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- (54) **Title:** CODEBOOK WITH FINE SPATIAL GRANULARITY FOR CSI REPORTING

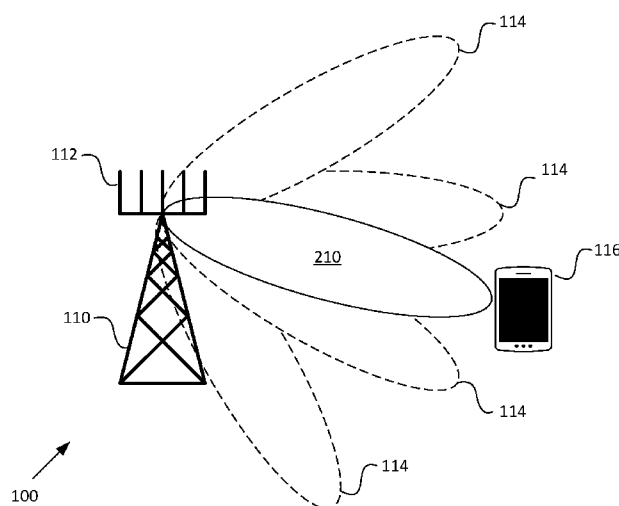


FIG. 2

(57) **Abstract:** Briefly, in accordance with one or more embodiments, an apparatus of a user equipment comprises baseband circuitry to decode a message from an evolved Node B (eNB) to obtain a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config), demodulate a first physical downlink shared channel (PDSCH) message to obtain a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission, demodulate a second PDSCH message to obtain a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams, configure a codebook based at least in part on the first set of beamforming vectors and second set of the beamforming vectors, process CSI-RS reference signals using the first set of beamforming vectors, and encode data to include a precoding matrix index (PMI) indicative of a high spatial granularity beam.

## CODEBOOK WITH FINE SPATIAL GRANULARITY FOR CSI REPORTING

## CROSS-REFERENCE TO RELATED APPLICATIONS

5           The present application claims the benefit of U.S. Application No. 62/290,811 (Attorney Docket No. P95929Z) filed Feb. 3, 2016. Said Application No. 62/290,811 is hereby incorporated herein by reference in its entirety.

## BACKGROUND

10           Elevation Beamforming and full dimension multiple-input, multiple output (FD-MIMO) for downlink data transmission was introduced in Release 13 (Rel-13) of the Long Term Evolution (LTE) standard for the Third Generation Partnership Project (3GPP). Elevation Beamforming/FD-MIMO in LTE Rel-13 is based on two types of channel state information (CSI) feedback schemes. The first scheme, referred to as Class A, utilizes non-precoded CSI Reference Signals (CSI-RS).  
15           The second scheme, class B, utilizes beamformed CSI-RS reference signals. In Class A, each CSI-RS antenna port of the CSI-RS resources may be transmitted by the evolved Node B (eNB) without beamforming, whereas in Class B beamforming on the CSI-RS antenna ports is utilized. The beamforming on CSI-RS antenna ports in Class B schemes provides additional coverage over Class A schemes.

20           In a Class B scheme, after the user equipment (UE) receives the CSI-RS configuration, the UE performs channel measurements and sends the CSI feedback to the eNB, which may contain the preferred precoding matrix index (PMI). In order to increase the cell-edge user performance, the set of the possible beams supported by the eNB may be increased by using beam oversampling. Supporting such fine spatial granularity of the beams, however, may introduce additional system  
25           overhead for Class B CSI reporting. The overhead results from transmission on the additional CSI-RS antenna ports with additional beamforming. As a result, alternative approaches of supporting fine granularity feedback in Class B CSI reporting without introducing additional overhead should be considered.

## DESCRIPTION OF THE DRAWING FIGURES

30           Claimed subject matter is particularly pointed out and distinctly claimed in the concluding portion of the specification. However, such subject matter may be understood by reference to the following detailed description when read with the accompanying drawings in which:

FIG. 1 is a diagram of network illustrating a set of beamformed channel state information  
35           reference signal (CSI-RS) beams having in accordance with one or more embodiments;

FIG. 2 is a diagram of the network of FIG. 1 illustrating an additional beamformed beam having a finer spatial granularity than the set of CSI-RS beams in accordance with one or more embodiments;

FIG. 3 is a flow diagram of a method to utilize a codebook with fine spatial granularity for CSI reporting in accordance with one or more embodiments; and

FIG. 4 is a diagram of example components of a wireless device in accordance with one or more embodiments.

It will be appreciated that for simplicity and/or clarity of illustration, elements illustrated in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, if considered appropriate, reference numerals have been repeated among the figures to indicate corresponding and/or analogous elements.

#### DETAILED DESCRIPTION

In the following detailed description, numerous specific details are set forth to provide a thorough understanding of claimed subject matter. However, it will be understood by those skilled in the art that claimed subject matter may be practiced without these specific details. In other instances, well-known methods, procedures, components and/or circuits have not been described in detail.

In the following description and/or claims, the terms coupled and/or connected, along with their derivatives, may be used. In particular embodiments, connected may be used to indicate that two or more elements are in direct physical and/or electrical contact with each other. Coupled may mean that two or more elements are in direct physical and/or electrical contact. Coupled, however, may also mean that two or more elements may not be in direct contact with each other, but yet may still cooperate and/or interact with each other. For example, "coupled" may mean that two or more elements do not contact each other but are indirectly joined together via another element or intermediate elements. Finally, the terms "on," "overlying," and "over" may be used in the following description and claims. "On," "overlying," and "over" may be used to indicate that two or more elements are in direct physical contact with each other. "Over", however, may also mean that two or more elements are not in direct contact with each other. For example, "over" may mean that one element is above another element but not contact each other and may have another element or elements in between the two elements. Furthermore, the term "and/or" may mean "and", it may mean "or", it may mean "exclusive-or", it may mean "one", it may mean "some, but not all", it may mean "neither", and/or it may mean "both", although the scope of claimed subject matter is not limited in this respect. In the following description and/or claims,

the terms "comprise" and "include," along with their derivatives, may be used and are intended as synonyms for each other.

Referring now to FIG. 1, a diagram of network illustrating a set of beamformed CSI-RS beams having in accordance with one or more embodiments will be discussed. As shown in FIG. 1, network 100 may comprise an evolved Node B (eNB) 110 having a set of antennas 112 to transmit one or more beamformed beams 114 to communicate with a user equipment (UE) 116. In one or more embodiments, network 100, eNB 110, and/or UE 116 may be compliant with a Third Generation Partnership Project (3GPP) standard such as a Fifth Generation (5G) Long Term Evolution Advanced (LTE-A) standard or the like, although the scope of the claimed subject matter is not limited in this respect.

In one or more embodiments, eNB 110 may be operating in accordance with a Class B arrangement in which beams 114 are beamformed in order to transmit channel state information reference signals (CSI-RS) to obtain the state of the channel between eNB 110 and UE 116 using Class B full dimension multiple-input and multiple output (FD-MIMO) transmissions. As an example, the CSI feedback in Class B FD-MIMO is supported by using codebook based feedback. Currently in Class B, the codebook comprises the set of the precoding matrices, which are responsible for the beam selection and co-phasing. Each column in the matrix is a vector containing all zeros elements except two. The Class B codebook is specified in the 3GPP Technical Standard (TS) 36.213 v.13.0.1 and is provided below as an example:

| Codebook index, $n$ | Number of layers $v$                                       |                                                             |
|---------------------|------------------------------------------------------------|-------------------------------------------------------------|
|                     | 1                                                          | 2                                                           |
| 0                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}$  | $\frac{1}{2} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$ |
| 1                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -1 \end{bmatrix}$ | $\frac{1}{2} \begin{bmatrix} 1 & 1 \\ j & -j \end{bmatrix}$ |
| 2                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ j \end{bmatrix}$  | -                                                           |
| 3                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -j \end{bmatrix}$ | -                                                           |

Table 1: Codebook for  $v$ -layer CSI reporting using antenna ports

| Codebook index, $n$ | Number of layers $\nu$                                                             |                                                                                               |                                                                                                                             |                                                                                                                                                          |
|---------------------|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
|                     | 1                                                                                  | 2                                                                                             | 3                                                                                                                           | 4                                                                                                                                                        |
| 0                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_0^{(2)} \\ e_0^{(2)} \end{bmatrix}$          | $\frac{1}{2} \begin{bmatrix} e_0^{(2)} & e_0^{(2)} \\ e_0^{(2)} & -e_0^{(2)} \end{bmatrix}$   | $\frac{1}{\sqrt{6}} \begin{bmatrix} e_0^{(2)} & e_0^{(2)} & e_1^{(2)} \\ e_0^{(2)} & -e_0^{(2)} & -e_1^{(2)} \end{bmatrix}$ | $\frac{1}{2\sqrt{2}} \begin{bmatrix} e_0^{(2)} & e_1^{(2)} & e_0^{(2)} & e_1^{(2)} \\ e_0^{(2)} & e_1^{(2)} & -e_0^{(2)} & -e_1^{(2)} \end{bmatrix}$     |
| 1                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_0^{(2)} \\ -e_0^{(2)} \end{bmatrix}$         | $\frac{1}{2} \begin{bmatrix} e_0^{(2)} & e_0^{(2)} \\ je_0^{(2)} & -je_0^{(2)} \end{bmatrix}$ | $\frac{1}{\sqrt{6}} \begin{bmatrix} e_1^{(2)} & e_0^{(2)} & e_1^{(2)} \\ e_1^{(2)} & -e_0^{(2)} & -e_1^{(2)} \end{bmatrix}$ | $\frac{1}{2\sqrt{2}} \begin{bmatrix} e_0^{(2)} & e_1^{(2)} & e_0^{(2)} & e_1^{(2)} \\ je_0^{(2)} & je_1^{(2)} & -je_0^{(2)} & -je_1^{(2)} \end{bmatrix}$ |
| 2                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_0^{(2)} \\ j \cdot e_0^{(2)} \end{bmatrix}$  | $\frac{1}{2} \begin{bmatrix} e_1^{(2)} & e_1^{(2)} \\ e_1^{(2)} & -e_1^{(2)} \end{bmatrix}$   | $\frac{1}{\sqrt{6}} \begin{bmatrix} e_0^{(2)} & e_1^{(2)} & e_1^{(2)} \\ e_0^{(2)} & e_1^{(2)} & -e_1^{(2)} \end{bmatrix}$  | -                                                                                                                                                        |
| 3                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_0^{(2)} \\ -j \cdot e_0^{(2)} \end{bmatrix}$ | $\frac{1}{2} \begin{bmatrix} e_1^{(2)} & e_1^{(2)} \\ je_1^{(2)} & -je_1^{(2)} \end{bmatrix}$ | $\frac{1}{\sqrt{6}} \begin{bmatrix} e_1^{(2)} & e_0^{(2)} & e_0^{(2)} \\ e_1^{(2)} & e_0^{(2)} & -e_0^{(2)} \end{bmatrix}$  | -                                                                                                                                                        |
| 4                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_1^{(2)} \\ e_1^{(2)} \end{bmatrix}$          | $\frac{1}{2} \begin{bmatrix} e_0^{(2)} & e_1^{(2)} \\ e_0^{(2)} & -e_1^{(2)} \end{bmatrix}$   | -                                                                                                                           | -                                                                                                                                                        |
| 5                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_1^{(2)} \\ -e_1^{(2)} \end{bmatrix}$         | $\frac{1}{2} \begin{bmatrix} e_0^{(2)} & e_1^{(2)} \\ je_0^{(2)} & -je_1^{(2)} \end{bmatrix}$ | -                                                                                                                           | -                                                                                                                                                        |
| 6                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_1^{(2)} \\ j \cdot e_1^{(2)} \end{bmatrix}$  | $\frac{1}{2} \begin{bmatrix} e_1^{(2)} & e_0^{(2)} \\ e_1^{(2)} & -e_0^{(2)} \end{bmatrix}$   | -                                                                                                                           | -                                                                                                                                                        |
| 7                   | $\frac{1}{\sqrt{2}} \begin{bmatrix} e_1^{(2)} \\ -j \cdot e_1^{(2)} \end{bmatrix}$ | $\frac{1}{2} \begin{bmatrix} e_1^{(2)} & e_0^{(2)} \\ je_1^{(2)} & -je_0^{(2)} \end{bmatrix}$ | -                                                                                                                           | -                                                                                                                                                        |

Table 2: Codebook for  $\nu$ -layer CSI reporting using antenna ports

In Table 1 and Table 2, above, the term  $e_k^{(N)}$  is a length- $N$  column-vector where its  $l$ -th element is 1 for  $k=l$  ( $k, l \in \{0, 1, \dots, N-1\}$ ), and 0 otherwise. In accordance with one or more embodiments, a codebook design for Class B FD-MIMO is provided which is capable of supporting similar spatial beam granularity as Class A FD-MIMO without providing additional CSI-RS overhead increase. Spatial granularity of a beamformed beam using precoding may refer to the angular spacing of a set of MIMO beams emitted from an antenna array 112 of eNB 110. Higher spatial granularity may refer to one or more beams that may be directed or disposed in between the spacing of a set of beams with lower spatial granularity. For example, if two beams have a spatial granularity of 30 degrees in angular separation, a beam having higher spatial granularity may be capable of being directed in between the two beams at an angle of 15 degrees apart from either of the two beams, or at any angle in between the two beams that are spaced apart by 30 degrees or whichever angular spacing the two beams may have from each other. Such a codebook design to provide higher spatial granularity beams is discussed with respect to FIG. 2, below.

Referring now to FIG. 2, a diagram of the network of FIG. 1 illustrating an additional beamformed beam having a finer spatial granularity than the set of CSI-RS beams in accordance with one or more embodiments will be discussed. As shown in FIG. 2, the precoding matrices from the codebook are applied to the channel measured on the beamformed CSI-RS resources to

obtain a new set of beams with finer spatial granularity than CSI-RS beams. In one or more embodiments, it may be assumed that the CSI-RS are beamformed using discrete Fourier transform (DFT) vectors without oversampling. It should be noted that this is merely one example implementation, and the codebook described herein also may be extended to other types of beamforming approaches used on CSI-RS resource. The codebook as described herein is capable of achieving higher spatial granularity of the beams in comparison to the CSI-RS beams without CSI-RS overhead increase.

To achieve beam 210 of FIG. 2 with a higher spatial granularity than the CSI-RS beams 114, the following analysis may be applied in accordance with one or more embodiments. The subset of the DFT beams, which is used for CSI-RS transmission to the UE is denoted as:

$$\mathbf{T} = [t_{l_1, m_1} \quad t_{l_2, m_2} \quad \cdots \quad t_{l_{P/2}, m_{P/2}}]$$

where:

$$t_{l_i, m_i} = \begin{bmatrix} s_{m_i} & e^{j \frac{2\pi l_i}{N_1}} s_{m_i} & \cdots & e^{j \frac{2\pi l_i (N_1-1)}{N_1}} s_{m_i} \end{bmatrix}^T, \quad s_{m_i} = \begin{bmatrix} 1 & e^{j \frac{2\pi m_i}{N_2}} & \cdots & e^{j \frac{2\pi m_i (N_2-1)}{N_2}} \end{bmatrix}$$

For construction of the T matrix, the DFT beam indexes  $l_i, m_i$  are provided to the UE using higher-layer signaling. For example, the bitmap of length  $(N_1 \cdot N_2)$  can be provided to the UE, where each bit in the bitmap indicates whether the corresponding beam is used for the beamformed CSI-RS transmission. In total, the bitmap should contain  $P/2$  non-zero bits with indices  $k_i$  ( $i = 1, \dots, P/2$ ), where  $P$  is the number of CSI-RS antenna ports. In this case, the indices  $l_i$  and  $m_i$  can be obtained as follows:

$$l_i = \left\lfloor \frac{k_i}{N_2} \right\rfloor, m_i = k_i \bmod N_2, i = 1, \dots, P/2$$

Then the beamforming vector for the proposed codebook is derived at the UE as follows:

$$v_{l,m} = \mathbf{T}^H v'_{l,m}$$

where:

$$u_m = \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \dots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix}, v'_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \dots & e^{j\frac{2\pi l(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}^T$$

- 5 The values of  $N_1$ ,  $N_2$ ,  $O_1$ ,  $O_2$  and  $k_i$  ( $i=1,\dots,P/2$ ) may be configured to UE 116 with the higher-layer signaling.

The final proposed Class B codebook is constructed from vectors  $v_{l,m}$  for each polarization and provided in Tables 1-4 for rank 1, 2, 3 and 4, respectively, where  $\varphi_n = e^{j\pi n/2}$  is a scalar used to co-phase the beams corresponding to different polarizations.

10

| $i_{1,1}$                                                                                               | $i_{1,2}$                  | $i_2$                           |                                 |                                 |                                 |
|---------------------------------------------------------------------------------------------------------|----------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
|                                                                                                         |                            | 0                               | 1                               | 2                               | 3                               |
| $0, 1, \dots, O_1 N_1 - 1$                                                                              | $0, 1, \dots, O_2 N_2 - 1$ | $W_{i_{1,1}, i_{1,2}, 0}^{(1)}$ | $W_{i_{1,1}, i_{1,2}, 1}^{(1)}$ | $W_{i_{1,1}, i_{1,2}, 2}^{(1)}$ | $W_{i_{1,1}, i_{1,2}, 3}^{(1)}$ |
| where $W_{l,m,n}^{(1)} = \frac{1}{\sqrt{P}} \begin{bmatrix} v_{l,m} \\ \varphi_n v_{l,m} \end{bmatrix}$ |                            |                                 |                                 |                                 |                                 |

Table 3: Codebook for 1-layer CSI reporting

| $i_{1,2} = 0, \dots, N_2 O_2 - 1$                                                                                                       |                                                   |                                                   |                                                   |                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------------------------------|
| $i_{1,1}$                                                                                                                               | $i_2$                                             |                                                   |                                                   |                                                   |
|                                                                                                                                         | 0                                                 | 1                                                 | 2                                                 | 3                                                 |
| $0, \dots, N_1 O_1 - 1$                                                                                                                 | $W_{i_{1,1}, i_{1,1}, i_{1,2}, i_{1,2}, 0}^{(2)}$ | $W_{i_{1,1}, i_{1,1}, i_{1,2}, i_{1,2}, 1}^{(2)}$ | $W_{i_{1,1}, i_{1,1}, i_{1,2}, i_{1,2}, 2}^{(2)}$ | $W_{i_{1,1}, i_{1,1}, i_{1,2}, i_{1,2}, 3}^{(2)}$ |
| where $W_{l,m,n}^{(2)} = \frac{1}{\sqrt{2P}} \begin{bmatrix} v_{l,m} & v_{l,m} \\ \varphi_n v_{l,m} & -\varphi_n v_{l,m} \end{bmatrix}$ |                                                   |                                                   |                                                   |                                                   |

Table 4: Codebook for 2-layer CSI reporting

| $N_2 = 1$                                                                                                                                                                                                                                                                                              |                                           |                                                   |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|---------------------------------------------------|
| $i_{1,2} = 0$                                                                                                                                                                                                                                                                                          |                                           |                                                   |
| $i_{1,1}$                                                                                                                                                                                                                                                                                              | $i_2$                                     |                                                   |
|                                                                                                                                                                                                                                                                                                        | 0                                         | 1                                                 |
| $0, \dots, O_1 N_1 - 1$                                                                                                                                                                                                                                                                                | $W_{i_{1,1}, i_{1,1} + O_1, 0, 0}^{(3)}$  | $\tilde{W}_{i_{1,1}, i_{1,1} + O_1, 0, 0}^{(3)}$  |
| $O_1 N_1, \dots, 2O_1 N_1 - 1$                                                                                                                                                                                                                                                                         | $W_{i_{1,1}, i_{1,1} + 2O_1, 0, 0}^{(3)}$ | $\tilde{W}_{i_{1,1}, i_{1,1} + 2O_1, 0, 0}^{(3)}$ |
| $2O_1 N_1, \dots, 3O_1 N_1 - 1$                                                                                                                                                                                                                                                                        | $W_{i_{1,1}, i_{1,1} + 3O_1, 0, 0}^{(3)}$ | $\tilde{W}_{i_{1,1}, i_{1,1} + 3O_1, 0, 0}^{(3)}$ |
| where $W_{l,l,m,m'}^{(3)} = \frac{1}{\sqrt{3P}} \begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} \\ v_{l,m} & -v_{l,m} & -v_{l',m'} \end{bmatrix}$ , $\tilde{W}_{l,l,m,m'}^{(3)} = \frac{1}{\sqrt{3P}} \begin{bmatrix} v_{l,m} & v_{l',m'} & v_{l',m'} \\ v_{l,m} & v_{l',m'} & -v_{l',m'} \end{bmatrix}$ |                                           |                                                   |

15

| $N_2 = 1$                                                                                                                                                                                                                                                                                                |                                           |                                                   |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|---------------------------------------------------|
| $i_{1,2} = 0$                                                                                                                                                                                                                                                                                            |                                           |                                                   |
| $i_{1,1}$                                                                                                                                                                                                                                                                                                | $i_2$                                     |                                                   |
|                                                                                                                                                                                                                                                                                                          | 0                                         | 1                                                 |
| $0, \dots, O_1 N_1 - 1$                                                                                                                                                                                                                                                                                  | $W_{i_{1,1}, i_{1,1} + O_1, 0, 0}^{(3)}$  | $\tilde{W}_{i_{1,1}, i_{1,1} + O_1, 0, 0}^{(3)}$  |
| $O_1 N_1, \dots, 2O_1 N_1 - 1$                                                                                                                                                                                                                                                                           | $W_{i_{1,1}, i_{1,1} + 2O_1, 0, 0}^{(3)}$ | $\tilde{W}_{i_{1,1}, i_{1,1} + 2O_1, 0, 0}^{(3)}$ |
| $2O_1 N_1, \dots, 3O_1 N_1 - 1$                                                                                                                                                                                                                                                                          | $W_{i_{1,1}, i_{1,1} + 3O_1, 0, 0}^{(3)}$ | $\tilde{W}_{i_{1,1}, i_{1,1} + 3O_1, 0, 0}^{(3)}$ |
| where $W_{l,l',m,m'}^{(3)} = \frac{1}{\sqrt{3P}} \begin{bmatrix} v_{l,m} & v_{l,m} & v_{l',m'} \\ v_{l,m} & -v_{l,m} & -v_{l',m'} \end{bmatrix}$ , $\tilde{W}_{l,l',m,m'}^{(3)} = \frac{1}{\sqrt{3P}} \begin{bmatrix} v_{l,m} & v_{l',m'} & v_{l',m'} \\ v_{l,m} & v_{l',m'} & -v_{l',m'} \end{bmatrix}$ |                                           |                                                   |

Table 5: Codebook for 3-layer CSI reporting

| $N_1 > 1, N_2 > 1$                                                                                                                                                                                                 |                                                          |                                                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|
| $i_{1,2} = 0, 1, \dots, N_2 O_2 - 1$                                                                                                                                                                               |                                                          |                                                          |
| $i_{1,1}$                                                                                                                                                                                                          | $i_2$                                                    |                                                          |
|                                                                                                                                                                                                                    | 0                                                        | 1                                                        |
| $0, \dots, N_1 O_1 - 1$                                                                                                                                                                                            | $W_{i_{1,1}, i_{1,1} + O_1, i_{1,2}, i_{1,2}, 0}^{(4)}$  | $W_{i_{1,1}, i_{1,1} + O_1, i_{1,2}, i_{1,2}, 1}^{(4)}$  |
| $O_1 N_1, \dots, 2O_1 N_1 - 1$                                                                                                                                                                                     | $W_{i_{1,1}, i_{1,1} + 2O_1, i_{1,2}, i_{1,2}, 0}^{(4)}$ | $W_{i_{1,1}, i_{1,1} + 2O_1, i_{1,2}, i_{1,2}, 1}^{(4)}$ |
| where $W_{l,l',m,m',n}^{(4)} = \frac{1}{\sqrt{4P}} \begin{bmatrix} v_{l,m} & v_{l',m'} & v_{l,m} & v_{l',m'} \\ \varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l,m} & -\varphi_n v_{l',m'} \end{bmatrix}$ |                                                          |                                                          |

5

| $N_2 = 1$                                                                                                                                                                                                          |                                              |                                              |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|----------------------------------------------|
| $i_{1,2} = 0$                                                                                                                                                                                                      |                                              |                                              |
| $i_{1,1}$                                                                                                                                                                                                          | $i_2$                                        |                                              |
|                                                                                                                                                                                                                    | 0                                            | 1                                            |
| $0, \dots, O_1 N_1 - 1$                                                                                                                                                                                            | $W_{i_{1,1}, i_{1,1} + O_1, 0, 0, 0}^{(4)}$  | $W_{i_{1,1}, i_{1,1} + O_1, 0, 0, 1}^{(4)}$  |
| $O_1 N_1, \dots, 2O_1 N_1 - 1$                                                                                                                                                                                     | $W_{i_{1,1}, i_{1,1} + 2O_1, 0, 0, 0}^{(4)}$ | $W_{i_{1,1}, i_{1,1} + 2O_1, 0, 0, 1}^{(4)}$ |
| $2O_1 N_1, \dots, 3O_1 N_1 - 1$                                                                                                                                                                                    | $W_{i_{1,1}, i_{1,1} + 3O_1, 0, 0, 0}^{(4)}$ | $W_{i_{1,1}, i_{1,1} + 3O_1, 0, 0, 1}^{(4)}$ |
| where $W_{l,l',m,m',n}^{(4)} = \frac{1}{\sqrt{4P}} \begin{bmatrix} v_{l,m} & v_{l',m'} & v_{l,m} & v_{l',m'} \\ \varphi_n v_{l,m} & \varphi_n v_{l',m'} & -\varphi_n v_{l,m} & -\varphi_n v_{l',m'} \end{bmatrix}$ |                                              |                                              |

Table 6: Codebook for 4-layer CSI reporting

Referring now to FIG. 3, a flow diagram of a method to utilize a codebook with fine spatial granularity for CSI reporting in accordance with one or more embodiments will be discussed. The codebook to obtain beam 210 with a finer spatial granularity may be utilized according to method

10



300. Method 300 may include more or fewer operations than shown in FIG.3, and/or the operations may be arranged in one or more various other orders than shown in FIG. 3, and the scope of the claimed subject matter is not limited in these respects. Furthermore, method 300 may be realized as logic circuitry and/or may be realized as machine readable instructions, optionally stored on a non-transitory computer readable medium having instructions stored thereon that, if executed by a machine such as an applications processor, result in implementation of method 300 in whole or in part. At operation 310, UE 116 receives a CSI-RS configuration from eNB 110. The CSI-RS configuration may be transmitted from eNB 110 to UE 116 as one or more information elements (IEs), for example the CSI-RS-Config information elements as specified in Section 6.3.2 “Radio Resource Control Elements” of Release 13 of Technical Specification 36.331 of the Third Generation Partnership Project (3GPP) that are used to specify the Channel-State Information reference signal configuration for the transmission of reference signals used in channel quality indicator (CQI) reporting and precoding matrix indicator (PMI) selection and feedback. The CSI-RS-Config used to specify the Channel-State Information (CSI) reference signal configuration may be as follows:

```
-- ASN1START
```

```
CSI-RS-Config-r10 ::= SEQUENCE {
    csi-RS-r10 CHOICE {
        release NULL,
        setup SEQUENCE {
            antennaPortsCount-r10 ENUMERATED {an1, an2, an4, an8},
            resourceConfig-r10 INTEGER (0..31),
            subframeConfig-r10 INTEGER (0..154),
            p-C-r10 INTEGER (-8..15)
        }
    }
    OPTIONAL, --
Need ON
    zeroTxPowerCSI-RS-r10 ZeroTxPowerCSI-RS-Conf-r12 OPTIONAL
-- Need ON
}
```

```
CSI-RS-Config-v1250 ::= SEQUENCE {
```

```

zeroTxPowerCSI-RS-r12      ZeroTxPowerCSI-RS-Conf-r12      OPTIONAL,
-- Need ON
ds-ZeroTxPowerCSI-RS-r12    CHOICE {
    release                NULL,
5    setup                  SEQUENCE {
        zeroTxPowerCSI-RS-List-r12      SEQUENCE (SIZE (1..maxDS-ZTP-CSI-RS-
r12)) OF ZeroTxPowerCSI-RS-r12
    }
    }
10 - Need ON
}

CSI-RS-Config-v1310 ::= SEQUENCE {
    eMIMO-Type-r13          CSI-RS-ConfigEMIMO-r13          OPTIONAL --
15 Need ON
}

CSI-RS-ConfigEMIMO-r13 ::= CHOICE {
    release                NULL,
20    setup                  CHOICE {
        nonPrecoded-r13          CSI-RS-ConfigNonPrecoded-r13,
        beamformed-r13          CSI-RS-ConfigBeamformed-r13
    }
}

25
CSI-RS-ConfigNonPrecoded-r13 ::= SEQUENCE {
    p-C-AndCBSRList-r13      P-C-AndCBSR-PerResourceConfig-r13
    OPTIONAL, -- Need OR
    codebookConfigN1-r13      ENUMERATED {n1, n2, n3, n4, n8},
30    codebookConfigN2-r13      ENUMERATED {n1, n2, n3, n4, n8},
    codebookOverSamplingRateConfig-O1-r13ENUMERATED {n4, n8}
    OPTIONAL, -- Need OR
    codebookOverSamplingRateConfig-O2-r13ENUMERATED {n4,n8}
    OPTIONAL, -- Need OR
35    codebookConfig-r13        INTEGER (1..4),

```

```

    csi-IM-ConfigIdList-r13          SEQUENCE (SIZE (1..2)) OF CSI-IM-
ConfigId-r13  OPTIONAL,  -- Need OR
    csi-RS-ConfigNZP-EMIMO-r13      CSI-RS-ConfigNZP-EMIMO-r13
    OPTIONAL  -- Need ON
5  }

CSI-RS-ConfigBeamformed-r13 ::= SEQUENCE {
    csi-RS-ConfigNZPIdListExt-r13    SEQUENCE (SIZE (1..7)) OF CSI-RS-
ConfigNZPId-r13  OPTIONAL,  -- Need OR
10  csi-IM-ConfigIdList-r13          SEQUENCE (SIZE (1..8)) OF CSI-IM-
ConfigId-r13  OPTIONAL,  -- Need OR
    p-C-AndCBSR-PerResourceConfigList-r13 SEQUENCE (SIZE (1..8)) OF P-C-AndCBSR-
PerResourceConfig-r13 OPTIONAL,  -- Need OR
    ace-For4Tx-PerResourceConfigList-r13 SEQUENCE (SIZE (1..7)) OF BOOLEAN
15  OPTIONAL,  -- Need OR
    alternativeCodebookEnabledBeamformed-r13 ENUMERATED {true}  OPTIONAL, -
- Need OR
    channelMeasRestriction-r13        ENUMERATED {on}          OPTIONAL -
- Need OR
20  }

ZeroTxPowerCSI-RS-Conf-r12 ::= CHOICE {
    release          NULL,
    setup            ZeroTxPowerCSI-RS-r12
25  }

ZeroTxPowerCSI-RS-r12 ::= SEQUENCE {
    zeroTxPowerResourceConfigList-r12 BIT STRING (SIZE (16)),
    zeroTxPowerSubframeConfig-r12     INTEGER (0..154)
30  }

-- ASN1STOP

```

The CSI-RS-Config field descriptions for the IE, above, may be as follows:

35

| <b>CSI-RS-Config field descriptions</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b><i>ace-For4Tx-PerResourceConfigList</i></b></p> <p>The field indicates the <i>alternativeCodeBookEnabledFor4TX-r12</i> per CSI-RS resource. E-UTRAN configures the field only if <i>csi-RS-ConfigNZPIdListExt</i> is configured.</p>                                                                                                                                                                                                                                                                                                                                                     |
| <p><b><i>antennaPortsCount</i></b></p> <p>Parameter represents the number of antenna ports used for transmission of CSI reference signals where value an1 corresponds to 1 antenna port, an2 to 2 antenna ports and so on, see TS 36.211 [21, 6.10.5].</p>                                                                                                                                                                                                                                                                                                                                     |
| <p><b><i>alternativeCodebookEnabledBeamformed</i></b></p> <p>The field indicates whether code book in TS 36.213 [23, Tab 7.2.4-18 to Tab 7.2.4-20] is being used for deriving CSI feedback and reporting for a CSI process. E-UTRAN configures the field only for a process referring to a single RS configuration using non-zero power transmission (i.e a process for which <i>csi-RS-ConfigNZPIdListExt</i> is not configured). Field <i>alternativeCodebookEnabledBeamformed</i> corresponds to parameter <i>alternativeCodebookEnabledCLASSB_K1</i> in TS36.212 and TS36.213 [22, 23]</p> |
| <p><b><i>codebookConfig</i></b></p> <p>Indicates a sub-set of the codebook entry, see TS 36.213 [23].</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

| <b>CSI-RS-Config field descriptions</b>         |                                                                                                                                                                                                       |
|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b><i>codebookConfigNx</i></b>                  | Indicates the number of antenna ports per polarization in dimension x as used for transmission of CSI reference signals. Value n1 corresponds to 1, n2 to 2 and so on, see TS 36.213 [23].            |
| <b><i>codebookOverSamplingRateConfig-Ox</i></b> | Indicates the spatial over-sampling rate in dimension x as used for transmission of CSI reference signals. Value n1 corresponds to 1, n2 to 2 and so on, see TS 36.213 [23].                          |
| <b><i>csi-IM-ConfigId(List)</i></b>             | E-UTRAN configures the field <i>csi-IM-ConfigIdList</i> only if the IE is included in CSI-Process is configured (i.e. when TM10 is configured for the serving cell).                                  |
| <b><i>CSI-RS-ConfigBeamformed</i></b>           | If <i>csi-RS-ConfigNZPIdListExt-r13</i> is configured, E-UTRAN configures the same total number of entries for NZP, <i>csi-IM-ConfigIdList-r13</i> and <i>p-C-AndCBSR-PerResourceConfigList-r13</i> . |
| <b><i>ds-ZeroTxPowerCSI-RS</i></b>              | Parameter for additional <i>zeroTxPowerCSI-RS</i> for a serving cell, concerning the CSI-RS included in discovery signals.                                                                            |
| <b><i>p-C</i></b>                               | Parameter: $P_c$ , see TS 36.213 [23, 7.2.5].                                                                                                                                                         |
| <b><i>p-C-AndCBSRList</i></b>                   | E-UTRAN includes 2 entries in <i>p-C-AndCBSRList</i> when configuring both <i>cqi-pmi-ConfigIndex</i> and <i>cqi-pmi-ConfigIndex2</i> . If configured with TM9, E-UTRAN configures a single entry.    |
| <b><i>resourceConfig</i></b>                    | Parameter: CSI reference signal configuration, see TS 36.211 [21, table 6.10.5.2-1 and 6.10.5.2-2].                                                                                                   |
| <b><i>subframeConfig</i></b>                    | Parameter: $I_{\text{CSI-RS}}$ , see TS 36.211 [21, table 6.10.5.3-1].                                                                                                                                |
| <b><i>zeroTxPowerCSI-RS2</i></b>                | Parameter for additional <i>zeroTxPowerCSI-RS</i> for a serving cell. E-UTRAN configures the field only if <i>csi-MeasSubframeSets-r12</i> and <i>TM 1 – 9</i> are configured for the serving cell.   |

| <b>CSI-RS-Config field descriptions</b>     |                                                                        |
|---------------------------------------------|------------------------------------------------------------------------|
| <b><i>zeroTxPowerResourceConfigList</i></b> | Parameter: <i>ZeroPowerCSI-RS</i> , see TS 36.213 [23, 7.2.7].         |
| <b><i>zeroTxPowerSubframeConfig</i></b>     | Parameter: $I_{\text{CSI-RS}}$ , see TS 36.211 [21, table 6.10.5.3-1]. |

The CSI-RS configuration information elements may include the number of antennas used by eNB 110 to transmit the CSI reference signals to UE 116, including for example an indication that an alternative codebook will be utilized, and/or other parameters to configure UE 116 to be able to receive the CSI reference signals and to create a custom codebook utilized for transmit beamforming of the data signal transmitted from eNB 110 to UE 116. The CSI-RS configuration as described in 36.331 accordingly may be involved to allow to allow a custom configured codebook to be created.

In accordance with one or more embodiments, four transmit beams may be emitted from eNB 110 at predetermined angles. As shown in FIG. 1 and FIG. 2, UE 116, may be positioned at a location between two of the four beams such that none of the four beams is ideal for UE 116. As a result, in accordance with one or more embodiments, a custom codebook may be created such that the CSI-RS transmission and CQI and PMI reporting from UE 116 to eNB 110 in response to UE 110 processing the CSI-RS signals received from eNB 110. Such a custom codebook may be utilized to allow eNB 116 to form a beam between one of the four standard set of four CSI-RS beams, wherein the formed beam may have a higher spatial granularity than the standard set of four CSI-RS beams such that this formed beam may be pointed directly at, or at least more directly at, UE 116 than any one of the standard four CSI-RS beams. It should be noted that since the codebook is configurable as described herein, the codebook may be created to obtain higher spatial granularity than the standard set of reference beams for a given UE 116 while the conditions between eNB 110 and UE 116 remain relatively unchanged or valid, for example while UE 116 maintains a relative position and/or a relative distance with respect to eNB 110, and/or while UE 116 maintains connectivity with eNB 110, and so on. In the event conditions change, for example UE 116 disconnects from eNB 110 and later reconnects to eNB 110 at a later time and/or at a different location with respect to eNB 110, the codebook may be updated and/or a new codebook may be configured to create a codebook with updated and/or different higher spatial granularity beams in a new relative spacing with respect to the four standard CSI-RS beams, and the scope of the claimed subject matter is not limited in these respects.

At operation 312, eNB 110 transmits a first set of beamforming vectors used for CSI-RS transmissions to UE 116. At operation 314, eNB 110 transmits a second set of beamforming vectors with a high spatial resolution, for example including parameters  $N_1$ ,  $N_2$ ,  $O_1$ , and/or  $O_2$ , from which to determine one or more high spatial granularity beams such as beam 210. At operation 316 UE 116 configures a codebook based at least in part on the first and second sets of beamforming vectors wherein the codebook includes high spatial granularity beams. At operation 318, eNB 110 transmits CSI-RS reference signals to UE 116 using the first set of beamforming vectors, for example via beams 114 of FIG. 1. At operation 320, UE performs CSI measurements on the CSI-RS reference signals transmitted via beams 114. At operation 322, UE 116 selects a best high spatial granularity beam, for example beam 210, from the codebook based at least in part on the CSI measurements. At operation 324, UE 116 reports back a precoding matrix indicator (PMI) to eNB 110 indicating the selected high spatial granularity beam, such as beam 210. At operation 326, eNB 110 transmits data to UE 116 using the selected high spatial granularity beam, such as beam 210, based on the PMI received from UE 116. It should be noted that in the example shown in FIG. 2, one particular high spatial granularity beam, beam 210, is illustrated for purposes of example. The codebooks herein may describe multiple high spatial granularity beams in addition to beam 210, and the scope of the claimed subject matter is not limited in this respect.

Referring now to FIG. 4, example components of a wireless device such as an evolved NodeB (eNB) 110 device or a User Equipment (UE) 116 device in accordance with one or more embodiments will be discussed. In some embodiments, device 400 may include application circuitry 402, computer readable storage medium or media 412, baseband circuitry 404, Radio Frequency (RF) circuitry 406, front-end module (FEM) circuitry 408 and one or more antennas 410, coupled together at least as shown. In other embodiments, the above described circuitries may be included in various devices, in whole or in part, for example an eNB 110 according to a cloud-RAN (C-RAN) implementation, and the scope of the claimed subject matter is not limited in these respects. Computer readable medium or media 412 may comprise one or more of various types of memory or storage devices including volatile memory and/or non-volatile memory, for example flash memory, dynamic random-access memory (DRAM), static random-access memory (SRAM), NOT OR (NOR) memory, and/or NOT AND (NAND) memory, and the scope of the claimed subject matter is not limited in this respect.

As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or

functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software.

5        Application circuitry 400 may include one or more application processors. For example, application circuitry 400 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The one or more processors may include any combination of general-purpose processors and dedicated processors, for example graphics processors, application processors, and so on. The processors may be coupled with and/or may include memory and/or  
10       storage and may be configured to execute instructions stored in the memory and/or storage to enable various applications and/or operating systems to run on the system.

Baseband circuitry 404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. Baseband circuitry 404 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of  
15       RF circuitry 406 and to generate baseband signals for a transmit signal path of the RF circuitry 406. Baseband processing circuitry 404 may interface with the application circuitry 402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 406. For example, in some embodiments, the baseband circuitry 404 may include a second generation (2G) baseband processor 404a, third generation (3G) baseband processor 404b, fourth  
20       generation (4G) baseband processor 404c, and/or one or more other baseband processors 404d for other existing generations, generations in development or to be developed in the future, for example fifth generation (5G), sixth generation (6G), and so on. Baseband circuitry 404, for example one or more of baseband processors 404a through 404d, may handle various radio control functions that enable communication with one or more radio networks via RF circuitry 406. The  
25       radio control functions may include, but are not limited to, signal modulation and/or demodulation, encoding and/or decoding, radio frequency shifting, and so on. In some embodiments, modulation and/or demodulation circuitry of baseband circuitry 404 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping and/or demapping functionality. In some embodiments, encoding and/or decoding circuitry of baseband circuitry 404 may include  
30       convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder and/or decoder functionality. Embodiments of modulation and/or demodulation and encoder and/or decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.



In some embodiments, baseband circuitry 404 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements.

- 5 Processor 404e of the baseband circuitry 404 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processors (DSP) 404f. The one or more audio DSPs 404f may include elements for compression and/or decompression and/or echo cancellation and may include other suitable processing elements in other embodiments.
- 10 Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of baseband circuitry 404 and application circuitry 402 may be implemented together such as, for example, on a system on a chip (SOC). In some embodiments, computer readable storage medium or media 412 may be disposed in whole or at least in part on a
- 15 separate chip from application circuitry 402, and in other embodiments may be integrated in whole or at least in part on application circuitry 402, although the scope of the claimed subject matter is not limited in these respects.

In some embodiments, baseband circuitry 404 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, baseband circuitry 404

20 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which baseband circuitry 404 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

- 25 RF circuitry 406 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, RF circuitry 406 may include switches, filters, amplifiers, and so on, to facilitate the communication with the wireless network. RF circuitry 406 may include a receive signal path which may include circuitry to down-convert RF signals received from FEM circuitry 408 and provide baseband signals to
- 30 baseband circuitry 404. RF circuitry 406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 404 and provide RF output signals to FEM circuitry 408 for transmission.

- In some embodiments, RF circuitry 406 may include a receive signal path and a transmit signal path. The receive signal path of RF circuitry 406 may include mixer circuitry 406a,
- 35 amplifier circuitry 406b and filter circuitry 406c. The transmit signal path of RF circuitry 406 may

include filter circuitry 406c and mixer circuitry 406a. RF circuitry 406 may also include synthesizer circuitry 406d for synthesizing a frequency for use by the mixer circuitry 406a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 406a of the receive signal path may be configured to down-convert RF signals received from FEM circuitry 408 based on the synthesized frequency provided by synthesizer circuitry 406d. Amplifier circuitry 406b may be configured to amplify the down-converted signals and the filter circuitry 406c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to baseband circuitry 404 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this may be optional. In some embodiments, mixer circuitry 406a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

In some embodiments, mixer circuitry 406a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by synthesizer circuitry 406d to generate RF output signals for FEM circuitry 408. The baseband signals may be provided by the baseband circuitry 404 and may be filtered by filter circuitry 406c. Filter circuitry 406c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

In some embodiments, mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include two or more mixers and may be arranged for quadrature down conversion and/or up conversion respectively. In some embodiments, mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include two or more mixers and may be arranged for image rejection, for example Hartley image rejection. In some embodiments, mixer circuitry 406a of the receive signal path and the mixer circuitry 406a may be arranged for direct down conversion and/or direct up conversion, respectively. In some embodiments, mixer circuitry 406a of the receive signal path and mixer circuitry 406a of the transmit signal path may be configured for super-heterodyne operation.

In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, RF circuitry 406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry, and baseband circuitry 404 may include a digital baseband interface to communicate with RF circuitry 406. In some dual-mode embodiments, separate radio integrated circuit (IC) circuitry may be provided for processing

signals for one or more spectra, although the scope of the embodiments is not limited in this respect.

In some embodiments, synthesizer circuitry 406d may be a fractional-N synthesizer or a fractional  $N/N+1$  synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 406d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

Synthesizer circuitry 406d may be configured to synthesize an output frequency for use by mixer circuitry 406a of RF circuitry 406 based on a frequency input and a divider control input.

In some embodiments, synthesizer circuitry 406d may be a fractional  $N/N+1$  synthesizer.

In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although this may be optional. Divider control input may be provided by either baseband circuitry 404 or applications processor 402 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by applications processor 402.

Synthesizer circuitry 406d of RF circuitry 406 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or  $N+1$ , for example based on a carry out, to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into  $N_d$  equal packets of phase, where  $N_d$  is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

In some embodiments, synthesizer circuitry 406d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency, for example twice the carrier frequency, four times the carrier frequency, and so on, and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a local oscillator (LO) frequency (fLO). In some embodiments, RF circuitry 406 may include an in-phase and quadrature (IQ) and/or polar converter.

FEM circuitry 408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 710, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 406 for further processing. FEM circuitry 408 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by RF circuitry 406 for transmission by one or more of the one or more antennas 410.

In some embodiments, FEM circuitry 408 may include a transmit/receive (TX/RX) switch to switch between transmit mode and receive mode operation. FEM circuitry 408 may include a receive signal path and a transmit signal path. The receive signal path of FEM circuitry 408 may include a low-noise amplifier (LNA) to amplify received RF signals and to provide the amplified received RF signals as an output, for example to RF circuitry 406. The transmit signal path of FEM circuitry 408 may include a power amplifier (PA) to amplify input RF signals, for example provided by RF circuitry 406, and one or more filters to generate RF signals for subsequent transmission, for example by one or more of antennas 410. In some embodiments, device 400 may include additional elements such as, for example, memory and/or storage, display, camera, sensor, and/or input/output (I/O) interface, although the scope of the claimed subject matter is not limited in this respect.

The following are example implementations of the subject matter described herein. It should be noted that any of the examples and the variations thereof described herein may be used in any permutation or combination of any other one or more examples or variations, although the scope of the claimed subject matter is not limited in these respects. In example one, an apparatus of a user equipment (UE) comprises baseband circuitry, including one or more processors, to decode a Radio Resource Control (RRC) message from an evolved Node B (eNB) to obtain one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config), demodulate a first physical downlink shared channel (PDSCH) message from the eNB to obtain a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission, demodulate a second PDSCH message from the eNB to obtain a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams, configure a codebook based at least in part on the first set of beamforming vectors and second set of the beamforming vectors, process CSI-RS reference signals transmitted from the eNB to the UE using the first set of beamforming vectors, and encode physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to include a precoding matrix index (PMI) indicative of a high spatial granularity beam. In example two, the apparatus may include the subject matter of example one or any of the examples described herein, and further may comprise radio frequency

(RF) circuitry to receive data from the eNB via the high spatial granularity beam. In example three, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is based on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix. In example four, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is indicated by a bitmap wherein indices of non-zero bits correspond to selected vectors. In example five, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional (2D) discrete Fourier transform (DFT) matrix. In example six, the apparatus may include the subject matter of example one or any of the examples described herein, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors. In example seven, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the codebook is constructed from the first set of beamforming vectors and the second set of beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar. In example eight, the apparatus may include the subject matter of example one or any of the examples described herein, wherein codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

In example nine, an apparatus of an evolved Node B (eNB) comprises baseband circuitry, including one or more processors, to encode a Radio Resource Control (RRC) message to be sent to a user equipment (UE) to include one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config), modulate a first physical downlink shared channel (PDSCH) message to be sent to the UE to include a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission, modulate a second PDSCH message from to the UE to include a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams, generate CSI-RS reference signals to be sent to the UE, decode physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to including a precoding matrix index (PMI) indicative of a high spatial granularity beam, and encode data to be transmitted to the UE via the high spatial granularity beam. In example ten, the apparatus may include the subject matter of example one or any of the examples described herein, and further may comprise radio frequency (RF) circuitry to transmit data to the UE via the high spatial granularity beam. In example eleven, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is based

on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix. In example twelve, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is indicated by a bitmap wherein indices of non-zero bits correspond to selected vectors. In example thirteen, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional (2D) discrete Fourier transform (DFT) matrix. In example fourteen, the apparatus may include the subject matter of example one or any of the examples described herein, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors. In example fifteen, the apparatus may include the subject matter of example one or any of the examples described herein, wherein the codebook is constructed from the first set of beamforming vectors and the second set of beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar. In example sixteen, the apparatus may include the subject matter of example one or any of the examples described herein,, wherein codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

In example seventeen, one or more computer-readable media may include instructions stored thereon that, if executed by a user equipment (UE), result in decoding a Radio Resource Control (RRC) message from an evolved Node B (eNB) to obtain one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config), demodulating a first physical downlink shared channel (PDSCH) message from the eNB to obtain a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission, demodulating a second PDSCH message from the eNB to obtain a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams, configuring a codebook based at least in part on the first set of beamforming vectors and second set of the beamforming vectors, processing CSI-RS reference signals transmitted from the eNB to the UE using the first set of beamforming vectors, and encoding physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to include a precoding matrix index (PMI) indicative of a high spatial granularity beam. In example eighteen, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is based on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix. In example nineteen, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is indicated by a bitmap wherein indices of non-zero bits correspond to

selected vectors. In example twenty, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional (2D) discrete Fourier transform (DFT) matrix. In example twenty-one, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors. In example twenty-two, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the codebook is constructed from the first set of beamforming vectors and the second set of beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar. In example twenty-three, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

In example twenty-four, one or more computer-readable media may include instructions stored thereon that, if executed by an evolved Node B (eNB), result in encoding a Radio Resource Control (RRC) message to be sent to a user equipment (UE) to include one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config), modulating a first physical downlink shared channel (PDSCH) message to be sent to the UE to include a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission, modulating a second PDSCH message from to the UE to include a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams, generating CSI-RS reference signals to be sent to the UE, decoding physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to including a precoding matrix index (PMI) indicative of a high spatial granularity beam, and encoding data to be transmitted to the UE via the high spatial granularity beam. In example twenty-five, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is based on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix. In example twenty-six, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the first set of beamforming vectors is indicated by a bitmap wherein indices of non-zero bits correspond to selected vectors. In example twenty-seven, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional

(2D) discrete Fourier transform (DFT) matrix. In example twenty-eight, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors. In example twenty-nine, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein the codebook is constructed from the first set of beamforming vectors and the second set of beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar. In example thirty, the one or more computer-readable media may include the subject matter of example one or any of the examples described herein, wherein codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

In example thirty-one, an apparatus comprises means for decoding a Radio Resource Control (RRC) message from an evolved Node B (eNB) to obtain one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config), means for demodulating a first physical downlink shared channel (PDSCH) message from the eNB to obtain a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission, means for demodulating a second PDSCH message from the eNB to obtain a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams, means for configuring a codebook based at least in part on the first set of beamforming vectors and second set of the beamforming vectors, means for processing CSI-RS reference signals transmitted from the eNB to the UE using the first set of beamforming vectors, and means for encoding physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to include a precoding matrix index (PMI) indicative of a high spatial granularity beam. In example thirty-two, an apparatus comprises means for encoding a Radio Resource Control (RRC) message to be sent to a user equipment (UE) to include one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config), means for modulating a first physical downlink shared channel (PDSCH) message to be sent to the UE to include a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission, means for modulating a second PDSCH message from to the UE to include a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams, means for generating CSI-RS reference signals to be sent to the UE, means for decoding physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to including a precoding matrix index (PMI) indicative of a high spatial granularity



beam, and means for encoding data to be transmitted to the UE via the high spatial granularity beam.

Although the claimed subject matter has been described with a certain degree of particularity, it should be recognized that elements thereof may be altered by persons skilled in the art without departing from the spirit and/or scope of claimed subject matter. It is believed that the subject matter codebook with fine spatial granularity for CSI reporting and many of its attendant utilities will be understood by the forgoing description, and it will be apparent that various changes may be made in the form, construction and/or arrangement of the components thereof without departing from the scope and/or spirit of the claimed subject matter or without sacrificing all of its material advantages, the form herein before described being merely an explanatory embodiment thereof, and/or further without providing substantial change thereto. It is the intention of the claims to encompass and/or include such changes.

## CLAIMS

What is claimed is:

5           1. An apparatus of a user equipment (UE) comprising baseband circuitry, including one or more processors, to:

          decode a Radio Resource Control (RRC) message from an evolved Node B (eNB) to obtain one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config);

10           demodulate a first physical downlink shared channel (PDSCH) message from the eNB to obtain a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission;

          demodulate a second PDSCH message from the eNB to obtain a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial  
15           granularity beams;

          configure a codebook based at least in part on the first set of beamforming vectors and second set of the beamforming vectors;

          process CSI-RS reference signals transmitted from the eNB to the UE using the first set of beamforming vectors; and

20           encode physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to include a precoding matrix index (PMI) indicative of a high spatial granularity beam.

          2. The apparatus of claim 1, further comprising:

25           radio frequency (RF) circuitry to receive data from the eNB via the high spatial granularity beam.

          3. The apparatus as claimed in any of claims 1-2, wherein the first set of beamforming vectors is based on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix.

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          4. The apparatus as claimed in any of claims 1-3, wherein the first set of beamforming vectors is indicated by a bitmap wherein indices of non-zero bits correspond to selected vectors.

5. The apparatus as claimed in any of claims 1-4, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional (2D) discrete Fourier transform (DFT) matrix.

6. The apparatus as claimed in any of claims 1-5, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors.

7. The apparatus as claimed in any of claims 1-6, wherein the codebook is constructed from the first set of beamforming vectors and the second set of beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar.

8. The apparatus as claimed in any of claims 1-7, wherein codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

9. An apparatus of an evolved Node B (eNB) comprising baseband circuitry, including one or more processors, to:

encode a Radio Resource Control (RRC) message to be sent to a user equipment (UE) to include one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config);

modulate a first physical downlink shared channel (PDSCH) message to be sent to the UE to include a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission;

modulate a second PDSCH message from to the UE to include a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams;

generate CSI-RS reference signals to be sent to the UE;

decode physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to including a precoding matrix index (PMI) indicative of a high spatial granularity beam; and

encode data to be transmitted to the UE via the high spatial granularity beam.

10. The apparatus of claim 9, further comprising:

radio frequency (RF) circuitry to transmit data to the UE via the high spatial granularity beam.

11. The apparatus as claimed in any of claims 9-10, wherein the first set of beamforming vectors is based on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix.

12. The apparatus as claimed in any of claims 9-11, wherein the first set of beamforming  
5 vectors is indicated by a bitmap wherein indices of non-zero bits correspond to selected vectors.

13. The apparatus as claimed in any of claims 9-12, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional (2D) discrete Fourier transform (DFT) matrix.

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14. The apparatus as claimed in any of claims 9-13, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors.

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15. The apparatus as claimed in any of claims 9-14, wherein the codebook is constructed from the first set of beamforming vectors and the second set of beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar.

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16. The apparatus as claimed in any of claims 9-15, wherein codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

17. One or more computer-readable media having instructions stored thereon that, if executed by a user equipment (UE), result in:

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decoding a Radio Resource Control (RRC) message from an evolved Node B (eNB) to obtain one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config);

demodulating a first physical downlink shared channel (PDSCH) message from the eNB to obtain a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission;

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demodulating a second PDSCH message from the eNB to obtain a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams;

configuring a codebook based at least in part on the first set of beamforming vectors and second set of the beamforming vectors;

processing CSI-RS reference signals transmitted from the eNB to the UE using the first set of beamforming vectors; and

encoding physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to include a precoding matrix index (PMI) indicative of a high spatial granularity beam.

18. The one or more computer-readable media as claimed in claim 17, wherein the first set of beamforming vectors is based on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix.

19. The one or more computer-readable media as claimed in any of claims 17-18, wherein the first set of beamforming vectors is indicated by a bitmap wherein indices of non-zero bits correspond to selected vectors.

20. The one or more computer-readable media as claimed in any of claims 17-19, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional (2D) discrete Fourier transform (DFT) matrix.

21. The one or more computer-readable media as claimed in any of claims 17-20, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors.

22. The one or more computer-readable media as claimed in any of claims 17-21, wherein the codebook is constructed from the first set of beamforming vectors and the second set of beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar.

23. The one or more computer-readable media as claimed in any of claims 17-22, wherein codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

24. One or more computer-readable media having instructions stored thereon that, if executed by an evolved Node B (eNB), result in:

encoding a Radio Resource Control (RRC) message to be sent to a user equipment (UE) to include one or more information elements (IEs) including a channel state information reference signal (CSI-RS) configuration (CSI-RS-Config);

5 modulating a first physical downlink shared channel (PDSCH) message to be sent to the UE to include a first set of beamforming vectors, wherein the first set of beamforming vectors is to be used for CSI-RS transmission;

modulating a second PDSCH message from to the UE to include a second set of beamforming vectors, wherein the second set of beamforming vectors is to be utilized to form high spatial granularity beams;

10 generating CSI-RS reference signals to be sent to the UE;

decoding physical uplink control channel (PUCCH) data or physical uplink shared channel (PUSCH) data to including a precoding matrix index (PMI) indicative of a high spatial granularity beam; and

encoding data to be transmitted to the UE via the high spatial granularity beam.

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25. The one or more computer-readable media as claimed in claim 24, wherein the first set of beamforming vectors is based on vectors of a two-dimensional (2D) discrete Fourier transform (DFT) matrix.

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26. The one or more computer-readable media as claimed in any of claims 24-25, wherein the first set of beamforming vectors is indicated by a bitmap wherein indices of non-zero bits correspond to selected vectors.

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27. The one or more computer-readable media as claimed in any of claims 24-26, wherein the second set of the beamforming vectors is based at least in part on vectors of an oversampled two-dimensional (2D) discrete Fourier transform (DFT) matrix.

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28. The one or more computer-readable media as claimed in any of claims 24-27, wherein vectors for the codebook are constructed by taking a product of a conjugate-transposed matrix derived from the first set of beamforming vectors and a matrix derived from the second set of beamforming vectors.

29. The one or more computer-readable media as claimed in any of claims 24-28, wherein the codebook is constructed from the first set of beamforming vectors and the second set of

beamforming vectors via concatenation of two vectors and multiplication of one of the two vectors by a complex scalar.

30. The one or more computer-readable media as claimed in any of claims 24-29, wherein  
5 codebook includes tables for rank 1, rank 2, rank 3, or rank 4, or a combination thereof.

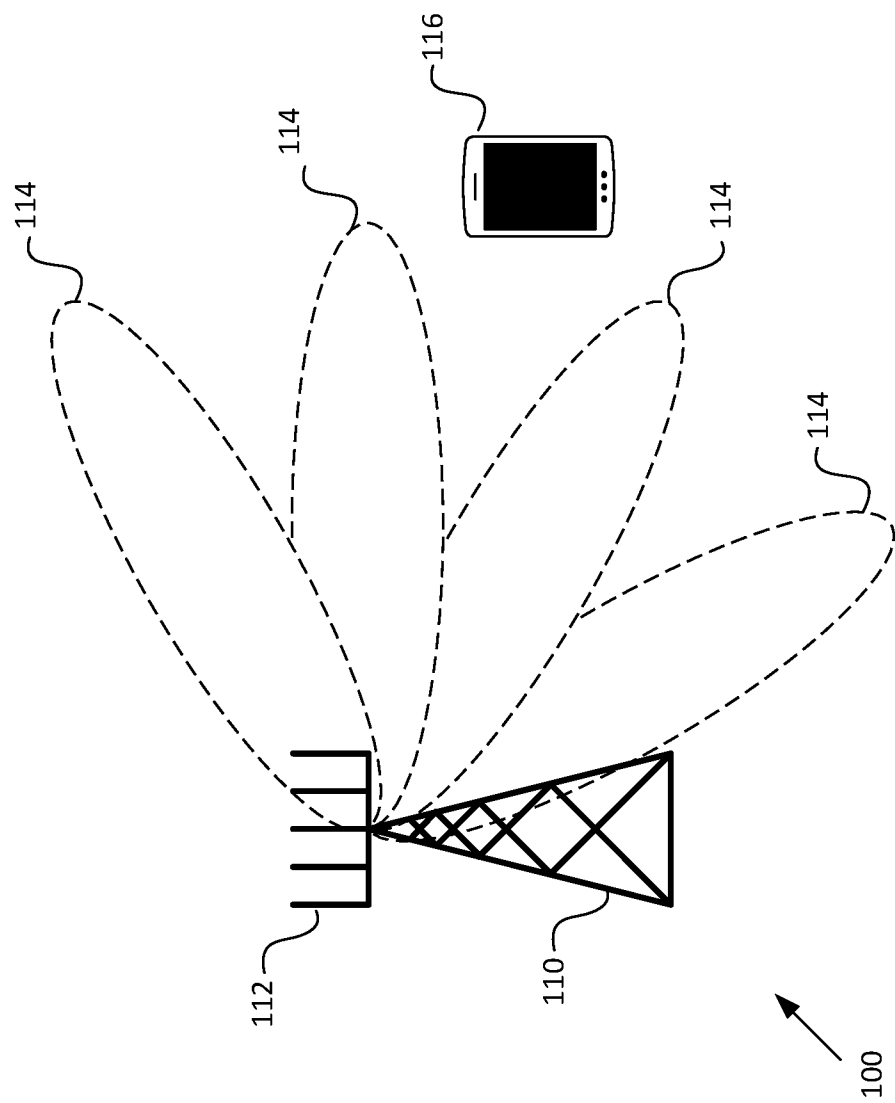


FIG. 1



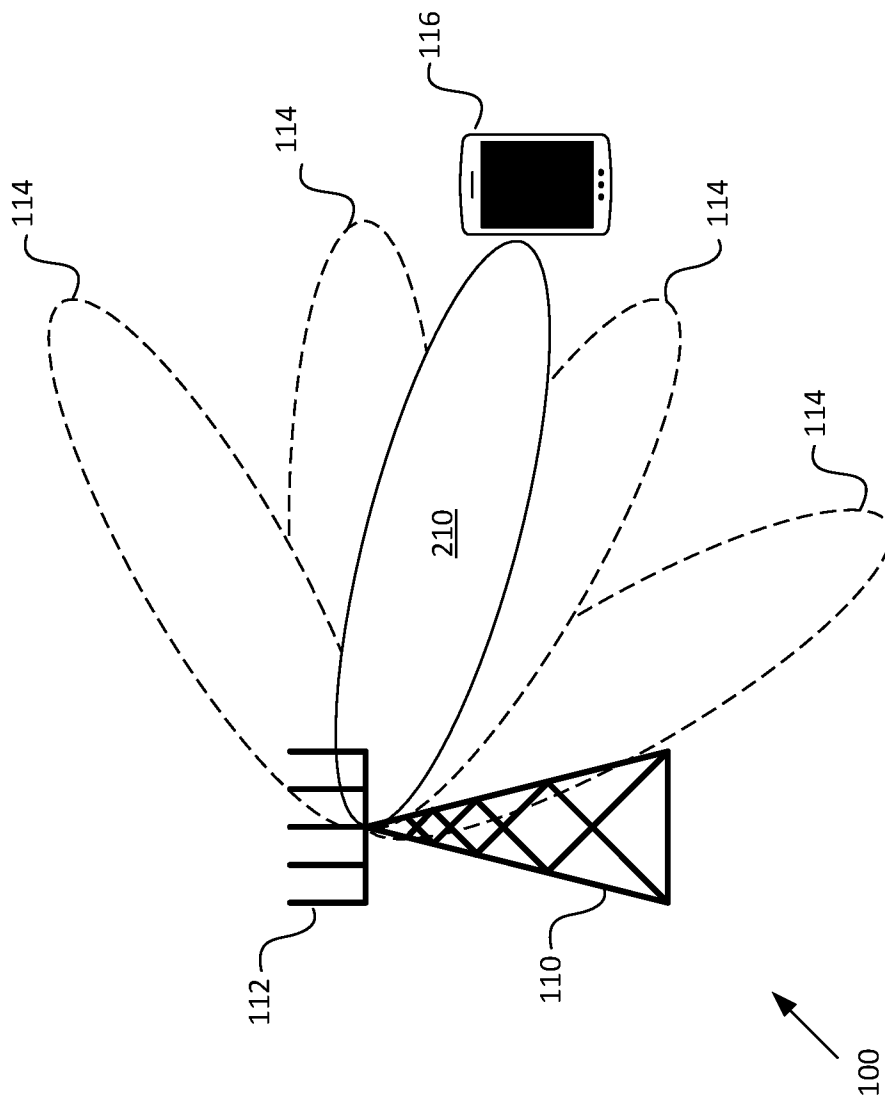


FIG. 2

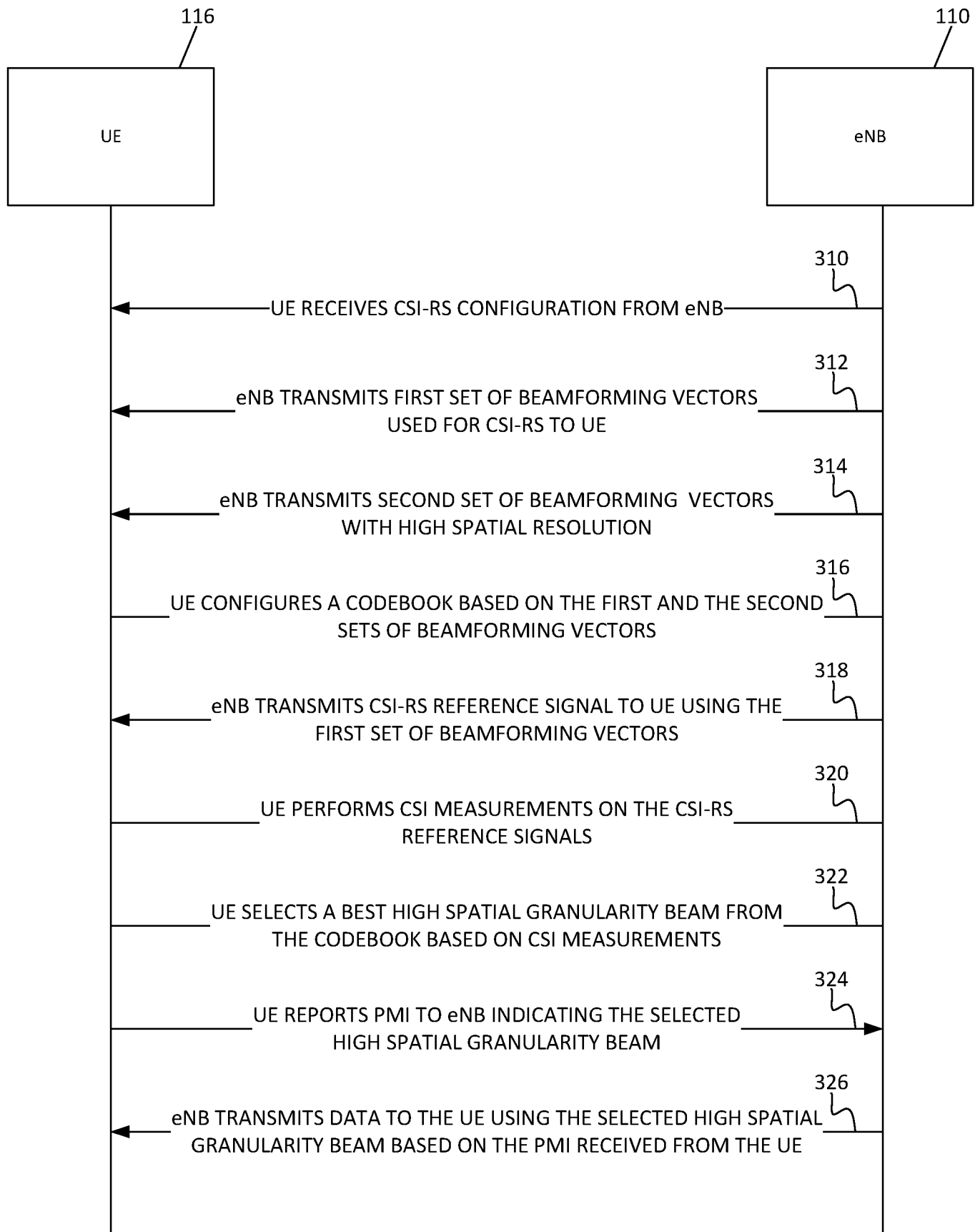


FIG. 3

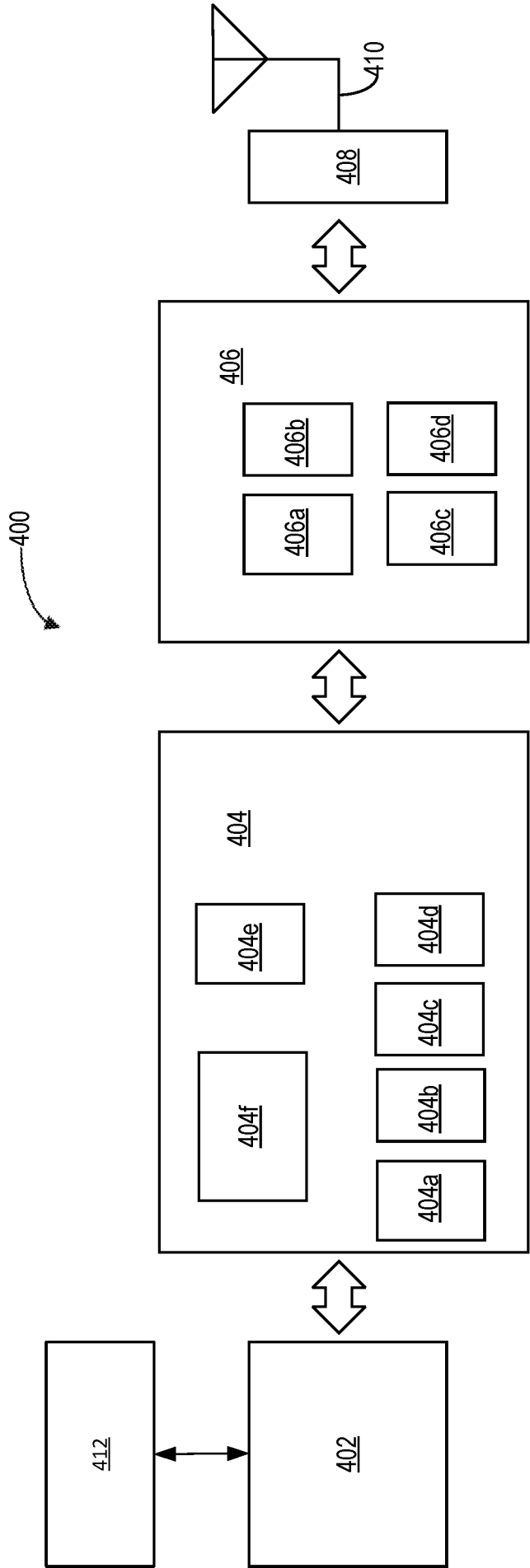


FIG. 4

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/US2016/037193

A. CLASSIFICATION OF SUBJECT MATTER  
INV. H04B7/06 H04L25/03  
ADD.

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)  
H04B H04L

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

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

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                 | Relevant to claim No. |
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| X         | EP 2 819 313 A1 (KOREA ELECTRONICS TELECOMM [KR])<br>31 December 2014 (2014-12-31)<br>paragraph [0090] - paragraph [0115]<br>----- | 1-30                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents :

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"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

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Date of the actual completion of the international search

18 October 2016

Date of mailing of the international search report

28/10/2016

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/037193

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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