linear algebra, the concept of distance between subspaces has been developed for a
30 long time. This concept can be used to measure how well a chosen set $[w_1 \ w_2 \ w_3]$ covers V by considering the subspace distance between the matrix $[w_1 \ w_2 \ w_3]$ and V . Once we have found a good fit (in this case $\{w_1, w_2, w_3\}$), then we can effectively take $[w_1 \ w_2 \ w_3]$ as the preferred

precoder by the UE, then we can give w_1, w_2, w_3 a weight of 1/3 as explained above.

In another scenario applied in the second embodiment described herein, the eNB may use different downtilts to the CSI-RS resources without the knowledge of the UE so that the UE can use these CSI-RS resources for the CSI feedback which includes the PMI feedback. This further scenario is disclosed in a co-owned PCT patent application “CSI Feedback With Elevation Beamforming”, International Application No. PCT/US2012/061082 filed on October 19, 2012.

It is noted that a further scenario can be used in the second embodiment described herein, when the eNB may apply some precoding vectors to the CSI-RS resources without the knowledge of the UE so that the UE can use these CSI-RS resources for the CSI feedback which includes the PMI feedback. This further scenario is disclosed in a co-owned PCT patent application “Codebook Construction Using CSI Feedback For Evolving Deployment Scenarios”, International Application No. PCT/US2012/054409, filed on September 10, 2012.

Furthermore, the preferred precoder may be completely described by the UE feedback and transmission choices at the eNB side. This approach for non-nested codebook can be applied using a **covariance matrix based design** as explained below. An example of a general case of the **covariance matrix based design** where the eNB can apply some precoding vectors to the CSI-RS resources is provided below.

For instance, all UEs may be required to send CSI reports to an eNB at subframes 1, 6, 11, 16 and 21, so that precoding vectors, e.g., corresponding to unitary matrices $M_1, M_2, M_3, \dots$, may be applied to the CSI-RS at subframes 1, 6, 11, 16 and 21. Suppose that the eNB applies a unitary matrix M_1 at subframe 1 which may be given by:

$$M_1 = \begin{bmatrix} -0.5705 & -0.3613 & -0.1621 & 0.7196 \\ -0.3061 & 0.1444 & 0.9401 & 0.0416 \\ -0.6310 & -0.3268 & -0.1247 & -0.6924 \\ -0.4274 & 0.8613 & -0.2729 & 0.0321 \end{bmatrix}.$$

Further, the unitary matrix applied at subframe 6 may be given by:

$$M_2 = \begin{bmatrix} -0.6092 & -0.6306 & 0.1504 & 0.4566 \\ -0.5193 & 0.4978 & 0.6582 & -0.2222 \\ -0.5042 & -0.1248 & -0.5297 & -0.6705 \\ -0.3240 & 0.5822 & -0.5134 & 0.5408 \end{bmatrix}, \text{ etc.}$$

Then for a UE1, the eNB may find that the received CQI corresponding to PMI=[1 -1 -1 -1]^T at subframe 1 at subbands k=1, 2, 3, 4, 5 and 6 is the highest among all CSI

reports from the UE1, so that the best precoding vector for the UE1 is $U_{1,k} = M_1[1 -1 -1 -1]^T$ at subbands $k = 1, 2, 3, 4, 5$ and 6.

In general, we can use $U_{i,k} = [U_{i,k,1} \cdots U_{i,k,r_{i,k}}]$ for the preferred precoding vector for UE_i at subband k , which includes both the PMI feedback (PMI = $[1 -1 -1 -1]^T$) and the precoding vector (e.g., M_1 for the subframe 1) applied at the eNB side during the UE's CSI measurement. Here $r_{i,k}$ is a rank indication feedback from the UE_i for the subband k .

As a result of this approach the effective size of the codebook may be enlarged, e.g., proportionally to a number of different matrices applied by the eNB to the CSI-RS. It may happen that different UEs have different preferences, and no precoding vector (or a set of precoding vectors) receives an overwhelming score. Then a scheme is needed for the eNB to derive a relatively small set of precoding vectors. Now the problem can be formulated as finding a subspace or a set of precoding vectors (which may not necessarily be the basis vectors for a subspace, so that the precoding vectors may not be necessarily orthogonal to each other) to determine the preferred precoding vectors for all the UEs at all the subbands.

In other words, the eNB needs to select a set of precoders so that, e.g., the broadcast information can be conveyed to all the UEs using that set of precoders. One possibility is to form a subspace approximation to the space spanned by the column vectors of $U_{i,k}$ for all the UEs and the subbands with feedback. The following scheme may be used:

- a) Form a covariance matrix $R = \sum_{i,k} U_{i,k} U_{i,k}^H$, where H is a conjugate transpose operator. The covariance matrix can provide indication on average what are the preferred precoding vectors.
- b) Perform Eigen decomposition on R : and r_1, r_2, r_3, r_4 (assume there are 4 Tx antenna ports from the eNB) may be the found eigenvectors, and the corresponding eigenvalues are $d_1 \geq d_2 \geq d_3 \geq d_4$. Procedures for eigen-decomposition can be found, for example, on pp.391-469, "Matrix Computations", The Johns Hopkins University Press, (3rd Edition), by Gene H. Golub and Charles F. van Van Loan, 1996.

- c) r_1 corresponds to the single precoding vector which can serve best all the UEs on average, yet some UEs will suffer if r_1 , which is the eigenvector corresponding to the largest eigenvalue d_1 , is not well aligned with their preferred precoding vectors. r_4 , which is the eigenvector corresponding to the smallest eigenvalue d_4 , is the single precoding vector which

is least favored by all UEs on average, yet a minority UEs' preferred precoding vectors may be well aligned with r_4 which may serve them quite well. If we use $\{r_1\}$ as a set of precoders, then some UEs such as UE_{j1} may be served well if the correlation between r_1 and $U_{j1,k}$ is high; and some UEs such as UE_{j2} may be served poorly if the correlation between r_1 and $U_{j2,k}$ is low. Then we can expand the set of precoders from $\{r_1\}$ to $\{r_1, r_2\}$ with the hope that the worst off UE is helped in this process. And this process can continue to expand the set of precoders to $\{r_1, r_2, r_3, r_4\}$. The score for each eigenvector is given by d_i , i.e. $s_i = d_i$. And the probability of transmitting eigenvector r_i is given by

$$P_i = \frac{d_i}{\sum_{j \in \{\text{indices of selected eigenvectors}\}} d_j} \quad (6).$$

10

d) The transmit power of each precoder can be also adjusted to achieve a trade-off between UEs. For example, if r_1, r_2, r_3, r_4 are all included in the selected precoding vectors, the transmit power for r_1, r_2, r_3, r_4 can be adjusted according to two conflicting goals of serving UEs in general well and serving the worst off UEs well, e.g., r_4 may be given more power than r_1 .

15

e) The probability of transmission of each precoding vector can be also adjusted to reconcile between the two conflicting goals of serving UEs in general well and serving the worst off UEs well. For example, by the goal of serving UEs in general, if r_1, r_2, r_3, r_4 are all included in the selected precoding vectors, e.g., r_4 may be transmitted as frequently as prescribed (see

Equation 6) by $P_4 = \frac{d_4}{\sum_{j=1}^4 d_j}$ (e.g., $P_4=10\%$), and r_1 is transmitted as frequently as prescribed

20

(see Equation 6) by $P_1 = \frac{d_1}{\sum_{j=1}^4 d_j}$ (e.g., $P_1=35\%$). However, considering the second goal of

serving the worst off UEs well, r_4 may be transmitted more frequently than $P_4 = \frac{d_4}{\sum_{j=1}^4 d_j}$ (say

r_4 is transmitted at 15%) and r_1 may be transmitted less frequently than $P_1 = \frac{d_1}{\sum_{j=1}^4 d_j}$ (say r_1 is transmitted at 30%).

- f) We can also modify the covariance matrix by giving a weight to each $U_{i,k}$ as in the first embodiment: $R = \sum_{i,k} W_{i,k} U_{i,k} U_{i,k}^H$, and follow the procedure given above.

It is noted that the above scheme with elements a) through f) may be applied to a simplified case of the CSI (PMI) feedback from the UEs without applying by the eNB precoding vectors to the CSI-RS, i.e., $M_1, M_2, M_3, \dots$ being identity matrices in the above algorithm.

- According to a **third embodiment**, the network element (eNB) can start with a default codebook and collect statistics regarding channel estimates, for example, using sounding reference signals (SRS) and/or preferred PMI feedback from the UEs (like in the first and/or second embodiments described herein). Then the eNB can construct a new codebook based on the collected channel information such as SRSs and/or appropriate feedback (e.g., PMI). This new codebook may be significantly smaller than the default codebook. Note that the new codebook should not be the same as 3GPP LTE Release-8 codebook. Then the eNB can use a scoring and determining selection probabilities (see Equations 1-5) for each precoding vector in the new codebook as described herein in reference to the first and second embodiments. In other words, the first or second embodiments may be applied to the precoding vectors in the new codebook.

- Figure 4 shows an exemplary flow chart demonstrating implementation of embodiments of the invention by a network element (e.g., eNB). It is noted that the order of steps shown in Figure 4 is not absolutely required, so in principle, the various steps may be performed out of the illustrated order. Also certain steps may be skipped, different steps may be added or substituted, or selected steps or groups of steps may be performed in a separate application.

- In a method according to the exemplary embodiment shown in Figure 4, in a first step **40**, the network element (eNB) receives UL reference signals from UEs (e.g., in a cell served by the eNB) and ranks precoding vectors for each received uplink reference signal using a predefined quality parameter (e.g., SINR), the precoding vectors corresponds to codewords from a default codebook. In a next step **42**, the eNB may generate (optionally) a reduced

codebook by removing a number of codewords from the default codebook based on the ranking of the precoded vectors by selecting preferred one or more precoding vectors.

In a next step **44**, the eNBs calculates a score for each precoding vector comprised in the default or reduced codebook based on the ranking of precoding vectors for each received
5 uplink reference signal. In a next step **46**, the eNB determines the probability of each precoding vector in the default or reduced codebook based on the calculated scores for all precoding vectors in the default or reduced codebook.

In a next step **47**, the eNB selects a plurality of precoding vectors with the determined probability (e.g., some precoding vectors with zero probability or a low probability below a
10 predefined threshold may be excluded). In a next step **48**, the eNB sends data to the UEs using selected precoding vectors based on the determined probability for each selected precoding vector.

It is further noted that according to a further embodiment, steps **40-48** can be repeated, e.g., every predefined time period.

15 Figure 5 shows another exemplary flow chart demonstrating implementation of embodiments of the invention by the network element such as eNB. It is noted that the order of steps shown in Figure 5 is not absolutely required, so in principle, the various steps may be performed out of the illustrated order. Also certain steps may be skipped, different steps may be added or substituted, or selected steps or groups of steps may be performed in a separate
20 application.

In a method according to the exemplary embodiment shown in Figure 5, in a first step **50**, the network element (eNB) receives feedback signals from UEs, each feedback signal comprising information on one or more preferred precoding vectors. In a next step **52**, the eNB may optionally generate a reduced codebook by removing a number of codewords from a
25 default codebook based on the feedback signals received from the UEs. In a next step **54**, the eNB calculates a score for each precoding vector comprised in a default or reduced codebook using the received information. In a next step **56**, the eNB determines the probability of each precoding vector in the default or reduced codebook based on the calculated scores for all precoding vectors in the default or reduced codebook.

30 In a next step **57**, the eNB selects a plurality of precoding vectors with the determined probability (e.g., some precoding vectors with zero probability or a low probability below a predefined threshold may be excluded). In a next step **58**, the eNB sends data to the UEs using selected precoding vectors based on the determined probability for each selected precoding vector.

It is further noted that according to a further embodiment, steps **50-58** can be repeated, e.g., every predefined time period.

Figure 6 shows an example of a block diagram demonstrating wireless devices (e.g., in LTE) including a network element (e.g., eNB) **80** comprised in a network **100**, and a UE **82** communicating with the eNB **80**, according to an embodiment of the invention. Figure 6 is a simplified block diagram of various electronic devices that are suitable for practicing the exemplary embodiments of this invention, and a specific manner in which components of an electronic device are configured to cause that electronic device to operate. The UE **82** may be a mobile phone, a camera mobile phone, a wireless video phone, a portable device or a wireless computer, etc.

The eNB **80** may comprise, e.g., at least one transmitter **80a**, at least one receiver **80b**, at least one processor **80c** at least one memory **80d** and a precoder vector selection application module **80e**. The transmitter **80a** and the receiver **80b** may be configured to provide a wireless communication with the UE **82** (and others not shown in Figure 6), e.g., through a corresponding link **81**, according to the embodiments of the invention. The transmitter **80a** and the receiver **80b** may be generally means for transmitting/receiving and may be implemented as a transceiver, or a structural equivalence thereof. It is further noted that the same requirements and considerations are applied to transmitter and receiver of the UE **82**.

Various embodiments of the at least one memory **80d** (e.g., computer readable memory) may include any data storage technology type which is suitable to the local technical environment, including but not limited to semiconductor based memory devices, magnetic memory devices and systems, optical memory devices and systems, fixed memory, removable memory, disc memory, flash memory, DRAM, SRAM, EEPROM and the like. Various embodiments of the processor **80c** include but are not limited to general purpose computers, special purpose computers, microprocessors, digital signal processors (DSPs) and multi-core processors. Similar embodiments are applicable to memories and processors in other wireless devices such as UE **82** shown in Figure 6.

The precoder vector selection application module **80e** may provide various instructions for performing steps **40-48** shown in Figure 4 and steps **50-58** shown in Figure 5. The module **80e** may be implemented as an application computer program stored in the memory **80d**, but in general it may be implemented as software, firmware and/or hardware module or a combination thereof. In particular, in the case of software or firmware, one embodiment may be implemented using a software related product such as a computer readable memory (e.g., non-transitory computer readable memory), computer readable medium or a computer

readable storage structure comprising computer readable instructions (e.g., program instructions) using a computer program code (i.e., the software or firmware) thereon to be executed by a computer processor. Furthermore, the module **80e** may be implemented as a separate block or may be combined with any other module/block of the device **80**, or it may be split into several blocks according to their functionality.

The UE **82** may have similar components as the eNB **80**, as shown in Figure 6, so that the above discussion about components of the eNB **80** is fully applicable to the components of the UE **82**.

It is noted that various non-limiting embodiments described herein may be used separately, combined or selectively combined for specific applications.

Further, some of the various features of the above non-limiting embodiments may be used to advantage without the corresponding use of other described features. The foregoing description should therefore be considered as merely illustrative of the principles, teachings and exemplary embodiments of this invention, and not in limitation thereof.

It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the scope of the invention, and the appended claims are intended to cover such modifications and arrangements.

CLAIMS:

What is claimed is:

1. A method comprising:
selecting, by a network element using a statistical predefined criterion, a plurality of precoding vectors with a probability determined for each selected precoding vector; and
signaling by the network element to the user equipments using the selected precoding vectors based on the determined probability for each selected precoding vector.
2. The method of claim 1, wherein the network element is an eNB and the user equipments are in a cell supported by the eNB.
3. The method of claim 1, wherein the selecting comprises:
receiving by the network element uplink reference signals from the user equipments and ranking precoding vectors for each received uplink reference signal using a predefined quality parameter, the precoding vectors corresponding to codewords from a default codebook.
4. The method of claim 3, wherein the uplink reference signals are sounding reference signals.
5. The method of claim 3, wherein the predefined quality parameter is a signal to interference plus noise ratio.
6. The method of claim 3, wherein the selecting further comprises:
generating a reduced codebook by removing a number of codewords from the default codebook based on the ranking of the precoded vectors by selecting preferred one or more precoding vectors.
7. The method according to claims 3-6, wherein, if it is more than one of the preferred precoding vectors the selecting further comprises:
calculating a score for each preferred precoding vector in the reduced codebook based on the ranking of each precoding vector for each received uplink reference signal; and
determining the probability of each precoding vector in the reduced codebook based on

the calculated scores for all precoding vectors in the reduced codebook.

8. The method of claim 3, wherein the selecting further comprises:
calculating a score for each precoding vector in the default codebook based on the ranking of each precoding vector for each received uplink reference signal; and
determining the probability of each precoding vector in the default codebook based on the calculated scores for all precoding vectors in the default codebook.

9. The method of claim 8, removing selected precoding vectors from the default codebook if determined probabilities of the selected precoding vectors are zeros or below a predefined threshold.

10. The method of claim 8, wherein the score for each precoding vector i from the default codebook is calculated as follows:

$$s_i = \sum_k w_k n_{k,i},$$

where w_k is a weight for k -th preferred vector and $n_{k,i}$ is a preferred vector count for a precoding vector i , and

the probability of each precoding vector i is determined as follows:

$$p_i = \frac{s_i}{\sum_i s_i}.$$

11. The method of claim 8, wherein the calculating the score for each precoding vector is based on a time dependence of information received from the user equipments.

12. The method of claim 1, wherein the selecting comprises:
receiving by the network element feedback signals from the user equipments, each feedback signal comprising information on one or more preferred precoding vectors;
calculating a score for each precoding vector in a default codebook using the received information; and
determining the probability of each precoding vector in the default codebook based on the calculated scores for all precoding vectors.

13. The method of claim 12, wherein the score for each precoding vector i from the default codebook is calculated as follows:

$$s_i = \sum_k n_{k,i} ,$$

where $n_{k,i}$ is a count for a precoding vector i , and

the probability of each precoding vector i is determined as follows:

$$p_i = \frac{s_i}{\sum_i s_i}.$$

14. The method of claim 12, wherein the received information is a channel state information feedback comprising at least precoding matrix index information for the one or more preferred precoding vectors.

15. The method of claim 14, wherein the one or more preferred precoding vectors comprise more than one of the preferred precoding vectors, and the received information comprises channel quality indicator information for each preferred precoding vector, the channel quality indicator information is used for ranking the preferred precoding vectors.

16. The method of claim 12, wherein the received information comprises a precoding matrix having a rank of two or more and defining two or more precoding vectors with a rank of one which are assigned equal ranking.

17. The method of claim 12, removing selected precoding vectors from the default codebook if determined probabilities of the selected precoding vectors are zeros or below a predefined threshold.

18. The method of claim 12, wherein the calculating the score for each precoding vector is based on a time dependence of the information received from the user equipments.

19. The method of claim 12, wherein the selecting comprises:

receiving by the network element feedback signals from the user equipments, each feedback signal comprising information on one or more preferred precoding vectors;

generating a reduced codebook by removing a number of codewords from a default codebook based on the feedback signals received from the user equipments;

calculating a score for each precoding vector in a reduced codebook using the received information; and

determining the probability of each precoding vector in the reduced codebook based on

the calculated scores for all precoding vectors in the reduced codebook.

20. The method of claim 12, wherein before receiving the feedback signals, the method comprises:

sending by the network element channel state information reference signals, where at least two of the channel state information reference signals, sent using different resources, have different downtilt angles applied by the network element without a knowledge of the user equipments.

21. The method of claim 12, wherein before receiving the feedback signals, the method comprises:

sending by the network element channel state information reference signals, where each of the channel state information reference signals comprises a precoding vector applied by the network element without a knowledge of the user equipments.

22. The method of claim 1, wherein the signals are channel state information feedback signals and where the probability is determined for each selected precoding vector using a covariance matrix based design.

23. The method of claim 1, wherein the signals are received from the user equipments in multiple time instances.

24. The method of claim 1, wherein the signaling comprises sending data or synchronization signals.

25. The method of claim 1, wherein the signaling comprises sending multiple physical resource blocks, where a different selected precoding vector is used for each physical resource block based on the determined probability for each selected precoding vector.

26. The method of claim 1, wherein the probability is determined based on a time dependence of information received from the user equipments.

27. An apparatus comprising:

a processing system comprising at least one processor and a memory storing a set of

computer instructions, in which the processing system is arranged to cause the apparatus to:

- selecting, using a statistical predefined criterion, a plurality of precoding vectors with a probability determined for each selected precoding vector; and
- signaling by the network element to the user equipments using the selected precoding vectors based on the determined probability for each selected precoding vector.

28. The apparatus of claim 27, wherein apparatus comprises an eNB and the user equipments are in a cell supported by the eNB.

29. The apparatus of claim 27, wherein the selecting comprises receiving by the apparatus network reference signals from the user equipments and ranking precoding vectors for each received uplink reference signal using a predefined quality parameter, the precoding vectors corresponding to codewords from a default codebook.

30. The apparatus of claim 29, wherein the uplink reference signals are sounding reference signals.

31. The apparatus of claim 27, wherein the probability is determined based on a time dependence of information received from the user equipments.

32. The apparatus of claim 27, wherein the selecting comprises: receiving feedback signals from the user equipments, each feedback signal comprising information on one or more preferred precoding vectors; calculating a score for each precoding vector in a default codebook using the received information; and determining the probability of each precoding vector in the default codebook based on the calculated scores for all precoding vectors.

33. The apparatus of claim 32, wherein the received information is a channel state information feedback comprising at least precoding matrix index information for the one or more preferred precoding vectors.

34. A computer program product comprising a computer readable medium bearing computer program code embodied herein for use with a computer, the computer program code comprising:

- code for selecting, by a network element using a statistical predefined criterion, a

plurality of precoding vectors with a probability using signals received from user equipments, determined for each selected precoding vector; and

code for signaling by the network element to the user equipments using the selected precoding vectors based on the determined probability for each selected precoding vector.

35. The computer program product of claim 34, wherein the probability is determined using signals received from user equipments.

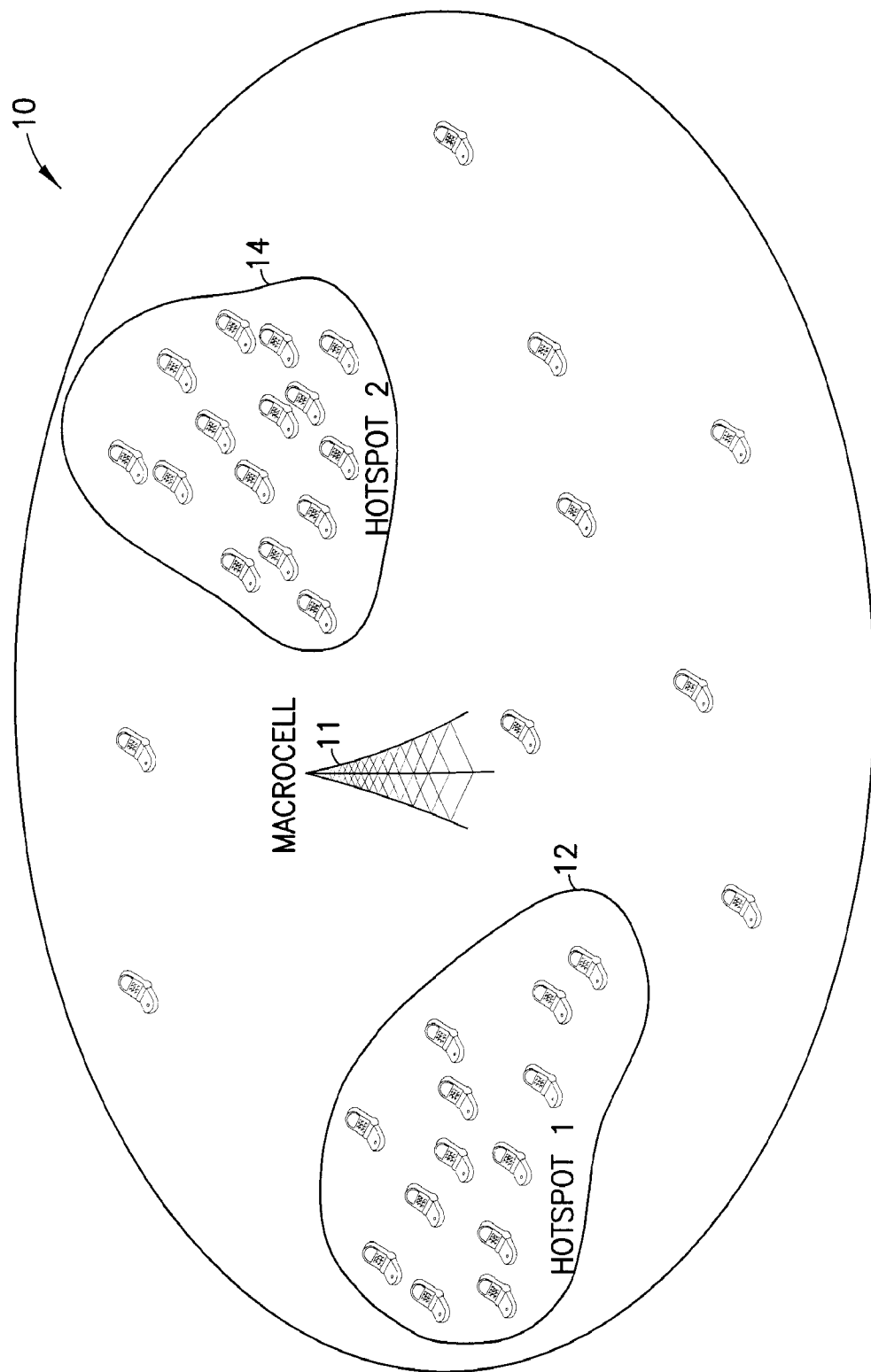
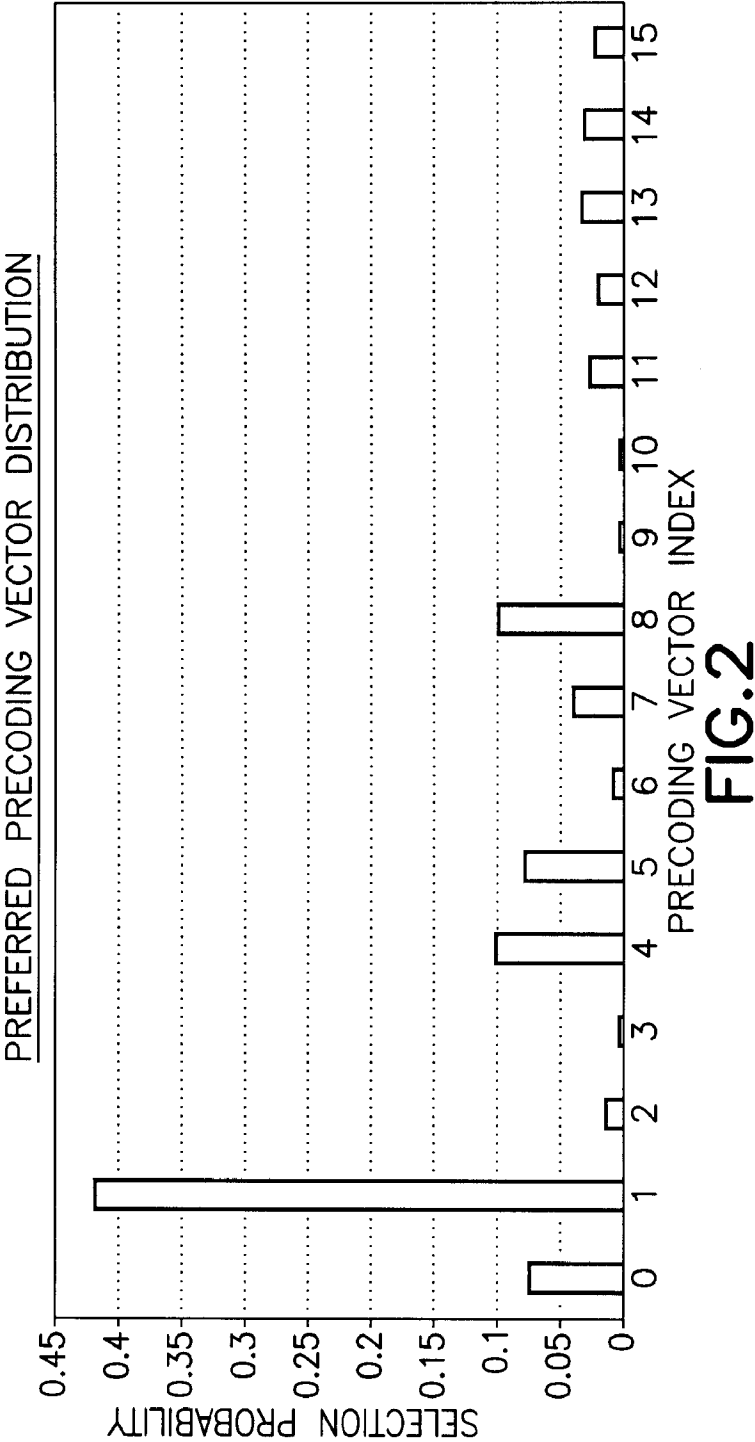
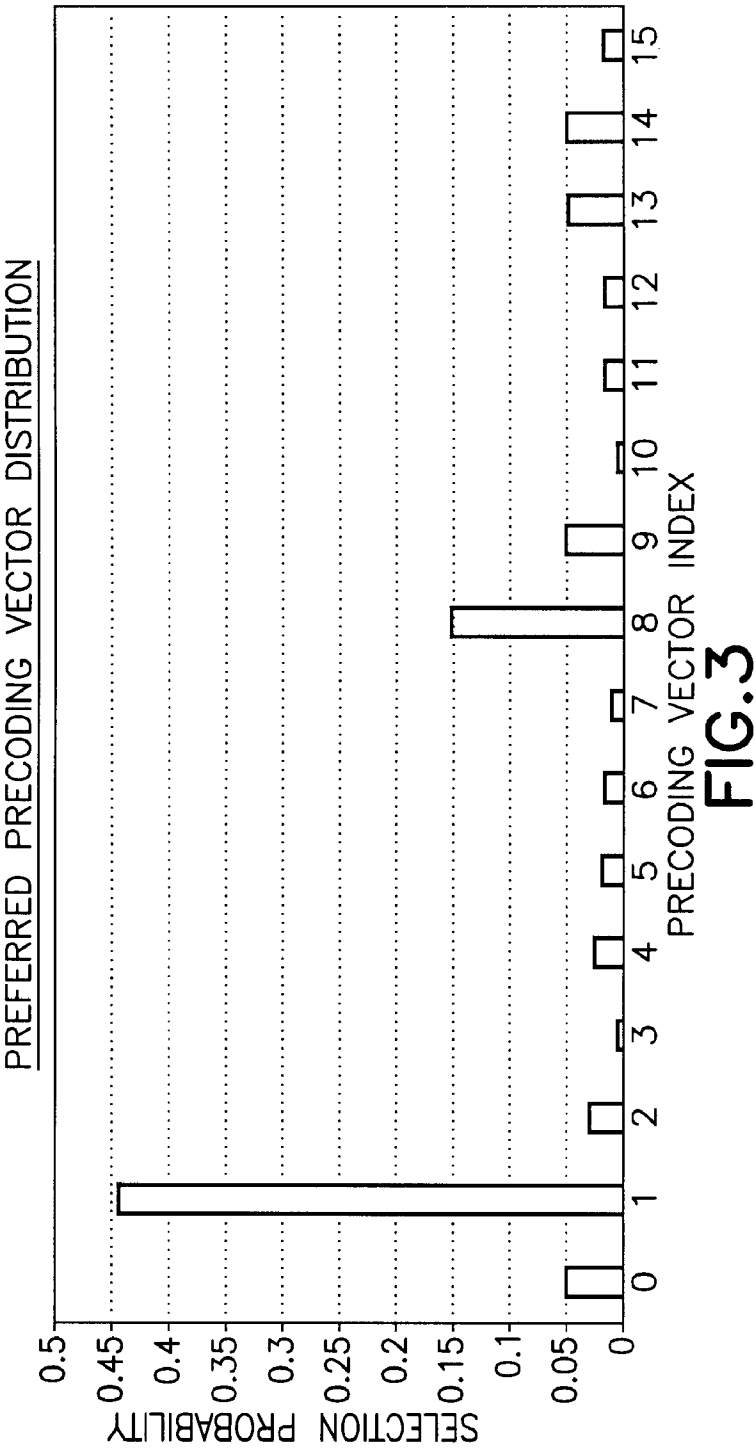


FIG.1





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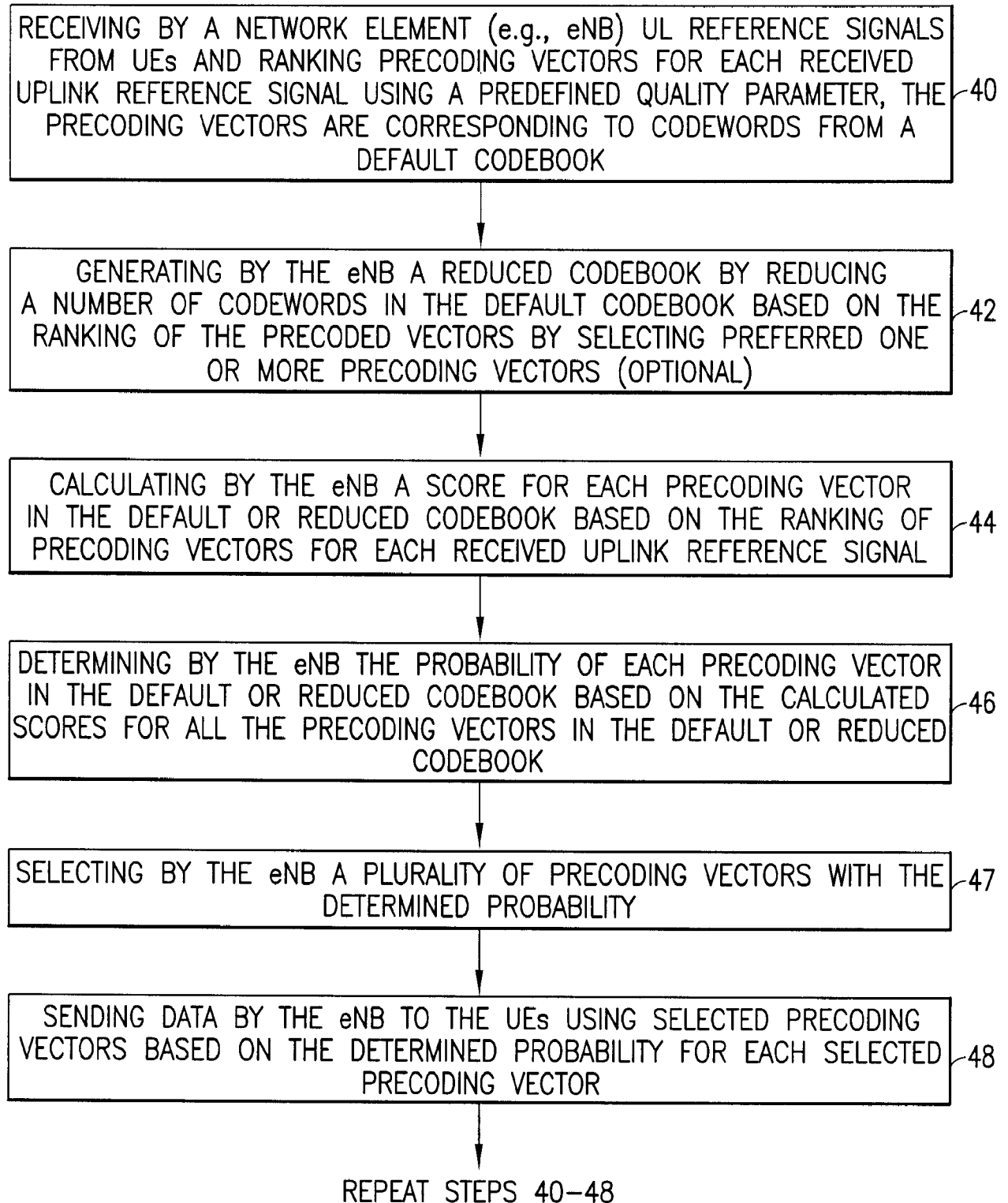
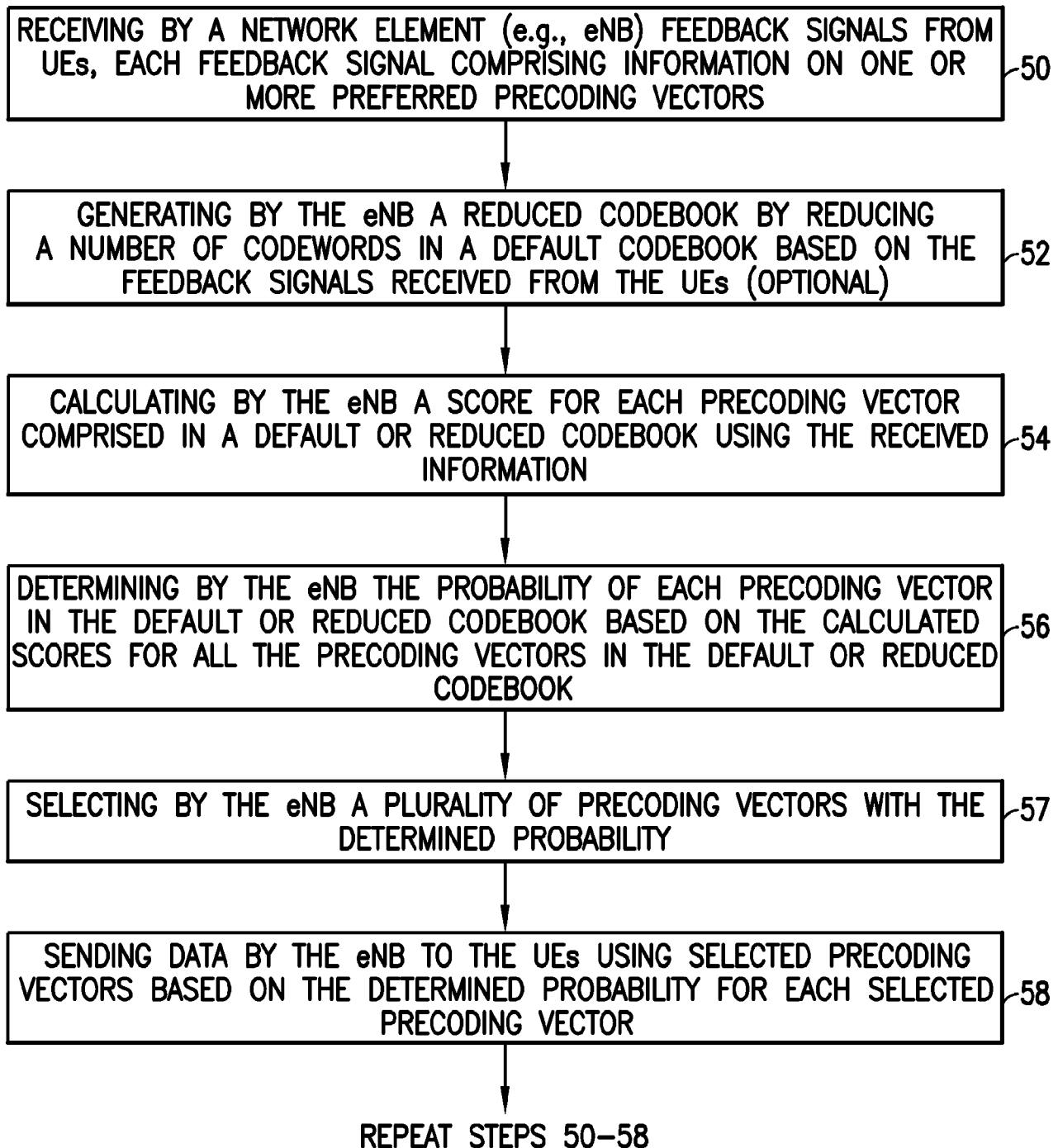


FIG.4

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**FIG.5**

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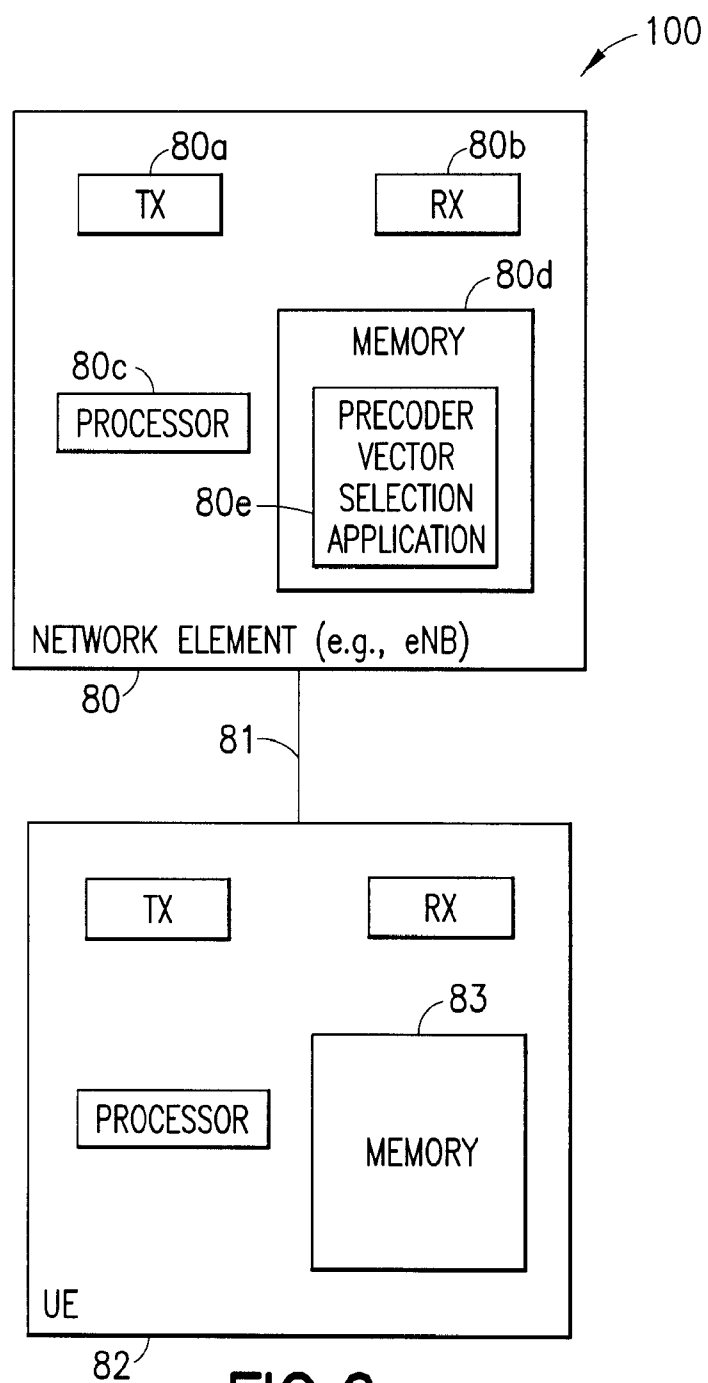


FIG.6

A. CLASSIFICATION OF SUBJECT MATTER**H04J 11/00(2006.01)i, H04B 7/04(2006.01)i, H04L 1/00(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)

H04J 11/00; H04L 27/00; H03M 7/00; H04B 7/06; H04L 1/02; H04B 7/216; H04W 72/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: precoder, selection, channel quality

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011-0103493 A1 (PENGFEI XIA et al.) 5 May 2011 See paragraphs [0051]-[0054], [0080], [0112], [0146], [0170], [0186]-[0193]; and figures 3, 9, 15, 19.	1-35
A	US 2011-0164701 A1 (HOSEIN NIKOPOURDEILAMI et al.) 7 July 2011 See paragraphs [0067]-[0080]; and figures 14-16.	1-35
A	EP 2061162 A1 (NOKIA SIEMENS NETWORKS S.P.A. et al.) 20 May 2009 See paragraphs [0013]-[0017]; and figure 1.	1-35
A	US 8254944 B2 (YOUNG HOON KWON et al.) 28 August 2012 See column 3, line 30 - column 4, line 26; and figures 1-3.	1-35
A	US 2010-0238913 A1 (PENGFEI XIA et al.) 23 September 2010 See paragraphs [0017]-[0047]; and figure 1.	1-35



Further documents are listed in the continuation of Box C.



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

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"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

Date of the actual completion of the international search

14 May 2013 (14.05.2013)

Date of mailing of the international search report

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Name and mailing address of the ISA/KR

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Telephone No. 82-42-481-5560



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2012/065168

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