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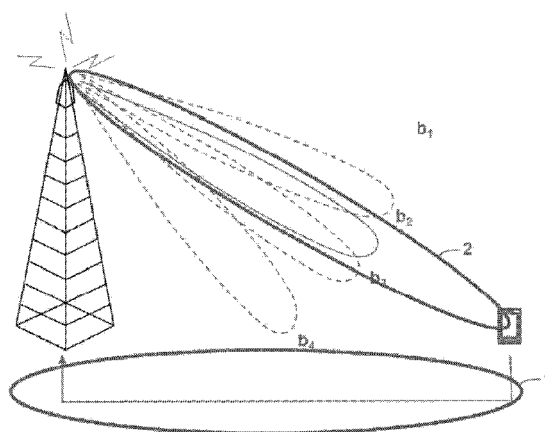


FIGURE 10

(57) Abstract: Example embodiments presented herein are directed towards an eNodeB (401), and method therein, for establishing beamforming for downlink communications in a multiple antenna system. The eNodeB may be configured to receive, from a user equipment, a plurality of signal quality assessments which correspond to a distinct direction within at least one correlated domain (e.g., an elevation and/or azimuth domain). Based on the signal quality assessments, at least one first and second signal quality assessment may be identified according to a predetermined signal characteristic. Thereafter, a transmission direction may be determined based on the at least one first and second signal quality assessment and associated directions within the at least one correlated domain. Based on the determined transmission direction, downlink communications may be transmitted to the user equipment.

NODE AND METHOD FOR ESTABLISHING BEAMFORMING FOR DOWNLINK COMMUNICATIONS

5 TECHNICAL FIELD

Example embodiments presented herein are directed towards establishing beamforming for downlink communications in a multiple antenna system.

BACKGROUND

10 Overview of Multi-Antenna Systems

Multi-antenna techniques may be used to significantly increase the data rates and reliability of a wireless communication system. System performance may in particular be improved if both the transmitter and the receiver are equipped with multiple antennas, which results in a multiple-input multiple-output (MIMO) communication channel. Such
15 systems and/or related techniques are commonly referred to as MIMO.

The LTE standard is currently evolving with enhanced MIMO support. A core component in LTE is the support of MIMO antenna deployments and MIMO related techniques. For instance there is LTE-Advanced support for a spatial multiplexing mode with the possibly channel dependent precoding. Precoding is a form of beamforming to
20 support multi-layer transmission in multi-antenna wireless communications. Beamforming is a signal processing technique used in sensor arrays for directional signal transmission or reception.

Spatial multiplexing is transmission techniques in MIMO wireless communications to transmit independent and separately encoded data signals from each of the multiple
25 transmit antennas. The spatial multiplexing mode is aimed for high data rates in favorable channel conditions. An illustration of the spatial multiplexing operation is provided in **Figure 1**.

As seen Figure 1, the information carrying symbol vector $\mathbf{s}$ is multiplied by an $N_T \times r$ precoder matrix $\mathbf{W}_{N_T \times r}$, which serves to distribute the transmit energy in a subspace of the
30 N_T (corresponding to N_T antenna ports) dimensional vector space. The precoder matrix is typically selected from a codebook of possible precoder matrices, and typically indicated by means of a precoder matrix indicator (PMI), which specifies a unique precoder matrix in the codebook for a given number of symbol streams. The r symbols in $\mathbf{s}$ each

correspond to a layer and r is referred to as the transmission rank. In this way, spatial multiplexing is achieved since multiple symbols can be transmitted simultaneously over the same time/frequency resource element (TFRE). The number of symbols r is typically adapted to suit the current channel properties.

- 5 LTE uses OFDM in the downlink (and DFT precoded OFDM in the uplink) and hence the received $N_R \times 1$ vector $\mathbf{y}_n$ for a certain TFRE on subcarrier n (or alternatively data TFRE number n) is thus modeled by:

$$\mathbf{y}_n = \mathbf{H}_n \mathbf{W}_{N_T \times r} \mathbf{s}_n + \mathbf{e}_n$$

- where $\mathbf{e}_n$ is a noise/interference vector obtained as realizations of a random process. The
 10 precoder, $\mathbf{W}_{N_T \times r}$, may be a wideband precoder, which is constant over frequency, or frequency selective. Note that the signals above (e.g., $\mathbf{y}_n$) could alternatively represent a signal in the time-domain. It is generally understood that signals described herein may represent signals in other domains than in the time-frequency grid of an OFDM system.

- The precoder matrix is often chosen to match the characteristics of the $N_R \times N_T$ MIMO
 15 channel matrix $\mathbf{H}$, resulting in so-called channel dependent precoding. This is also commonly referred to as closed-loop precoding and generally strives for focusing the transmit energy into a subspace which is strong in the sense of conveying much of the transmitted energy to the user equipment. In addition, the precoder matrix may also be selected to strive for orthogonalizing the channel, meaning that after proper linear
 20 equalization at the user equipment the inter-layer interference is reduced.

- In closed-loop precoding for the LTE downlink, the user equipment transmits, based on channel measurements in the forward link (downlink), recommendations to the eNodeB of a suitable precoder to use. The user equipment selects a precoder out of a countable and finite set of precoder alternatives, referred to as a precoder codebook. A
 25 single precoder that is supposed to cover a large bandwidth (wideband precoding) may be fed back. It may also be beneficial to match the frequency variations of the channel and feedback a frequency-selective precoding report, e.g., several precoders, one per sub-band. This is an example of the more general case of channel state information (CSI) feedback, which also encompasses feeding back other entities than precoders to assist
 30 the eNodeB in subsequent transmissions to the user equipment. Such other information may comprise channel quality indicators (CQIs) as well as a transmission rank indicator (RI). For the LTE uplink, the use of closed-loop precoding means the eNodeB is selecting precoder(s) and transmission rank and thereafter signals the selected precoder that the user equipment is supposed to use.

SUMMARY

Active antennas may comprise many subelements and arrays of active antennas may comprise even more. Such antenna configurations were neither thought of, nor taken into account, when existing codebooks were designed. Thus, at least one
5 example object of the example embodiments presented herein is to provide spatial multiplexing transmission techniques in MIMO wireless communications which account for the various subelements which may be comprised in active antenna arrays. Some of the example embodiments are also directed providing improved data communications which may provide beamformers with a finer granularity for spatial multiplexing transmission
10 techniques.

Thus, some of the example embodiments are directed towards a method, in an eNodeB, for establishing beamforming for downlink communications in a multiple antenna system. The eNodeB is comprised in a wireless communications network. The method comprises receiving, from a user equipment, a plurality of signal quality assessments.
15 Each of the plurality of signal quality assessments corresponds to a signal quality level for a distinct direction within at least one correlated domain of the multiple antenna system. The method also comprises identifying at least one first signal quality assessment, of the plurality of signal quality assessments, which corresponds to a pre-determined signal characteristic. The method further comprises identifying at least one second signal quality
20 assessment that corresponds to a neighboring direction, of a direction associated with said at least one first signal quality assessment, within said at least one correlated domain of the multiple antenna system. The method also comprises determining at least one transmission direction within the at least one correlated domain based on signal quality levels of the at least one first signal quality assessment, the at least one second signal
25 quality assessment, and associated directions within the at least one correlated domain. The method further comprises transmitting, to the user equipment, downlink communications beamformed into the determined at least one transmission direction.

Some of the example embodiments may also be directed towards an eNodeB, for establishing beamforming for downlink communications in a multiple antenna system.
30 The eNodeB is comprised in a wireless communications network. The eNodeB comprises radio circuitry configured to receive, from a user equipment, a plurality of signal quality assessments, wherein each of the plurality of signal quality assessments corresponds to a signal quality level for a distinct direction within at least one correlated domain of the multiple antenna system. The eNodeB also comprises processing circuitry configured to
35 identify at least one first signal quality assessment, of the plurality of signal quality

assessments, which corresponds to a pre-determined signal characteristic. The processing circuitry is further configured to identify at least one second signal quality assessment that corresponds to a neighboring direction, of a direction associated with the at least one first signal quality assessment, within the at least one correlated domain of the multiple antenna system. The processing circuitry is further configured to determine at least one transmission direction within the at least one correlated domain based on signal quality levels of the at least one first signal quality assessment, the at least one second signal quality assessment, and associated directions within the at least one correlated domain. The radio circuitry is further configured to transmit, to the user equipment, downlink communications beamformed into the determined at least one transmission direction.

DEFINITIONS

	3GPP	3rd Generation Partnership Project
15	CoMP	Coordinated Multi Point
	CRS	Common Reference Symbols
	CSI	Channel State Information
	CQI	Channel Quality Indicator
	DFT	Discrete Fourier Transform
20	DL	Downlink
	eNB	Evolve Node B
	EPRE	Energy Per Resource Element
	FDD	Frequency Division Duplexing
	GSM	Global System for Mobile communications
25	LTE	Long Term Evolution
	MIMO	Multiple Input Multiple Output
	OFDM	Orthogonal Frequency-Division Multiplexing
	PUSCH	Physical Uplink Shared Channel
	PMI	Precoder Matrix Indicator
30	RAN	Radio Access Network
	RF	Radio Frequency
	RI	Rank Indicator
	RRC	Radio Resource Control
	RS	Reference Signal
35	RSRP	Reference Signal Received Power

	RSRQ	Reference Signal Received Quality
	RSSI	Received Signal Strength Indicator
	Rx	Receive
	TFRE	Time/Frequency Resource Element
5	Tx	Transmit
	UMB	Ultra-Mobile Broadband
	UE	User Equipment
	UL	Uplink
	WCDMA	Wideband Code Division Multiple Access
10	WiMax	Worldwide Interoperability for Microwave Access

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing will be apparent from the following more particular description of the example embodiments, as illustrated in the accompanying drawings in which like
 15 reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the example embodiments.

FIG. 1 is an illustration of a transmission structure for a precoded spatial multiplexing mode in LTE;

20 FIG. 2A is an example illustration of a co-polarized antenna configuration;

FIG. 2B is an example illustration of a cross-polarized antenna configuration;

FIG. 3 is a depiction of codebook based precoding with a 2 Tx cross-polarized antenna array;

FIG. 4A is an illustration of an antenna subelement;

25 FIG. 4B is an illustration of an antenna subelement featuring orthogonal polarization compared to the subelement of FIG. 4A;

FIG. 4C is an illustration of an active antenna array;

FIG. 5A is an illustration of a 2 Tx active antenna array;

FIG. 5B is an illustration of a 8 Tx active antenna array;

30 FIGS. 6 and 7 are example illustrations of message transmission, according to some of the example embodiments;

FIG. 8 is a graphical example of measured RSRP as a function of angle for an incoming signal for two different beamformers;

FIG. 9 is a graphical representation of the corresponding quotient $RSRP_1/RSRP_2$ of
 35 the example of FIG. 8;

FIG. 10 is a further example illustration of message transmission, according to some of the example embodiments;

FIG. 11 is an example node configuration of an eNodeB, according to some of the example embodiments; and

5 FIG. 12 is a flow diagram of example operations which may be taken by the eNodeB of FIG. 11, according to some of the example embodiments.

DETAILED DESCRIPTION

In the following description, for purposes of explanation and not limitation, specific
10 details are set forth, such as particular components, elements, techniques, etc. in order to provide a thorough understanding of the example embodiments. However, the example embodiments may be practiced in other manners that depart from these specific details. In other instances, detailed descriptions of well-known methods and elements are omitted so as not to obscure the description of the example embodiments.

15 Some of the example embodiments presented herein are directed towards providing user equipment specific beamforming for downlink communications. As part of the development of the example embodiments presented herein, a problem will first be identified and discussed. The description below is organized as follows.

First, examples of existing precoders will be briefly discussed under the sub-
20 heading "Examples of Existing Precoder Codebooks for LTE". Thereafter, an introduction on reference symbols which a user equipment may utilize for precoder determination is provided under the subheading "Channel State Information Reference Symbols (CSI-RS)". Afterwards an introduction of CoMP transmission is provided under the subheading "Coordinated Multipoint Transmission". CoMP feedback may be used by the user
25 equipment to send signal quality measurements to the eNodeB. The eNodeB may in-turn provide the downlink communications based on, at least in part, these measurements, according to some of the example embodiments. Thereafter, an introduction to antenna arrays and active antennas is provided under the subheadings "Antenna Arrays" and "Active Antennas", respectively. Afterwards, a detailed analysis of some of the example
30 embodiments will be provided.

Examples of Existing Precoder Codebooks for LTE

2 Tx Codebook

LTE Release-8, the first release of LTE, features the support codebook based
35 precoding for 2 antennas. Up to two layers can be transmitted (rank 1 and rank 2), thus

making the precoder matrix $W_{2 \times r}$ of dimension 2×1 and 2×2 , respectively.

8 Tx Codebook

LTE Release-10, and later specifications, support a transmission mode for up to 8-layer spatial multiplexing for 8 Tx antennas using user equipment specific RS. Rank adaptation and possibly channel dependent precoding is also supported. User equipment specific RS is used for demodulation purposes and because of that the eNodeB is free to use whatever precoder(s) it wants to, but it may be assisted in the determination of precoder(s) via CSI feedback from the user equipment that includes recommended precoder(s). For the time-frequency resource of interest, the user equipment selects a precoder $W_{8 \times r}$ out of a set of possible precoders in a precoder codebook which then is used together with an input symbol vector $s_{r \times 1}$ to produce an output signal $x_{8 \times 1} = W_{8 \times r} s_{r \times 1}$ for r layers.

15 Channel State Information Reference Symbols (CSI-RS)

In LTE Release-10, a new reference symbol sequence was introduced with the intent of estimating channel state information, the CSI-RS. The CSI-RS provides several advantages over basing the CSI feedback on the common reference symbols (CRS) which were used, for that purpose, in previous releases. Firstly, the CSI-RS is not used for demodulation of the data signal, and thus does not require the same density (i.e., the overhead of the CSI-RS is substantially less). Secondly, CSI-RS provides a much more flexible means to configure CSI feedback measurements (e.g., which CSI-RS resources to measure on may be configured in a user equipment specific manner). Moreover, the support of antenna configurations larger than 4 antennas should resort to CSI-RS, since the CRS is only defined for at most 4 antennas.

Based on the CSI-RS, the user equipment may estimate the channel and consequently also figure out which precoder suits the particular channel. For the purpose of CSI feedback determination, the user equipment assumes that each of the rows corresponds to an antenna port (ports 15 – 22) on which a CSI-RS port signal is transmitted. The first row represents antenna port 15, the second row represents antenna port 16, and so on. Each CSI-RS port signal is typically transmitted from an antenna of its own, meaning that there is a direct correspondence between a CSI-RS port and a physical antenna.

Coordinated Multipoint Transmission

Coordinated Multi Point (CoMP) transmission and reception refers to a system where the transmission and/or reception at multiple, geographically separated antenna sites is coordinated in order to improve system performance. The coordination can either
5 be distributed, by means of direct communication between the different sites, or by means of a central coordinating node.

CoMP is a tool introduced in LTE to improve the coverage of high data rates, the cell-edge throughput and/or to increase system throughput. In particular, the goal is to distribute the user perceived performance more evenly in the network by taking control of
10 the inter-cell interference.

CSI-RS Received Power

In order to enable efficient CoMP schemes, new forms of CSI feedback are potentially needed. For instance it is an agreed working assumption, for LTE Rel-11, that
15 the network can configure a user equipment to report signal qualities (e.g., received signal powers) based on measurements on a configured set of CSI-RS resources. A CSI-RS resource may loosely be described as the pattern of resource elements on which a particular CSI-RS configuration is transmitted. A CSI-RS resource may be configured through RRC signaling.

20 Such a measurement could be done coherently, in which case the user equipment needs to know the CSI-RS sequence that is transmitted on the CSI-RS resource, or incoherently in which case the transmitted actual sequence can be transparent to a user equipment. It should be appreciated that herein any signal quality measure based on measurements on CSI-RS resources is referred to as "CSI-RS received power" (CSI-
25 RSRP), but it should be understood that CSI-RSRP encompasses any quantity that represents a received quality of a CSI-RS signal. The estimated values of the CSI-RSRP may then be fed back from the user equipment to the eNodeB.

Antenna Arrays

30 On the network side, base stations are often equipped with multiple antennas to be used for reception and transmission. The antennas intended for a transmission point (e.g., a cell, and/or a sector), form a so-called antenna array. Some typical antenna array constellations are illustrated in **Figure 2**. For instance, one common antenna array layout is to use co-polarized antennas in order to construct antenna arrays as shown in **Figure**
35 **2(a)**. Furthermore, another common layout is to instead use cross-polarized antennas as

shown in **Figure 2(b)**.

Using, for example, a 2 Tx cross-polarized antenna array (c.f. the top most antenna setup in **Figure 2(b)**) implies that the antenna array is fed with two signals, x_1 and x_2 .

This is illustrated in **Figure 3** where it has been assumed that a 2 Tx antenna array is
 5 used with codebook based precoding, so that the transmitted signal is $\mathbf{x}_{2 \times 1} = \mathbf{W}_{2 \times r} \mathbf{s}_{r \times 1}$.

Active Antennas

An active antenna comprises a number of subelements that jointly form the antenna. In **Figure 4(a)** a subelement, in practice may be realized by a small physical
 10 device, as is illustrated. Each subelement will have a polarization direction which potentially can be orthogonal to another subelement's polarization. This is illustrated in **Figure 4(b)** where a subelement with orthogonal polarization compared to the subelement in **Figure 4(a)** is shown. Finally, in **Figure 4(c)** an active antenna array which consists of N_s subelements is shown. In general, but not necessarily, all the subelements of an
 15 active antenna are of the same polarization. Note that each given subelement i can be fed the given signal $x^{(i)}$ not necessarily equal to $x^{(j)}$.

Herein, when dealing with more than one active antenna, the notation $x_i^{(j)}$ will be utilized when referring to a signal, or function, related to the j :th subelement in the i :th antenna. These indexes will however be omitted when it is clear from the context what is
 20 being referred.

By combining two active antennas of different polarizations, as illustrated in **Figure 5(a)**, a 2 Tx antenna array may be created and fed with two different signals, x_1 and x_2 where $\mathbf{x}_i = [x_i^{(1)} \dots x_i^{(N_s)}]^T$. Furthermore, by combining multiple 2 Tx antenna arrays, as illustrated in **Figure 5(b)**, an 8 Tx antenna array may be created. Here the signals $x_i^{(j)}$
 25 are no longer explicitly shown but they are still assumed to be present in the same manner as in **Figure 5(a)**.

Existing precoder codebooks in different standards have been designed for conventional antenna arrays. For example, in LTE Release 10 and beyond, precoder codebooks for 2, 4 or 8 Tx antennas are supported. There is thus a precoder codebook
 30 suitable for each antenna array type. Hence, when using, for example, a 2 Tx antenna array, the standard is designed to use the 2 Tx codebook meaning that x_1 and x_2 can be fed to the antenna array just as in **Figure 3**.

Active antennas comprise many subelements and arrays of active antennas comprise even more. Such antenna setups were neither thought of, nor taken into account, when the existing codebooks were designed. Therefore, existing codebooks do not utilize the fact that the subelements can be accessed as illustrated in **Figure 5**.

5 Moreover, for large active antenna deployments, the sheer number of sub-element antenna ports can create so many degrees of freedom that the CSI feedback overhead from a user equipment becomes prohibitive.

Active antennas, antenna arrays and arrays of active antennas may be generalized to a system of multiple antennas. Herein, the phrase *multiple antenna system* is used to
10 describe a set of antennas (comprising one active antenna with multiple sub-elements) that constitutes a transmission point (i.e., with the intent to serve a sufficiently isolated region of space, such as a cell and/or sector).

Another option is to base the determination of a beamformer in a correlated domain by means of, for example, uplink measurements. Resorting to uplink measurements does
15 however have several limitations. An example of such a limitation may be in deployments with downlink inter-frequency carrier aggregation. In such a scenario, it is unlikely that all terminals support the matching uplink carrier aggregation. Hence, for this scenario it will not be possible to perform uplink measurements relevant for all carriers.

Another example of such a limitation is in FDD systems where the uplink and
20 downlink carriers are separated in frequency, and the measurements made in uplink may have reduced accuracy in the downlink. A further example is an implementation disadvantage to introduce coupling between uplink and downlink processing.

The techniques described herein allow for feedback from the user equipment to be generated and used for guiding user equipment specific beamforming in the azimuth
25 and/or elevation domain by using multiple antenna systems even when existing codebooks not are designed for this purpose.

The basic concept of the example embodiments is to configure a set of CSI-RS resources, precoded in such a way that each CSI-RS span a direction within a correlated domain (i.e., a correlated vector space) of a multiple antenna system. By configuring a
30 user equipment to measure and report the corresponding CSI-RSRP values to the network, the eNodeB can use these values to improve the directivity within the correlated domain of the transmission, such that the power transmitted along directions with poor signal quality is minimized, and power is transmitted along directions with good signal quality.

35 By utilizing the CSI-RSRP to acquire information about relatively stationary

directions, the regular rapid PMI reporting can be offloaded to cover only the more dynamic variations in the channel, for which it has been designed.

Overview of Beamforming According to the Example Embodiments

5 In this section, the example embodiments will be illustrated in more detail by a number of examples. It should be noted that these embodiments are not mutually exclusive. Components from one embodiment may be tacitly assumed to be present in another embodiment and it should be appreciated those components may be used in the other example embodiments.

10 The example embodiments will be presented as follows. First, a description of how feedback data may be utilized in providing user specific beamformed communications is provided under the subheading "Generating Beamforming from CSI-RSRP Feedback". Thereafter, a description on how feedback may be utilized to improve the beamformed communications is provided under the subheading "Refined Use of the Received CSI-
15 RSRP Beamforming Feedback". A description on how CSI-RSRP feedback may be utilized to provide beamforming with greater granularity is provided under the subheading "Using CSI-RSRP for Improved Resolution Elevation Beamforming". Finally, example node configurations and example node operations are provided under the subheadings "Example Node Configuration" and "Example Node Operations", respectively.

20

Generating Beamforming from CSI-RSRP Feedback

In the following exemplary embodiments the target is to illustrate how beamforming feedback may be created by using CSI-RSRP measurements, potentially in combination with regular RI/PMI/CQI feedback.

25

Generating elevation beamforming from CSI-RSRP feedback

Radio propagation channels tend to be highly correlated in the elevation direction (i.e., the elevation domain), in particular for antennas that are deployed over rooftops. Such correlation may result in almost all power of the radio wave, which reaches a user
30 equipment, typically traverses directions closely clustered in elevation domain. Specifically, typically all power is confined to one or two tight clusters in elevation.

In this example embodiment a set of CSI-RS signals are configured to span different elevation directions. By configuring a user equipment to measure and report the corresponding CSI-RSRP values, the network (e.g., eNodeB) may determine an elevation
35 beamformer guided by reported CSI-RSRP values, each corresponding to an associated

elevation. For example, the eNodeB may select the elevation beamformer used for the CSI-RS with the highest reported CSI-RSRP.

Figure 6 provides an example illustration of the communications which may be transmitted between an eNodeB and a user equipment. First, the eNodeB may transmit any number of CSI-RS reference signals to the user equipment (shown as circle 1). The eNodeB may configure the user equipment to measure and report the corresponding CSI-RSRP for at least a subset of transmitted signals. Thereafter, the eNodeB may receive the corresponding CSI-RSRP report for the user equipment (circle 2). Finally, the eNodeB may transmit data to the user equipment taking the received CSI-RSRP values into account in the selection of an elevation beamformer that is used in subsequent data transmissions.

The communications illustrated in Figure 6 will now be mathematically described. Consider the case with an N_A Tx active antenna array where each antenna comprises N_s subelements. A design featuring N_Q vectors yields the following:

$$\mathbf{b}_q = \begin{bmatrix} b_{1,q} \\ b_{2,q} \\ \vdots \\ b_{N_s,q} \end{bmatrix}, \quad q = 1, \dots, N_Q$$

where $\mathbf{b}_q$ corresponds to a beamforming vector when applied to the subelements of the i :th active antenna in the N_A Tx active antenna array. It should be appreciated that the above representation may be extended to configurations with different number of subelements in each antenna. Furthermore, it should be appreciated that the concept of a subelement is non-limiting in the sense that it may refer to any virtualization (e.g., linear mapping) of the physical antenna elements. For example, pairs of physical subelements may be fed the same signals, and hence share the same virtualized subelement antenna port.

The representation provided above will hence correspond to beamforming in the elevation assuming that the subelements are placed vertically, where each $\mathbf{b}_q$ typically corresponds to a targeted elevation direction. The following beamformer matrix may thereafter be created:

$$\mathbf{B}_{N_A N_S \times N_A}(q) = \begin{bmatrix} \mathbf{b}_q & 0 & \dots & 0 \\ 0 & \mathbf{b}_q & & \vdots \\ \vdots & & \ddots & \\ 0 & \dots & & \mathbf{b}_q \end{bmatrix}, \quad q = 1, \dots, N$$

The matrix presented above may be used to create the port to subelement mapping as

$$\tilde{\mathbf{x}}_{N_A N_S \times 1}(q) = \mathbf{B}_{N_A N_S \times N_A}(q) \mathbf{x}_{N_A \times 1}(q)$$

where $\mathbf{x}_{N_A \times 1}(q)$ is a CSI-RS signal for N_A ports. For the created output vector $\tilde{\mathbf{x}}_{N_A N_S \times 1}(q)$

- 5 it is assumed that the first N_S values correspond to the subelements of one active antenna and that the second N_S values correspond to the subelements of a second active antenna, etc. Hence, the equation above describes a mapping from the N_A ports CSI-RS to the $N_A N_S$ subelements. It should be appreciated that the structure here corresponds to each active antenna in the array having the same elevation beam. It is
10 however possible to use a different elevation beam on each active antenna.

Due to the special structure in the beamformer matrixes, each index q corresponds to a transmission in a certain direction defined by the beamformers $\mathbf{b}_1, \dots, \mathbf{b}_{N_Q}$. Typically, the different CSI-RS signals, $\mathbf{x}_{N_A \times 1}(q)$, may be configured to be orthogonal, for example, separated to different time/frequency resources.

- 15 Now, let the eNodeB be configured to transmit $\tilde{\mathbf{x}}_{N_A N_S \times 1}(q)$ for $q = 1, \dots, N_Q$.

Furthermore, assume some user equipments are configured to report back the corresponding CSI-RSRP values meaning that one signal quality assessment, $RSRP_q$ per reporting user equipment may be feedback for each transmitted $\tilde{\mathbf{x}}_{N_A N_S \times 1}(q)$, each corresponding to an associated elevation beam. This will provide the eNodeB with useful
20 information regarding which elevation beamforming vector to choose for subsequent transmissions (e.g., data transmissions) to a user equipment.

One potential choice for a beamforming vector may be for instance be to choose the elevation beamforming vector, $\mathbf{b}_q$, corresponding to the strongest $RSRP_q$. The subsequent data transmission may further combine the selected elevation beamformer
25 with, for example, azimuth and inter-polarization beamforming which, may be based on a PMI recommendation by the user equipment.

Alternatively, since the set of CSI-RS resources to measure RSRP on can be configured UE-specifically, a UE can be configured to feed back only those RSRP values

that are of relevance to a particular UE (i.e., there is no need for a distant UE to feed back RSRP values for CSI-RS resources that are associated with very steep elevation angles).

Using CSI-RS with fewer ports than N_A

- 5 According to some of the example embodiments, the CSI-RSRP measurements for generating elevation beamforming feedback may be created from any subset of N_A ports CSI-RS. For example, in common case of an N_A Tx cross-polarized active antenna, with $N_A / 2$ active antennas in each polarization, the beamformer matrix $\mathbf{B}_{N_A N_S \times N_A}(q)$ may be represented as:

$$10 \quad \mathbf{B}_{N_A N_S \times 2}(q) = \begin{bmatrix} \mathbf{b}_q & 0 \\ \vdots & \vdots \\ \mathbf{b}_q & 0 \\ 0 & \mathbf{b}_q \\ \vdots & \vdots \\ 0 & \mathbf{b}_q \end{bmatrix}$$

where it is assumed that the first column will target the first polarization and the second column will target the other polarization in the beamformer matrix. Applying the port to antenna mapping results in the follow equation:

$$\tilde{\mathbf{x}}_{N_A N_S \times 1}(q) = \mathbf{B}_{N_A N_S \times 2}(q) \mathbf{x}_{2 \times 1}(q)$$

- 15 where $\mathbf{x}_{N_A \times 1}$ is a two port CSI-RS which may enable elevation beamforming feedback that may be utilized for at least one of the polarizations. Hence, this will provide useful information for the eNodeB regarding which beamforming vector to choose for each polarization.

A more general case corresponds to adding a precoder, $\mathbf{W}$, that distributes a r port CSI-RS pattern into N_A ports, such that:

$$\tilde{\mathbf{x}}_{N_A N_S \times 1}(q) = \mathbf{B}_{N_A N_S \times N_A}(q) \mathbf{W}_{N_A \times r} \mathbf{x}_{r \times 1}(q),$$

where the above embodiment may be captured by configuring $\mathbf{W}$ as

$$\mathbf{W}_{N_A \times 2} = \begin{bmatrix} \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} \end{bmatrix},$$

where $\mathbf{0}$ and $\mathbf{1}$ are the vectors of all zeros and ones (with $N_A / 2$ elements), respectively.

- 25 For instance, for CSI-RS resources used to measure elevation directions, it would be useful to try to spread the CSI-RS as evenly as possible in the azimuth direction, which

corresponds to designing $\mathbf{W}$ to have as broad of an azimuth main lobe as possible. Typically, one would like to have the elevation lobe quite narrow and therefore the beamforming vector may be designed accordingly. The lobe in azimuth should on the other hand be quite wide and therefore the matrix $\mathbf{W}$ (which creates this lobe) may be designed accordingly. Such a wide lobe may be achieved by, for example, spreading each port of a CSI-RS on all antennas, but with the phase rotations such that in no targeted direction the transmitted signals all destructively (or constructively) combine. Another alternative, according to some of the example embodiments, is to introduce azimuth phase variations over frequency, in which case the beam, as seen over the entire bandwidth, may be very wide. Yet another alternative is to divide the transmit antennas in groups and transmit a specific CSI-RS port on antennas in one such group only (within a group of antennas the CSI-RS port can be transmitted with a wide lobe). This will have the benefit that there will be no destructive/constructive combining between the different groups of antennas because different antenna ports of a CSI-RS are quasi orthogonal. It should be appreciated that $\mathbf{W}$ may also be made dependent on q , where there could be one beamformer for each CSI-RS.

Alternatively, for deployments with copolarized antennas, or for which there is a negligible risk of destructive combining over the polarizations, (or the system bandwidth provides sufficient randomization over frequency), a single port CSI-RS may be used, $\mathbf{x}_{1 \times 1}(q)$, in combination with:

$$\mathbf{B}_{N_A N_S \times 1}(q) = \begin{bmatrix} \mathbf{b}_q \\ \vdots \\ \mathbf{b}_q \end{bmatrix}.$$

Furthermore, it should be appreciated that other beamformer matrixes $\mathbf{B}_{N_A N_S \times k}(q)$ may be utilized in order to adapt to k ports CSI-RS.

25 *Generating Azimuth Beamforming Feedback from CSI-RSRP*

In the above descriptions of the example embodiments, it is explained how CSI-RSRP may be utilized in order to generate elevation beamforming feedback. The example embodiments presented herein however are not restricted to be applied in the elevation domain. It should be appreciated that the example embodiments may be utilized in order to create beamforming feedback in any other domain or direction, for example in an azimuth domain or direction.

Generating Joint Azimuth and Elevation Beamforming Feedback from CSI-RSRP

It should also be appreciated that the example embodiments presented herein may be used to generate joint elevation and beamforming feedback. Following the example steps provided under the subheading "Generating Elevation Beamforming from CSI-

5 RSRP", the following representation of N_Q beamforming vectors may be provided:

$$\mathbf{b}_q = \begin{bmatrix} b_{1,q} \\ b_{2,q} \\ \vdots \\ b_{N_A N_S, q} \end{bmatrix}, \quad q = 1, \dots, N_Q$$

such that $\mathbf{b}_q$ corresponds to a polarization specific beamforming vector when applied to a cross polarized active antenna array (e.g., that has its antenna elements and subelements positioned to span both elevation and azimuth domain). This will hence potentially imply
10 beamforming in both elevation and azimuth. Now consider the following beamforming matrix:

$$\mathbf{B}_{N_A N_S \times 2}(q) = \begin{bmatrix} \mathbf{b}_q & 0 \\ 0 & \mathbf{b}_q \end{bmatrix}, \quad q = 1, \dots, N$$

where the two columns represent the two polarizations. Therefore, the port to subelement mapping may be provided as:

$$15 \quad \tilde{\mathbf{x}}_{N_A N_S \times 1}(q) = \mathbf{B}_{N_A N_S \times 2}(q) \mathbf{x}_{2 \times 1}(q)$$

where it is assumed that $\mathbf{x}_{2 \times 1}(q)$ is an CSI-RS for 2 ports. Hence, this will provide useful information for performing joint azimuth and elevation beamforming. It should be appreciated that the example embodiments described above may be extended to be used with copolarized arrays, and/or to use CSI-RS with less or more than 2 ports, by for
20 example applying a precoder to the CSI-RS or by modifying $\mathbf{B}_{N_A N_S \times r}(q)$ accordingly.

In summary, through a special configuration of CSI-RSRP and corresponding measurements, it is possible to generate information suitable as feedback for elevation beamforming. Based on this information the eNodeB may decide on elevation
25 beamforming vectors to use for the active antennas.

It should be appreciated that the beamformer matrices $\mathbf{B}_{N_A N_S \times N_A}$ may be extended to consider the case when different active antennas use different beamformer vectors $\mathbf{b}_q$. It should be noted that in the following we refer to a beamforming direction as a primary

pointing angle of a beamforming vector. Hence, a distinct beamforming direction corresponds to using a beamformer with primary pointing angle in the distinct direction.

It should further be appreciated that each of the reference signals may be transmitted in a distinct beamforming direction $\mathbf{b}_n$, however, the transmitted data itself
5 may be overlapping. It should also be appreciated that the reporting periodicity and/or mechanism is not essential for the example embodiments. The reporting may, for example, be configured so that a feedback report is triggered at a certain periodicity. Alternatively, the feedback report may be provided by an event based triggering that may be provided by the user equipment. Thus, the signal quality assessment, RSRP_q , may be
10 reported if a sufficient change has incurred.

Refined use of the received CSI-RSRP Beamforming Feedback

In this section further example embodiments are presented on how to use user equipment provided feedback in order to perform the beamforming based on the received
15 feedback. The example embodiments described in this subheading are explained with the use of elevation beamforming. It should be appreciated that any of the example embodiments presented herein may also be applied to other kinds of beamformings, for example, azimuth beamforming and joint azimuth and elevation beamforming.

Furthermore, in the following section it is assumed that the eNodeB may be
20 configured to transmit a set of CSI-RS in order to obtain elevation beamforming feedback as described as in the section entitled "Generating Beamforming Feedback from CSI-RSRP". It should be appreciated that the eNodeB also may be configured to transmit another set of CSI-RS corresponding to the 'traditional' use of CSI-RS, hence estimating the channel and generating CQI(s), etc. In order to distinguish between the two uses of
25 CSI-RS, in the following sections the term '(elevation) CSI-RS' will be utilized when referring to a CSI-RS configured for generating elevation beamforming feedback, and the term '(traditional) CSI-RS' will be utilized when referring to a CSI-RS configured for the traditional use of the CSI-RS. These clarifications will however be omitted when it is clear from the context what is being referred. It should be appreciated that the term traditional
30 CSI-RS is non-limiting and may, for example, refer to a CRS or any other signal used for user equipment based reporting of CSI (e.g., CQI, PMI, RI, etc.).

Using CSI-RSRP for Elevation Beamforming

In this subsection, example embodiments are presented on how to use the CSI-
35 RSRP feedback, described under the subheading "Generating Beamforming Feedback

from CSI-RS", to carry out elevation beamforming for data (and control) signals to a user equipment. As previously stated, one potential way to choose the elevation beamformer vector for the active antenna may be to use the elevation beam corresponding to the best reported signal quality assessment; for example, use the elevation beamformer $\mathbf{b}_{q_{\max}}$,

5 where

$$q_{\max} = \arg \max_q \{RSRP_q\}.$$

Hence, based on the received feedback, a new beamformer matrix may be provided. The beamformer matrix may be represented as:

$$\mathbf{B}_{N_A N_S \times N_A}^{(data)} = \begin{bmatrix} \mathbf{b}_{q_{\max}} & 0 & \dots & 0 \\ 0 & \mathbf{b}_{q_{\max}} & & \vdots \\ \vdots & & \ddots & \\ 0 & \dots & & \mathbf{b}_{q_{\max}} \end{bmatrix}$$

10 and the port to subelement mapping may be represented as:

$$\tilde{\mathbf{x}}_{N_A N_S \times 1} = \mathbf{B}_{N_A N_S \times N_A}^{(data)} \mathbf{x}_{N_A \times 1}$$

where $\mathbf{x}_{N_A \times 1}$ may comprise precoded data $\mathbf{x}_{N_A \times 1} = \mathbf{W}_{N_A \times r} \mathbf{s}_{r \times 1}$ of rank r .

For the (traditional) CSI-RS, another beamforming vector $\mathbf{b}_{N_S \times 1}^{(traditional)}$ may be created.

The traditional beamforming vector may be represented as:

15

$$\mathbf{B}_{N_A N_S \times N_A}^{(traditional)} = \begin{bmatrix} \mathbf{b}_{N_S \times 1}^{(traditional)} & 0 & \dots & 0 \\ 0 & \mathbf{b}_{N_S \times 1}^{(traditional)} & & \vdots \\ \vdots & & \ddots & \\ 0 & \dots & & \mathbf{b}_{N_S \times 1}^{(traditional)} \end{bmatrix}.$$

Thus, the (traditional) CSI-RS may be transmitted using the port to subelement mapping represented as:

$$\tilde{\mathbf{x}}_{N_A N_S \times 1} = \mathbf{B}_{N_A N_S \times N_A}^{(traditional)} \mathbf{x}_{N_A \times 1}.$$

20 Thus, by using the example embodiments described, it is possible to transmit data with the chosen beamforming vector $\mathbf{b}_{q_{\max}}$. At the same time, it is also possible to generate channel estimates (e.g., CQI, PMI, RI, etc.) or recommendations by transmitting (traditional) CSI-RS in the proposed manner. This feedback may then be used by the eNodeB, in a traditional fashion, and potential power offsets may, for example, be
25 compensated by an outer loop link adaptation in the network. It should be appreciated

that the use of the notation CQI, RI, and PMI in this context should be interpreted in the wider scope of general channel state information feedback used to assist the eNodeB in determining, for example, precoders, transmission rank, and coding and modulations schemes.

5 It should be appreciated that the (elevation) CSI-RS and the (traditional) CSI-RS need not be configured using the same number of ports N_A . The example embodiments may utilize a different number of ports for the different CSI-RS resources.

It should also be appreciated that one potential design choice for the example embodiments presented in this subsection is to set $\mathbf{b}_{N_s \times 1}^{(traditional)} = \mathbf{b}_{q_j}$, for some q_j . This
 10 implies that for this q_j the same CSI-RS may be used both as (elevation) CSI-RS and (traditional) CSI-RS thereby potentially decreasing the payload of the transmitted CSI-RS.

Improving CSI Estimates by using Received RSRP

Transmitting precoded data and (traditional) CSI-RS, as presented in section above,
 15 results in only the precoded data being affected by the decided elevation beamforming matrix, whereas the (traditional) CSI-RS will be unaffected since it is potentially using another beamformer matrix. This will therefore imply that the (traditional) CSI-RS and the transmitted precoded data will experience two different channels. Therefore, the produced channel estimate from the (traditional) CSI-RS does not necessarily correspond well with
 20 the channel experienced by the transmitted data. In the following embodiments we will present solutions to this. Thus, some of the example embodiments presented herein are directed towards utilizing received RSRP to remedy this discrepancy.

According to some of the example embodiments, the fact that access to both RSRP measurements from the (elevation) CSI-RS and the (traditional) CSI-RS are available may
 25 be exploited. Thus, the difference experienced in the channels may to some extent be estimated. For example, the quotient $RSRP_{q_{max}} / RSRP^{(traditional)}$ may indicate the difference in channel magnitude when transmitting with the beamformer vector q_{max} , used when transmitting data, and the beamformer corresponding to (traditional) CSI-RS. Hence, by exploiting these measurements the channel experienced by the data can be estimated
 30 from the (traditional) CSI-RS.

According to some of the example embodiments, one way is to use $RSRP_{q_{max}} / RSRP^{(traditional)}$ to derive an offset as to adjust SINR estimates derived from the reported CQI. The power measurement offset could alternatively be applied directly by the

terminal when it recommends a CQI. Such an user equipment-applied offset may be configured in LTE using, for example, the *nomPDSCH-RS-EPRE-Offset* parameter which is configured by the network, or the CSI-RS related parameter P_c in Rel-10: " P_c the assumed ratio of PDSCH EPRE to CSI-RS EPRE when UE derives CSI feedback", as is
 5 explained in 3GPP TR 36.813 V10.4.0.

Figure 7 illustrates an example of the communications which may be transmitted between the eNodeB and the user equipment according to some of the example embodiments described under the subheading "Refined use of the received CSI-RSRP Beamforming Feedback".

10 As shown in Figure 7, the eNodeB may send (elevation) CSI-RS to a user equipment (illustrated by circle 1 of Figure 7). The user equipment may provide feedback data to the eNodeB based on the (elevation) CSI-RS, as described under the subheading "Generating beamforming feedback from CSI-RSRP" (illustrated by numeral 2 of Figure 7). The eNodeB may also send (traditional) CSI-RSRP to the user equipment to be
 15 utilized as described under this subheading (illustrated by circle 3 of Figure 7). Thereafter, the eNodeB may determine a received power difference between the received feedback of (elevation) CSI-RSRP and the received feedback of (traditional) CSI-RSRP. With the power difference determined, the eNodeB may send communications to the user equipment (illustrated by numeral 4 in Figure 7). The communications may be
 20 compensated with respect to the determined power difference. It should be appreciated that each of the reference signals may comprise of two groups, (traditional) CSI-RS and (elevation) CSI-RS which may be elevation and/or azimuth related CSI-RS. It should also be appreciated while the example embodiment illustrates two distinct CSI-RS sets, these two sets may comprise overlapping components. In some example embodiments the two
 25 CSI-RS sets may be completely overlapping.

Using CSI-RSRP for Improved Resolution Elevation Beamforming

The example embodiments described under this subheading illustrate how the CSI-RSRP feedback created and feedback, from a limited number of beamforming vectors, as
 30 described under the subheading "Generating elevation beamforming from CSI-RSRP feedback", may be used in order to provide beamformers with a finer granularity. Furthermore, such information may be utilized to more accurately determine the actual directions (within a correlated domain) for which the transmitted signal reaches a user equipment with high signal quality.

35 It should be appreciated that the received $RSRP_q$ may comprise indirect spatial

information, which may be used for creating an estimate on the elevation angle(s) of the signal received (e.g., downlink communication data transmitted by the eNodeB) by the user equipment. According to some of the example embodiments, this may be achieved by using the largest received $RSRP_q$, and the strongest of its neighboring RSRP(s).

- 5 Assume, without loss of generality, that the largest $RSRP_q$ corresponds to index 1, and the strongest neighbor corresponds to the index 2. Since $RSRP_1$ and $RSRP_2$ will vary with the incoming angle of the signal, creating the quotient $RSRP_1 / RSRP_2$ will provide information on the actual angle of the incoming signal. It should be appreciated that the term neighboring may be interpreted in the sense that two RSRPs may correspond to
- 10 measurements on CS-RS that are broadcasted on neighboring elevation/azimuth directions.

Figure 8 illustrates an example of measured RSRP as a function of angle for an incoming signal for two different beamformers. **Figure 9** illustrates a corresponding quotient $RSRP_1 / RSRP_2$. As can be seen from Figures 8 and 9, the quotient

- 15 $RSRP_1 / RSRP_2$ may constitute an invertible mapping from angle to $RSRP_1 / RSRP_2$. Hence, by utilizing the quotient, the actual elevation angle of the signal may be estimated with significantly higher resolution, than confining the directions to those used for the CSI-RS broadcasts.

- Given the estimate of the angle for the incoming signal, the example embodiments
- 20 explained under the subheading Using CSI-RSRP for Elevation Beamforming "may be employed with the difference that a new set of beamforming vectors, corresponding to the estimated angle, are created and used for a subsequent data (or control) transmission to a user equipment. Hence, for an estimated angle α , a beamformer vector $\mathbf{b}(\alpha)$ may be created, for example, as a DFT vector directed in the angle α . With this vector the
- 25 corresponding beamformer matrix $\mathbf{B}_{N_A N_S \times N_A}^{(data)}(\alpha)$ may be created and data may then be transmitted, for example, by using the port to subelement mapping represented by:

$$\tilde{\mathbf{x}}_{N_A N_S \times 1} = \mathbf{B}_{N_A N_S \times N_A}^{(data)}(\alpha) \mathbf{x}_{N_A \times 1}.$$

- The example embodiments presented herein may be readily extended to cover the case where there are multiple dominant elevation angles for the signals that are received
- 30 by the user equipment, as long as the different angles are resolvable by the reported RSRP measurements. Specifically, the example embodiments may be utilized if the number of RSRP measurements is sufficiently larger than the number of elevation angles

(or more specifically, that sufficiently many CSI-RS are configured such that the elevation directions are sufficiently densely sampled). The above method can then be applied on each resolvable elevation cluster independently.

Some of the example embodiments discussed above may be further generalized to
 5 take more than one additional RSRP value into account in the estimation (e.g., both neighboring RSRPs could be used to increase the accuracy). Hence, an estimated elevation direction can be computed as a function of more RSRP values represented by:

$$f(RSRP_1, RSRP_2, RSRP_3, \dots)$$

where $RSRP_2, RSRP_3, \dots$ represents relevant neighboring directions of $RSRP_1$. It should
 10 be appreciated that any number of relevant neighboring directions may be utilized in the estimation.

According to some of the example embodiments, the enhanced elevation angle estimate may next be used to improve the transmission from the eNodeB to a user equipment, for example, by forming a narrower elevation beam to the user equipment.
 15 The narrower beamforming improves the signal quality and reduces the interference caused to other user equipment. Alternatively, the elevation beam can be tilted further down as to further minimize the interference caused to other user equipments.

Figure 10 is an example illustration of the communications which may be transmitted between an eNodeB and a user equipment. First, the eNodeB may receive a
 20 CSI-RSRP report from the user equipment (circle 1). The report may correspond to a number of CSI-RS signals that may be precoded in an elevation domain. Thereafter, the report, the eNodeB may determine an elevation beamformer for the user equipment based, at least in part, on the report. Finally, the eNodeB may transmit data to the user equipment with the user of the determined elevation beamformer (circle 2). It should be
 25 appreciated that each of the reference signals b_n may be transmitted in a distinct beamforming direction, however, the transmitted data itself may be overlapping.

Example Node Configurations

Figure 11 illustrates an example of an eNodeB 401 which may incorporate some of
 30 the example embodiments discussed above. As shown in Figure 11, the eNodeB 401 may comprise a radio circuitry 410 configured to receive and transmit any form of communications or control signals within a network. It should be appreciated that the radio circuitry 410 may be comprised as any number of transceiving, receiving, and/or transmitting units or circuitry. It should further be appreciated that the radio circuitry 410

may be in the form of any input/output communications port known in the art. The radio circuitry 410 may comprise RF circuitry and baseband processing circuitry (not shown).

The eNodeB 401 may further comprise at least one memory unit or circuitry 430 that may be in communication with the radio circuitry 410. The memory 430 may be
5 configured to store received or transmitted data and/or executable program instructions. The memory 430 may also be configured to store any form of beamforming information, reference signals, and/or feedback data or information. The memory 430 may be any suitable type of computer readable memory and may be of volatile and/or non-volatile type.

10 The eNodeB 401 may further comprise further comprises a network interface 440 and processing circuitry 420 which may be configured to generate and analyze reference signals, and generate beamformed communications. The processing circuitry 420 may be any suitable type of computation unit, e.g. a microprocessor, digital signal processor (DSP), field programmable gate array (FPGA), or application specific integrated circuit
15 (ASIC) or any other form of circuitry. It should be appreciated that the processing circuitry need not be provided as a single unit but may be provided as any number of units or circuitry.

Example Node Operations

20 **Figure 12** is a flow diagram depicting example operations which may be taken by the eNodeB of Figure 12, during data transmission in a multiple antenna system, according to some of the example embodiments. The example embodiments illustrated in the flow diagram are mainly explained under the subheading entitled "Using CSI-RSRP for Improved Resolution Elevation Beamforming". Some portions of the example
25 embodiments illustrated in Figure 9 are also explained under the subheadings entitled "Generating Beamforming from CSI-RSRP Feedback" and "Refined use of the received CSI-RSRP Beamforming Feedback".

It should also be appreciated that Figure 12 comprises some operations which are illustrated with a darker boarder and some operations which are illustrated with a lighter
30 boarder. The operations which are comprised in a darker boarder are operations which are comprised in the broadest example embodiment. The operations which are comprised in a lighter boarder are example embodiments which may be comprised in, or a part of, or are further operations which may be taken in addition to the operations of the boarder example embodiments. It should be appreciated that these operations need not
35 be performed in order. Furthermore, it should be appreciated that not all of the operations

need to be performed. The example operations may be performed in any order and in any combination.

Example Operation 40

5 According to some of the example embodiments, the eNodeB 401 may be configured to transmit 40, to a user equipment, a plurality of reference signals. Each reference signal may be beamformed into a distinct direction within at least one correlated domain in the multiple antenna system. The radio circuitry 410 may be configured to transmit the plurality of reference signals. An example of such a transmission is explained
10 under at least the subheading "Generating Beamforming from CSI-RSRP Feedback".

 According to some of the example embodiments, the plurality of reference signals may be CSI-RS signals. According to some of the example embodiments, the at least one correlated domain may be an elevation and/or an azimuth domain.

15 *Example Operation 42*

 According to some of the example embodiments, the eNodeB 401 may also configure 42 the user equipment to measure and report a plurality of signal quality assessments based on the plurality of reference signals. The processing circuitry 420 may configure the user equipment to measure and report the plurality of signal quality
20 assessments based on the plurality of reference signals. According to some of the example embodiments, at least one of the signal quality assessments may be a RSRP, RSRQ, or a RRSI.

Operation 44

25 The eNodeB 401 is configured to receive 44, from the user equipment, the plurality of signal quality assessments. Each of the plurality of signal quality assessments corresponds to a signal quality level for a distinct direction within at least one correlated domain of the multiple antenna system. The radio circuitry 410 is configured to receive the plurality of signal quality assessments.

30 According to some of the example embodiments, at least one of the signal quality assessments may be a RSRP, RSRQ, or a RRSI. According to some of the example embodiments, the at least one correlated domain may be an elevation and/or an azimuth domain. According to some of the example embodiments, the plurality of signal quality assessments are received via CQI feedback messaging.

Operation 46

The eNodeB 401 is also configured to identify at least one first signal quality assessment, of the plurality of quality assessments, which corresponds to a pre-determined signal characteristic. The processing circuitry is configured to identify the at
5 least one first signal quality assessment of the plurality of quality assessments, which corresponds to a pre-determined signal characteristic. According to some of the example embodiments, the pre-determined signal characteristic may be a highest signal quality level measurement value. Examples of such identification are provided under the subheading "Using CSI-RSRP for Improved Resolution Elevation Beamforming".

10

Operation 48

The eNodeB 401 is further configured to identify 48 at least one second signal quality assessment that corresponds to a neighboring direction. The neighboring direction is with respect to a direction associated with the at least one first signal quality
15 assessment within the at least one correlated domain. The processing circuitry 420 is configured to identify the at least one second signal quality assessment that corresponds to the neighboring direction.

According to some of the example embodiments, the at least one second signal quality assessment comprises a plurality of signal quality assessments which correspond
20 to the neighboring direction. According to some of the example embodiments, the at least one first signal quality assessment is a highest received power level measurement and the at least one second signal quality assessment is a next highest received power level measurement within a predetermined range from the at least one first signal quality assessment. As explained under the subheading "Using CSI-RSRP for Improved
25 Resolution Elevation Beamforming", the at least one second signal quality assessment may comprise any number of assessments. According to some of the example embodiments, the at least one highest neighboring received power level measurement may be a plurality of next highest received power level measurements within a predetermined range from the at least one first signal quality assessment.

30

Operation 52

The eNodeB 401 is further configured to determine 52 at least one transmission direction within the at least one correlated domain based on signal quality levels of the at least one first signal quality assessment, the at least one second signal quality
35 assessment, and associated directions within the at least one correlated domain. The

processing circuitry 420 is configured to determine the at least one transmission direction within the at least one correlated domain based on signal quality levels of the at least one first signal quality assessment, the at least one second signal quality assessment, and the associated directions within the at least one correlated domain.

5

Example Operation 54

According to some of the example embodiments, the determining 52 may further comprise determining 54 a measurement quotient of the at least one first signal quality assessment and the at least one second signal quality assessment. The processing circuitry 420 is configured to determine the measurement quotient of the at least one first signal quality assessment and the at least one second signal quality assessment. An example of such a quotient may be $RSRP_1 / RSRP_2$ as described in relation to Figures 8 and 9.

15

Example Operation 55

According to some of the example embodiments, the determining 54 may further comprise mapping 55 a measurement quotient of the at least one first signal quality assessment and the at least one second signal quality assessment. The processing circuitry 420 may be configured to map the measurement quotient of the at least one first signal quality assessment and the at least one second signal quality assessment. Such a mapping is discussed, for example, in relation to Figures 8 and 9.

Operation 56

The eNodeB 401 is further configured to transmit 56, to the user equipment, downlink communications beamformed into the determined at least one transmission direction. The radio circuitry 410 is configured to transmit, to the user equipment, the downlink communications beamformed into the determined at least one transmission direction.

30

Example Operation 58

According to some of the example embodiments, the transmitting 56 may further comprise transmitting 58 the downlink communications according to

$\bar{\mathbf{x}}_{N_A N_s \times 1} = \mathbf{B}_{N_A N_s \times N_A}^{(data)}(\alpha) \mathbf{x}_{N_A \times 1}$, where α is the at least one transmission direction, N_s is a number of sub-elements in each antenna, N_A is a number of antennas in the multiple

antenna system, $\tilde{\mathbf{x}}_{N_A N_S \times 1}$ is the transmitted downlink communications, $\mathbf{x}_{N_A \times 1}(q)$ is a channel state signal for each antenna of the multiple antenna system, and $\mathbf{B}_{N_A N_S \times N_A}^{(data)}$ is a matrix comprising the plurality of beamforming vectors. The radio circuitry 410 is configured to transmit the downlink communications according

- 5 to $\tilde{\mathbf{x}}_{N_A N_S \times 1} = \mathbf{B}_{N_A N_S \times N_A}^{(data)}(\alpha) \mathbf{x}_{N_A \times 1}$. According to some of the example embodiments a same beamforming vector may be applied for all polarizations.

Conclusion

It should be noted that although terminology from 3GPP LTE has been used herein
10 to explain the example embodiments, this should not be seen as limiting the scope of the example embodiments to only the aforementioned system. Other wireless systems, including WCDMA, WiMax, UMB and GSM, may also benefit from the example embodiments disclosed herein.

Also note that terminology such as eNodeB and user equipment should be
15 considered as non-limiting and does in particular not imply a certain hierarchical relation between the two. In general "eNodeB" could be considered as device 1 and "user equipment" as device 2, and these two devices communicate with each other over some radio channel. Furthermore, while the example embodiments focus on wireless transmissions in the downlink, it should be appreciated that the example embodiments are
20 equally applicable in the uplink.

The description of the example embodiments provided herein have been presented for purposes of illustration. The description is not intended to be exhaustive or to limit example embodiments to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various
25 alternatives to the provided embodiments. The examples discussed herein were chosen and described in order to explain the principles and the nature of various example embodiments and its practical application to enable one skilled in the art to utilize the example embodiments in various manners and with various modifications as are suited to the particular use contemplated. The features of the embodiments described herein may
30 be combined in all possible combinations of methods, apparatus, modules, systems, and computer program products. It should be appreciated that the example embodiments presented herein may be practiced in any combination with each other.

It should be noted that the word "comprising" does not necessarily exclude the presence of other elements or steps than those listed and the words "a" or "an" preceding

an element do not exclude the presence of a plurality of such elements. It should further be noted that any reference signs do not limit the scope of the claims, that the example embodiments may be implemented at least in part by means of both hardware and software, and that several "means", "units" or "devices" may be represented by the same
5 item of hardware.

A "device" as the term may be used herein, is to be broadly interpreted to include a radiotelephone having ability for Internet/intranet access, web browser, organizer, calendar, a camera (e.g., video and/or still image camera), a sound recorder (e.g., a microphone), and/or global positioning system (GPS) receiver; a personal
10 communications system (PCS) user equipment that may combine a cellular radiotelephone with data processing; a personal digital assistant (PDA) that can include a radiotelephone or wireless communication system; a laptop; a camera (e.g., video and/or still image camera) having communication ability; and any other computation or communication device capable of transceiving, such as a personal computer, a home
15 entertainment system, a television, etc. Furthermore, a device may be interpreted as any number of antennas or antenna elements.

Although the description is mainly given for a user equipment, as measuring or recording unit, it should be understood by the skilled in the art that "user equipment" is a non-limiting term which means any wireless device, terminal, or node capable of receiving
20 in DL and transmitting in UL (e.g. PDA, laptop, mobile, sensor, fixed relay, mobile relay or even a radio base station, e.g. femto base station).

A cell is associated with a radio node, where a radio node or radio network node or eNodeB used interchangeably in the example embodiment description, comprises in a general sense any node transmitting radio signals used for measurements, e.g., eNodeB,
25 macro/micro/pico base station, home eNodeB, relay, beacon device, or repeater. A radio node herein may comprise a radio node operating in one or more frequencies or frequency bands. It may be a radio node capable of CA. It may also be a single- or multi-RAT node. A multi-RAT node may comprise a node with co-located RATs or supporting multi-standard radio (MSR) or a mixed radio node.

30 The various example embodiments described herein are described in the general context of method steps or processes, which may be implemented in one aspect by a computer program product, embodied in a computer-readable medium, including computer-executable instructions, such as program code, executed by computers in networked environments. A computer-readable medium may include removable and non-
35 removable storage devices including, but not limited to, Read Only Memory (ROM),

Random Access Memory (RAM), compact discs (CDs), digital versatile discs (DVD), etc. Generally, program modules may include routines, programs, objects, components, data structures, etc. that perform particular tasks or implement particular abstract data types.

Computer-executable instructions, associated data structures, and program modules

5 represent examples of program code for executing steps of the methods disclosed herein.

The particular sequence of such executable instructions or associated data structures represents examples of corresponding acts for implementing the functions described in such steps or processes.

In the drawings and specification, there have been disclosed exemplary

10 embodiments. However, many variations and modifications can be made to these embodiments. Accordingly, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the embodiments being defined by the following claims.

CLAIMS

1. A method, in an eNodeB, for establishing beamforming for downlink communications in a multiple antenna system, the eNodeB being comprised in a wireless communications network, the method comprising:
 - 5 receiving (44), from a user equipment, a plurality of signal quality assessments, wherein each of the plurality of signal quality assessments corresponds to a signal quality level for a distinct direction within at least one correlated domain of the multiple antenna system;
identifying (46) at least one first signal quality assessment, of the plurality of
10 signal quality assessments, that corresponds to a pre-determined signal characteristic;
identifying (48) at least one second signal quality assessment that corresponds to a neighboring direction, of a direction associated with said at least one first signal quality assessment, within said at least one correlated domain of the
15 multiple antenna system;
determining (52) at least one transmission direction within the at least one correlated domain based on signal quality levels of the at least one first signal quality assessment, the at least one second signal quality assessment, and associated directions within the at least one correlated domain; and
20 transmitting (56), to the user equipment, downlink communications beamformed into the determined at least one transmission direction.
2. The method of claim 1, wherein at least one of the signal quality assessments and/or signal quality level is a reference signal received power, RSRP, a reference
25 signal received quality, RSRQ, or a received signal strength indicator, RSSI.
3. The method of any of claims 1-2, wherein the pre-determined signal characteristic is a highest signal quality level measurement value.
- 30 4. The method of any of claims 1-3, wherein the at least one second signal quality assessment comprises a plurality of signal quality assessments which correspond to a neighboring direction.

5. The method of any of claims 1-4, further comprising:
transmitting (40) a plurality of reference signals, each reference signal being beamformed into a distinct direction within the at least one correlated domain of the multiple antenna system; and
5 configuring (42) the user equipment to measure and report the plurality of signal quality assessments based on the plurality of reference signals.
6. The method of claims 5, wherein the plurality of reference signals are Channel State Information Reference Symbols, CSI-RS.
- 10 7. The method of any of claims 1-6, wherein the at least one correlated domain is an elevation and/or azimuth domain.
8. The example embodiments of any of claims 1-7, wherein the at least one first signal quality assessment is a highest received power level measurement, and said at
15 least one second signal quality assessment is a next highest received power level measurement within a predetermined range from the at least one first signal quality assessment.
- 20 9. The method of claim 8, wherein the at least one highest neighboring received power level measurement is a plurality of next highest received power level measurements within a predetermined range from the at least one first signal quality assessment.
10. The method of any of claims 8-9, wherein the determining (52) further comprises
25 determining (54) a measurement quotient of the at least one first signal quality assessment, and the at least one second signal quality assessment.
11. The method of claim 10, wherein the determining (54) further comprises mapping
30 (55) the downlink communications to a beamforming angle, said mapping being a function of the measurement quotient.
12. The method of any of claims 1-11, wherein the transmitting (56) further comprises transmitting (58) the downlink communications represented by

$$\tilde{\mathbf{x}}_{N_A N_S \times 1} = \mathbf{B}_{N_A N_S \times N_A}^{(data)}(\alpha) \mathbf{x}_{N_A \times 1},$$
where α is the at least one transmission direction, N_S is
35 a number of sub-elements in each antenna, N_A is a number of antennas in the

multiple antenna system, $\tilde{\mathbf{x}}_{N_A N_S \times 1}$ is the transmitted downlink communications, $\mathbf{x}_{N_A \times 1}(q)$ is a channel state signal for each antenna of the multiple antenna system, and $\mathbf{B}_{N_A N_S \times N_A}^{(data)}$ is a matrix comprising the plurality of beamforming vectors.

- 5 13. The method of claims 12, wherein a same beamforming vector is applied for all polarizations.
14. The method of any of claims 1-13, wherein the plurality of signal quality assessments are received via Channel Quality Indicator, CQI, feedback messaging.
- 10 15. An eNodeB, for establishing beamforming for downlink communications in a multiple antenna system, the eNodeB being comprised in a wireless communications network, the eNodeB comprising:
 - radio circuitry (410) configured to receive, from a user equipment, a plurality of
 - 15 signal quality assessments, wherein each of the plurality of signal quality assessments corresponds to a signal quality level for a distinct direction within at least one correlated domain of the multiple antenna system;
 - processing circuitry (420) configured to identify at least one first signal quality assessment, of the plurality of signal quality assessments, that corresponds to a
 - 20 pre-determined signal characteristic;
 - the processing circuitry (420) further configured to identify at least one second signal quality assessment that corresponds to a neighboring direction, of a direction associated with said at least one first signal quality assessment, within said at least one correlated domain of the multiple antenna system;
 - 25 the processing circuitry (420) further configured to determine at least one transmission direction within the at least one correlated domain based on signal quality levels of the at least one first signal quality assessment, the at least one second signal quality assessment, and associated directions within the at least one correlated domain; and
 - 30 the radio circuitry (410) is further configured to transmit, to the user equipment, downlink communications beamformed into the determined at least one transmission direction.

16. The eNodeB of claim 15, wherein at least one of the signal quality assessments and/or signal quality level is a reference signal received power, RSRP, a reference signal received quality, RSRQ, or a received signal strength indicator, RSSI.
- 5 17. The eNodeB of any of claims 15-16, wherein the pre-determined signal characteristic is a highest signal measurement value.
18. The eNodeB of any of claims 15-17, wherein the at least one second signal quality assessment comprises a plurality of signal quality assessments which correspond to
10 a neighboring direction.
19. The eNodeB of any of claims 15-18, wherein the radio circuitry (410) is further configured to transmit a plurality of reference signals, each reference signal being beamformed into a distinct direction within the at least one correlated domain of the
15 multiple antenna system; and the processing circuitry (420) is configured to instruct the user equipment to measure and report the plurality of signal quality assessments based on the plurality of reference signals.
20. The eNodeB of claim 19, wherein the plurality of reference signals are Channel
20 State Information Reference Symbols, CSI-RS.
21. The eNodeB of any of claims 15-20, wherein the at least one correlated domain is an elevation and/or azimuth domain.
- 25 22. The eNodeB of any of claims 15-21, wherein the at least one first signal quality assessment is a highest received power level measurement, and said at least one second signal quality assessment is a next highest received power level measurement within a predetermined range from the at least one first signal quality assessment.
30
23. The eNodeB of claim 22, wherein the highest neighboring received power level measurement is a plurality of next highest received power level measurements within a predetermined range from the at least one first signal quality assessment.

24. The eNodeB of any of claims 22-23, wherein the processing circuitry (420) is configured to determine a measurement quotient the at least one first signal quality assessment, the at least one second signal quality assessment.
- 5 25. The eNodeB of claim 24, wherein the processing circuitry (420) is configured to map the downlink communications to a beamforming angle, said mapping being a function of the measurement quotient.
26. The eNodeB of any of claims 15-25, wherein the processing circuitry (420) is
10 configured to transmit the downlink communications represented by

$$\tilde{\mathbf{x}}_{N_A N_S \times 1} = \mathbf{B}_{N_A N_S \times N_A}^{(data)}(\alpha) \mathbf{x}_{N_A \times 1},$$
where α is the at least one transmission direction, N_S is a number of sub-elements in each antenna, N_A is a number of antennas in the multiple antenna system, $\tilde{\mathbf{x}}_{N_A N_S \times 1}$ is the transmitted downlink communications, $\mathbf{x}_{N_A \times 1}(q)$ is a channel state signal for each antenna of the multiple antenna system,
15 and $\mathbf{B}_{N_A N_S \times N_A}^{(data)}$, is a matrix comprising the plurality of beamforming vectors.
27. The eNodeB of claim 26, wherein a same beamforming vector is applied for all polarizations.
- 20 28. The eNodeB of any of claims 15-27, wherein the plurality of signal quality assessments are received via Channel Quality Indicator, CQI, feedback messaging.

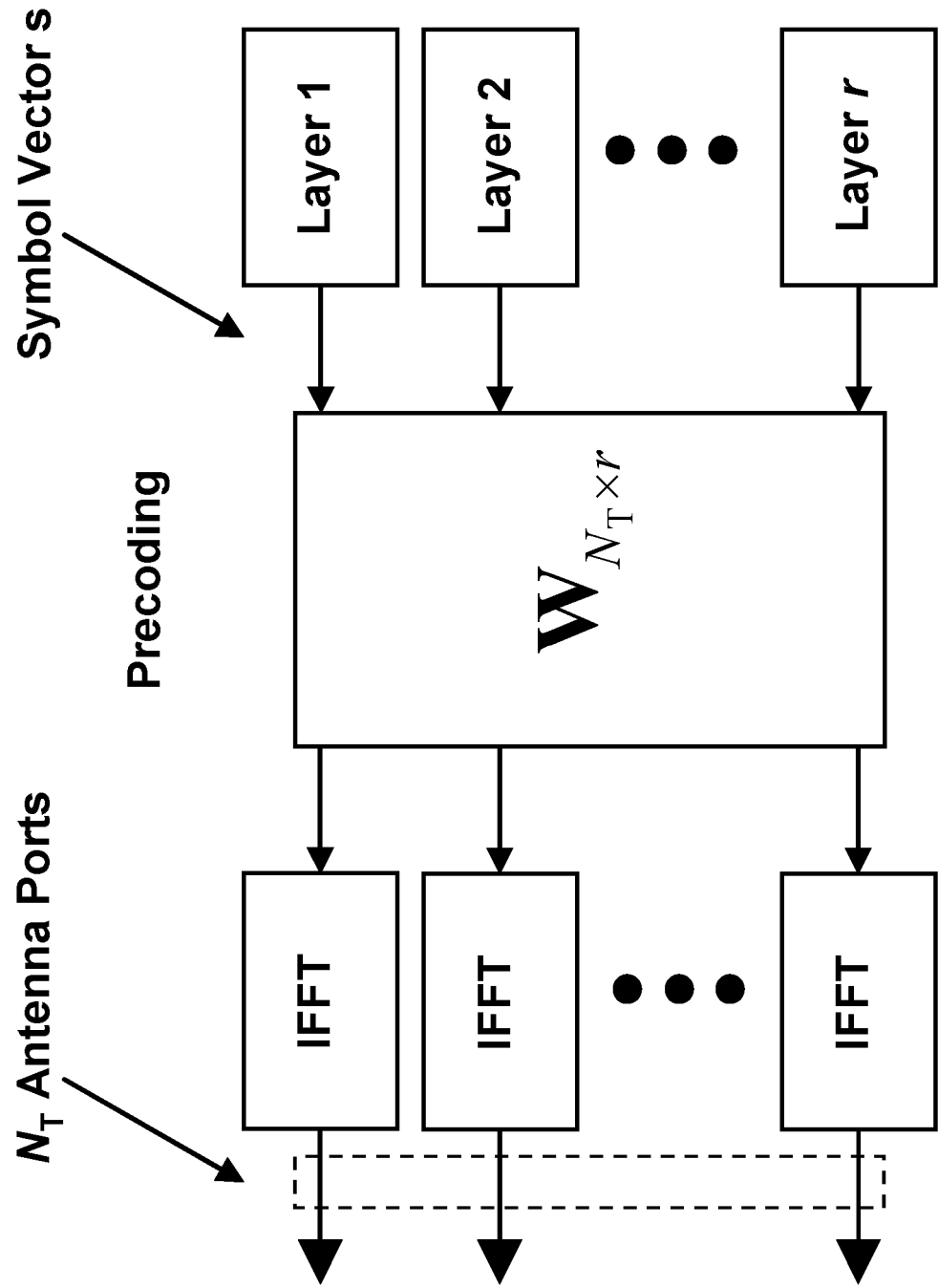


FIGURE 1

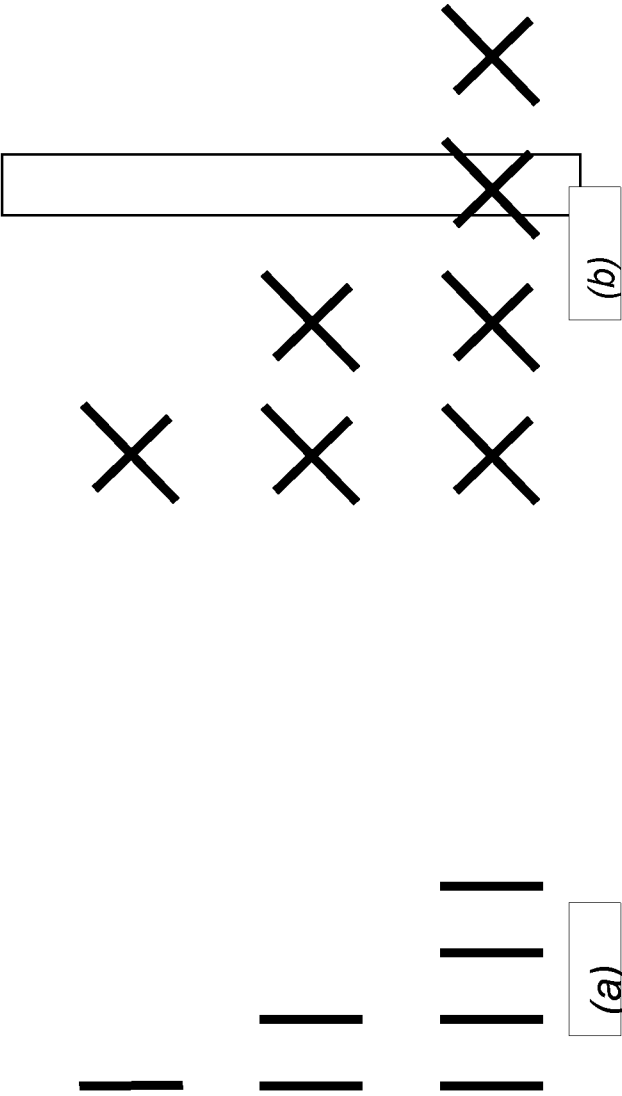


FIGURE 2

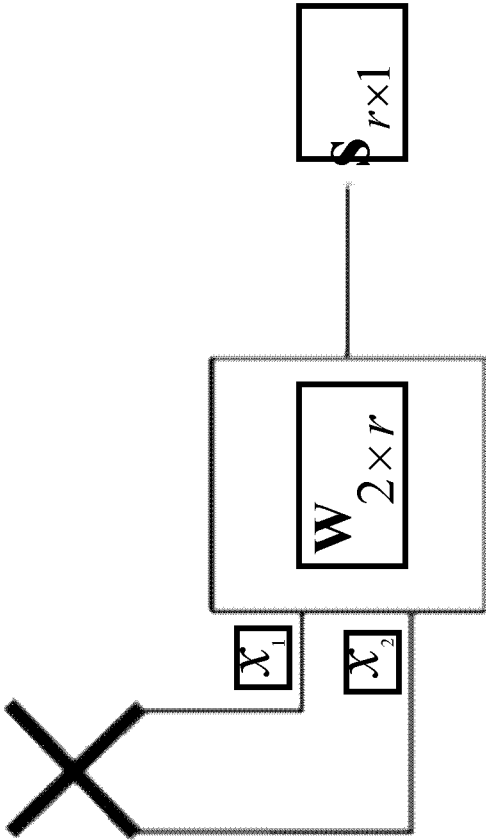


FIGURE 3

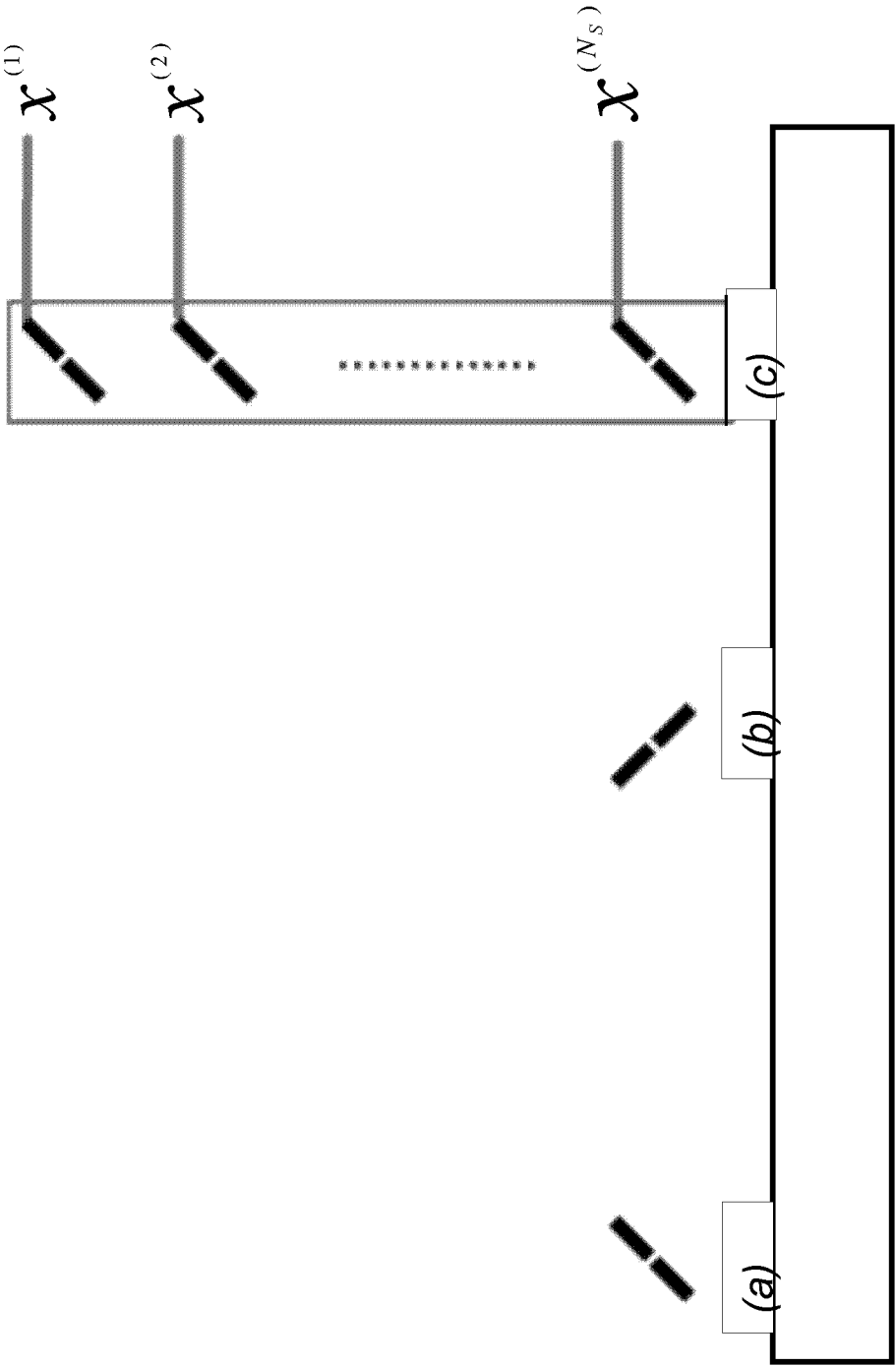


FIGURE 4

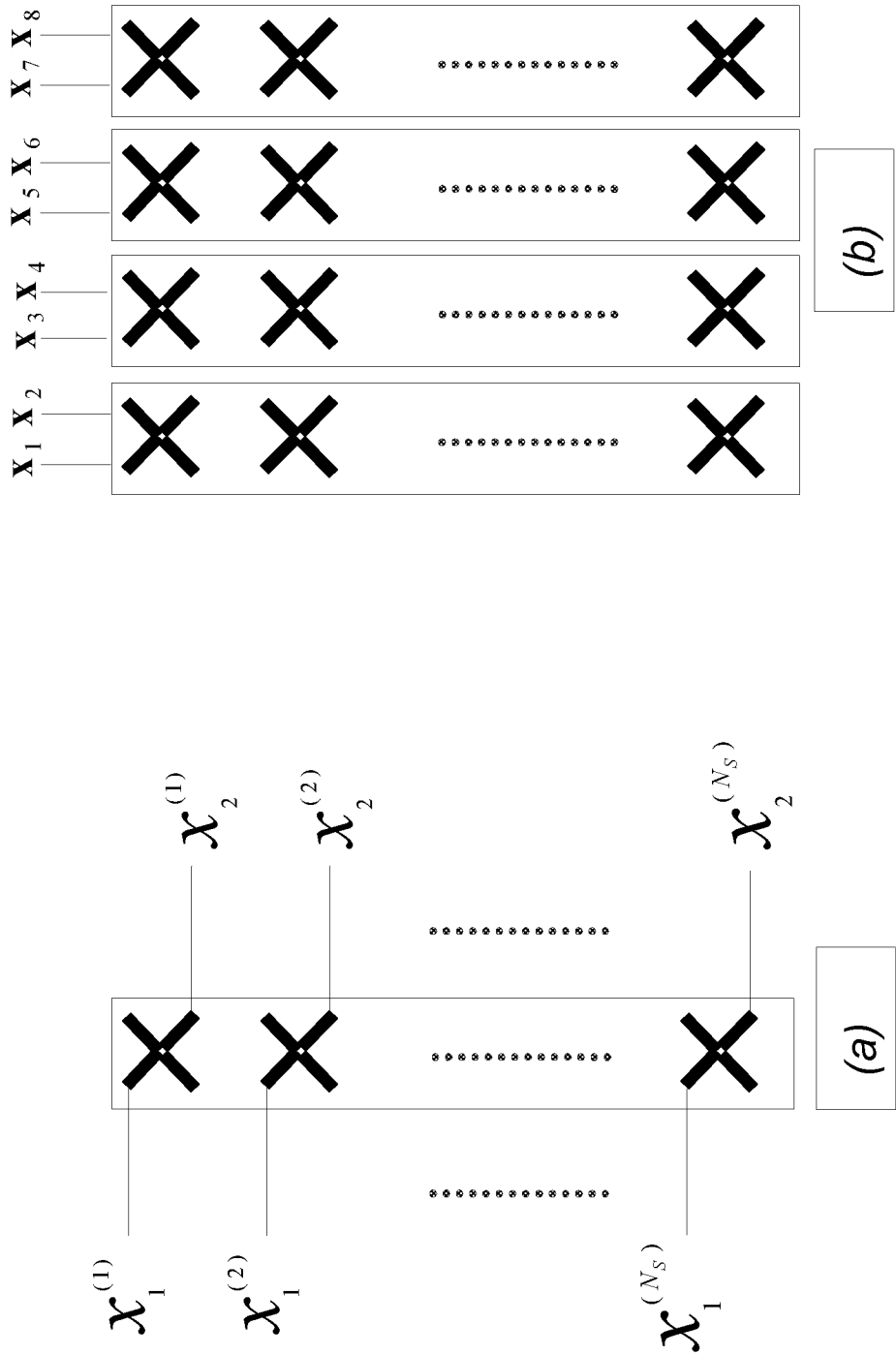


FIGURE 5

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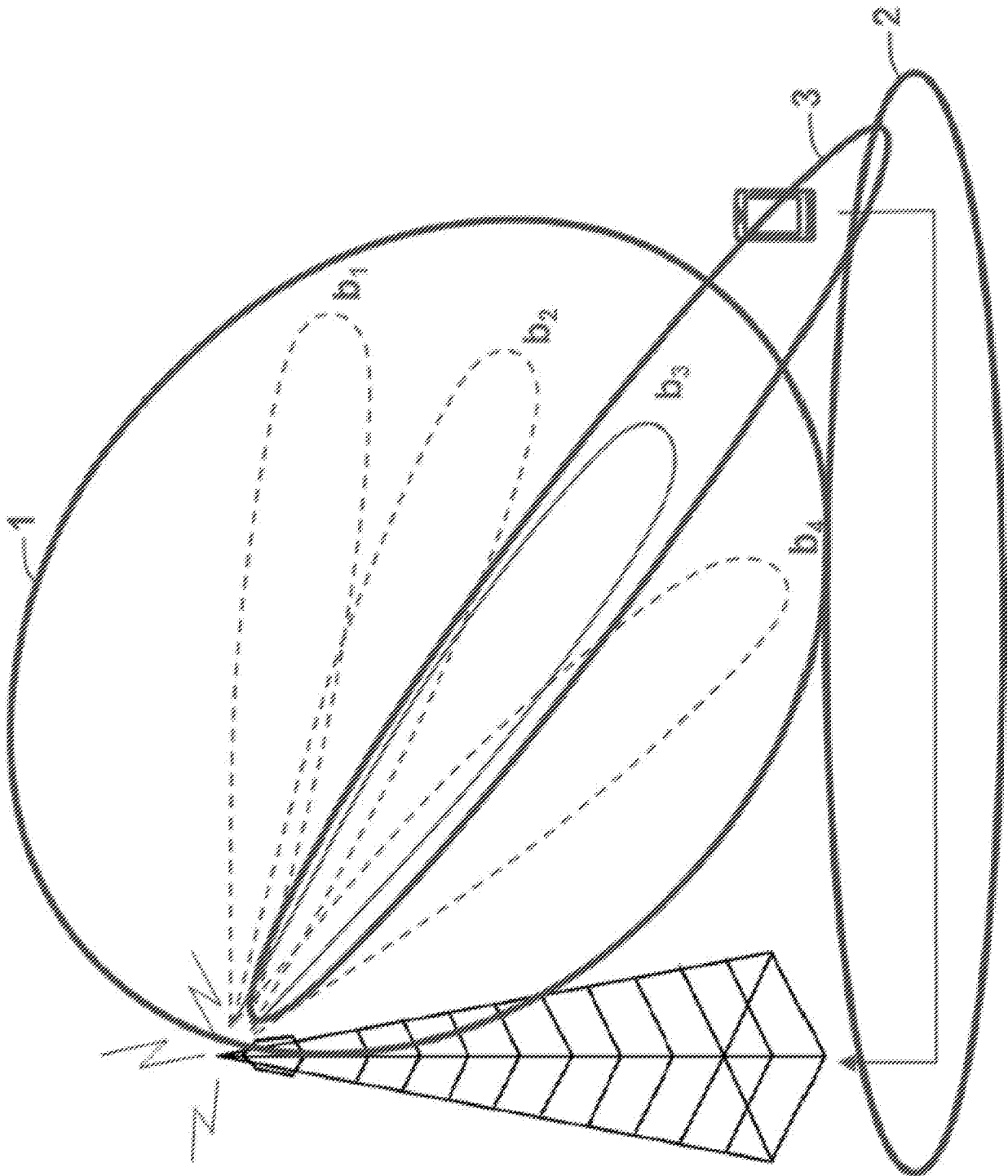


FIGURE 6

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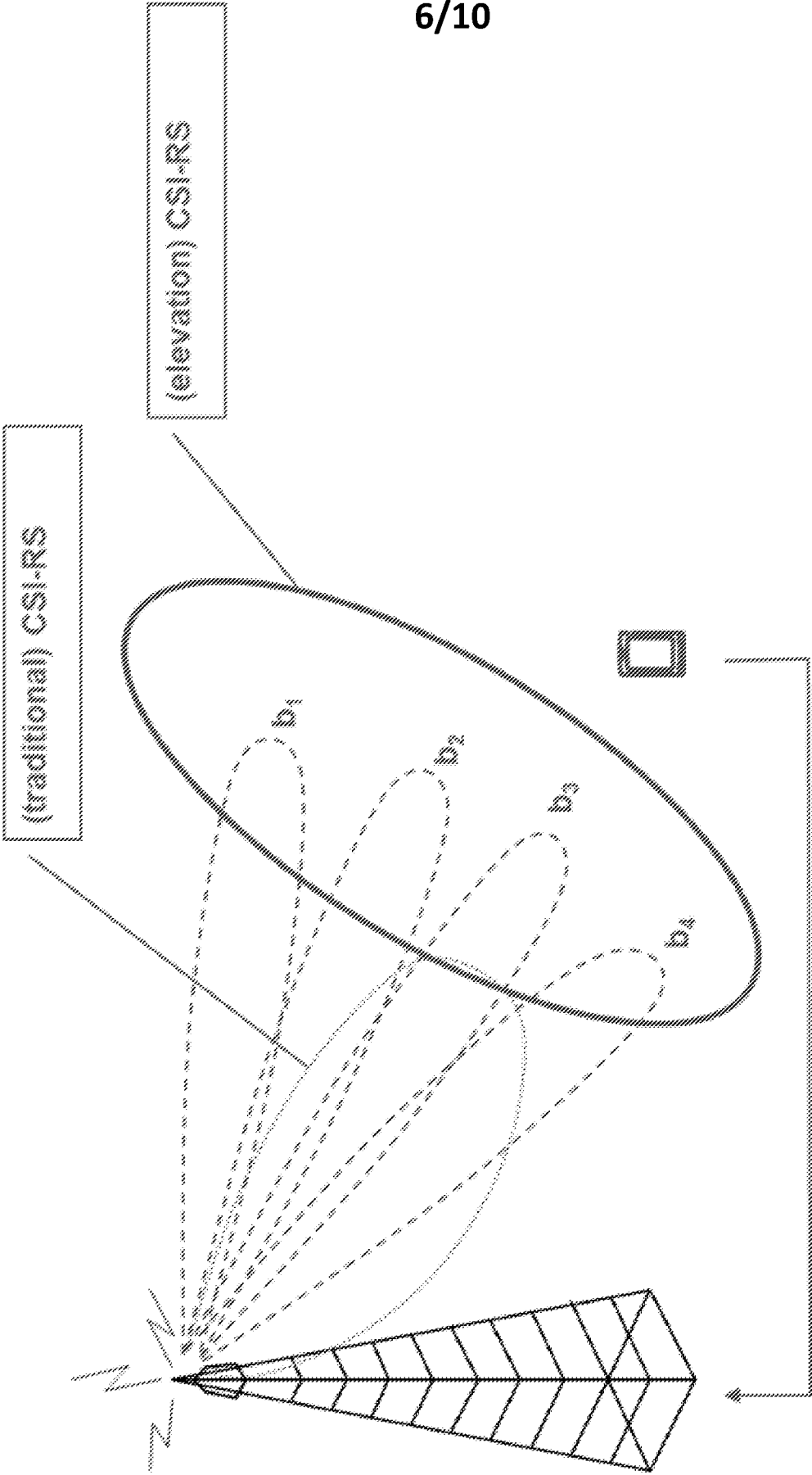


FIGURE 7

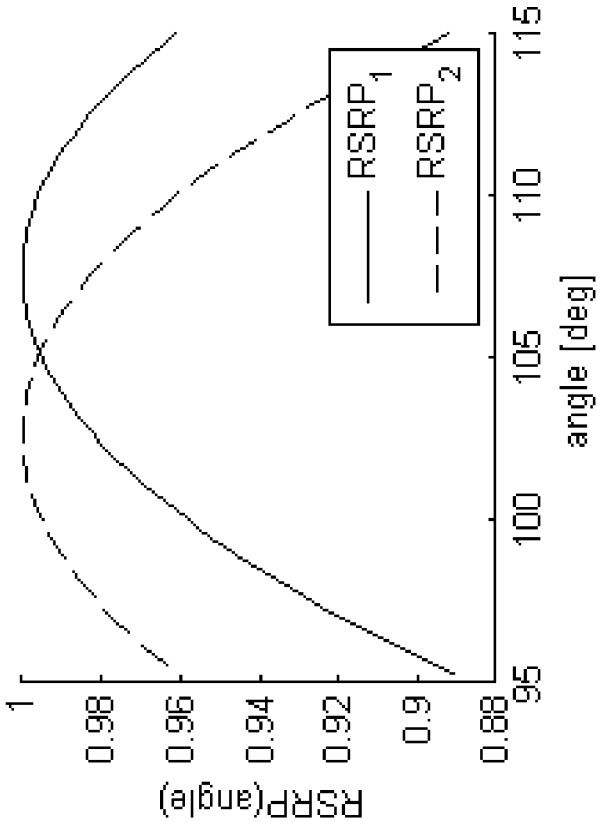


FIGURE 8

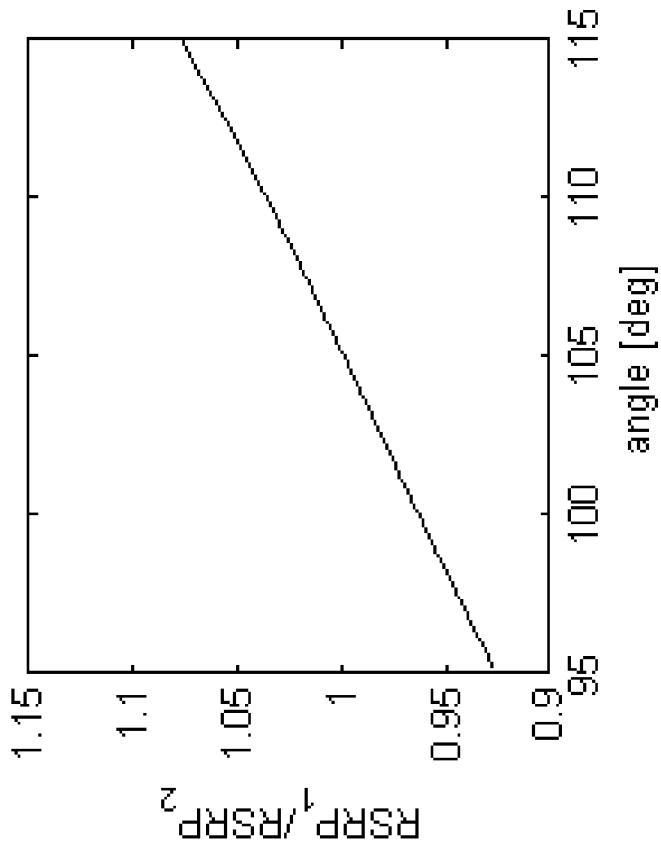


FIGURE 9

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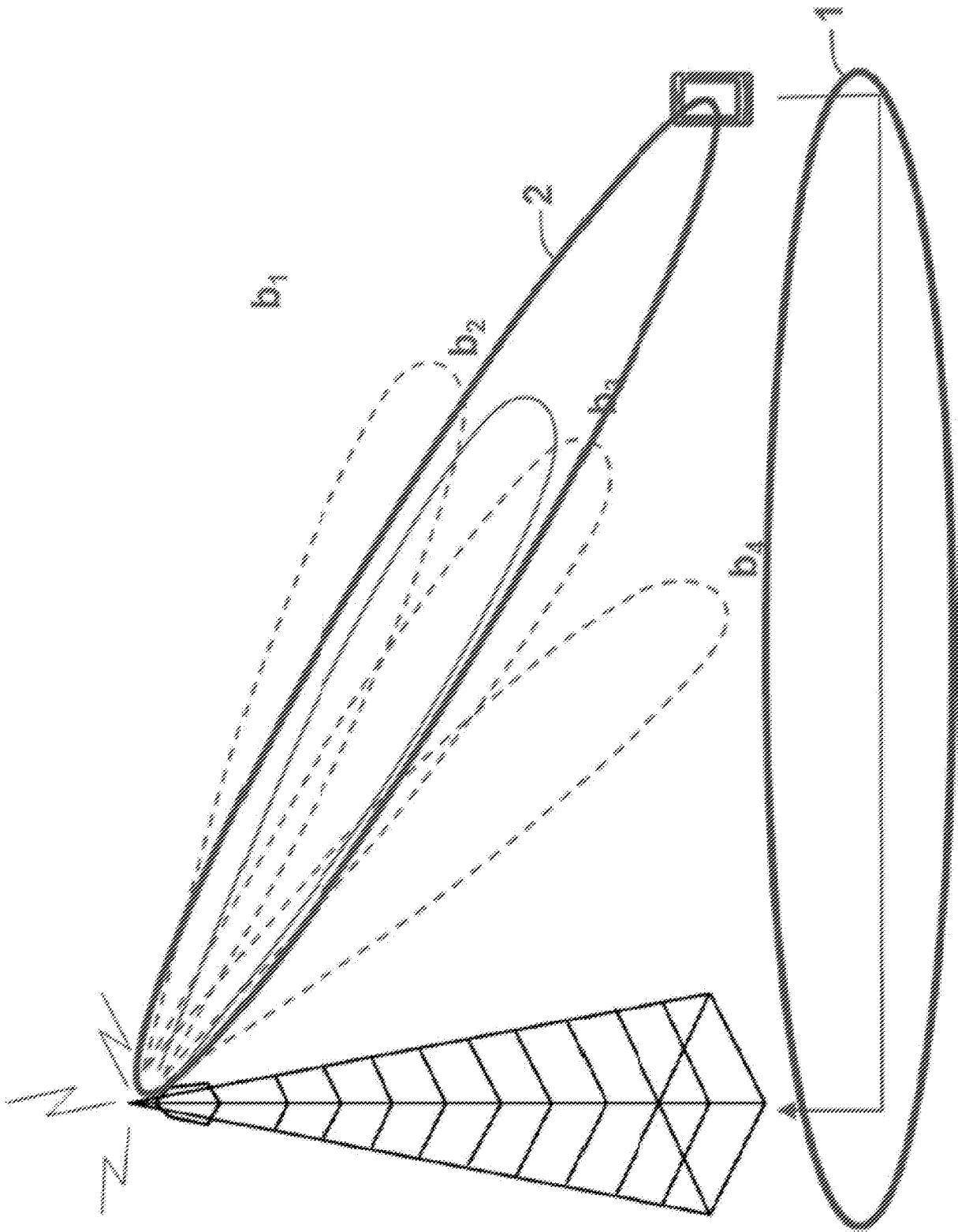


FIGURE 10

401

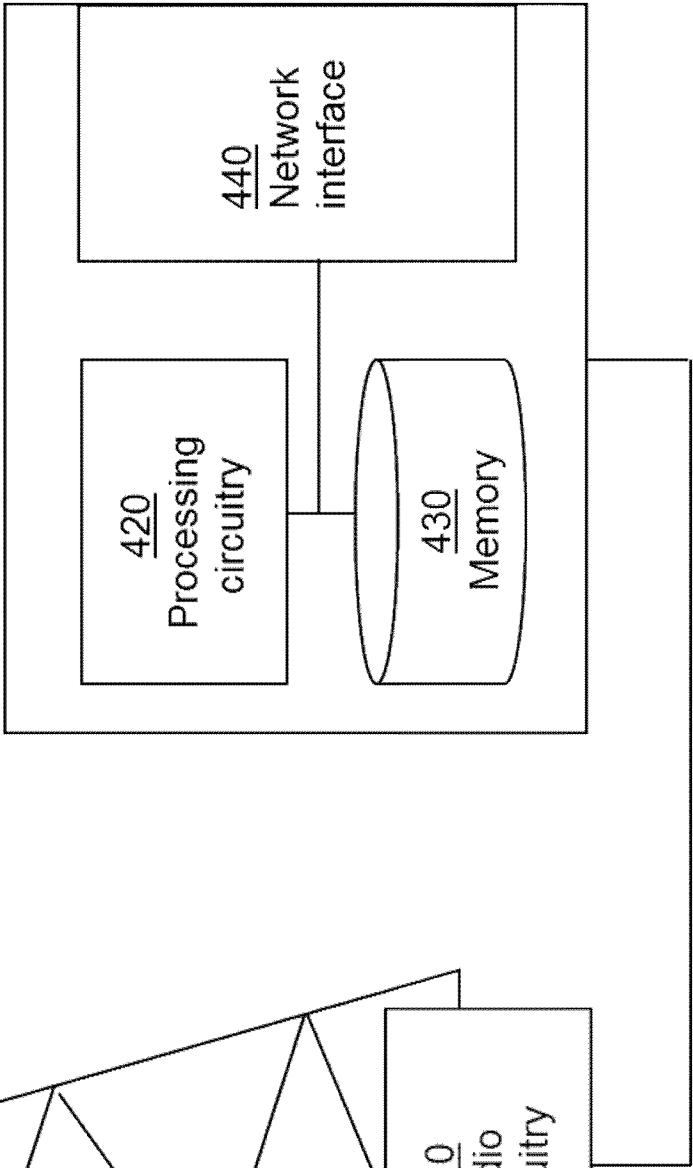
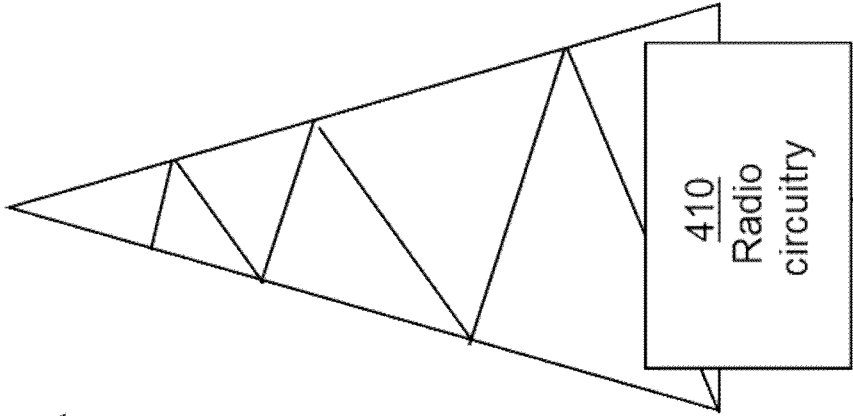


FIGURE 11

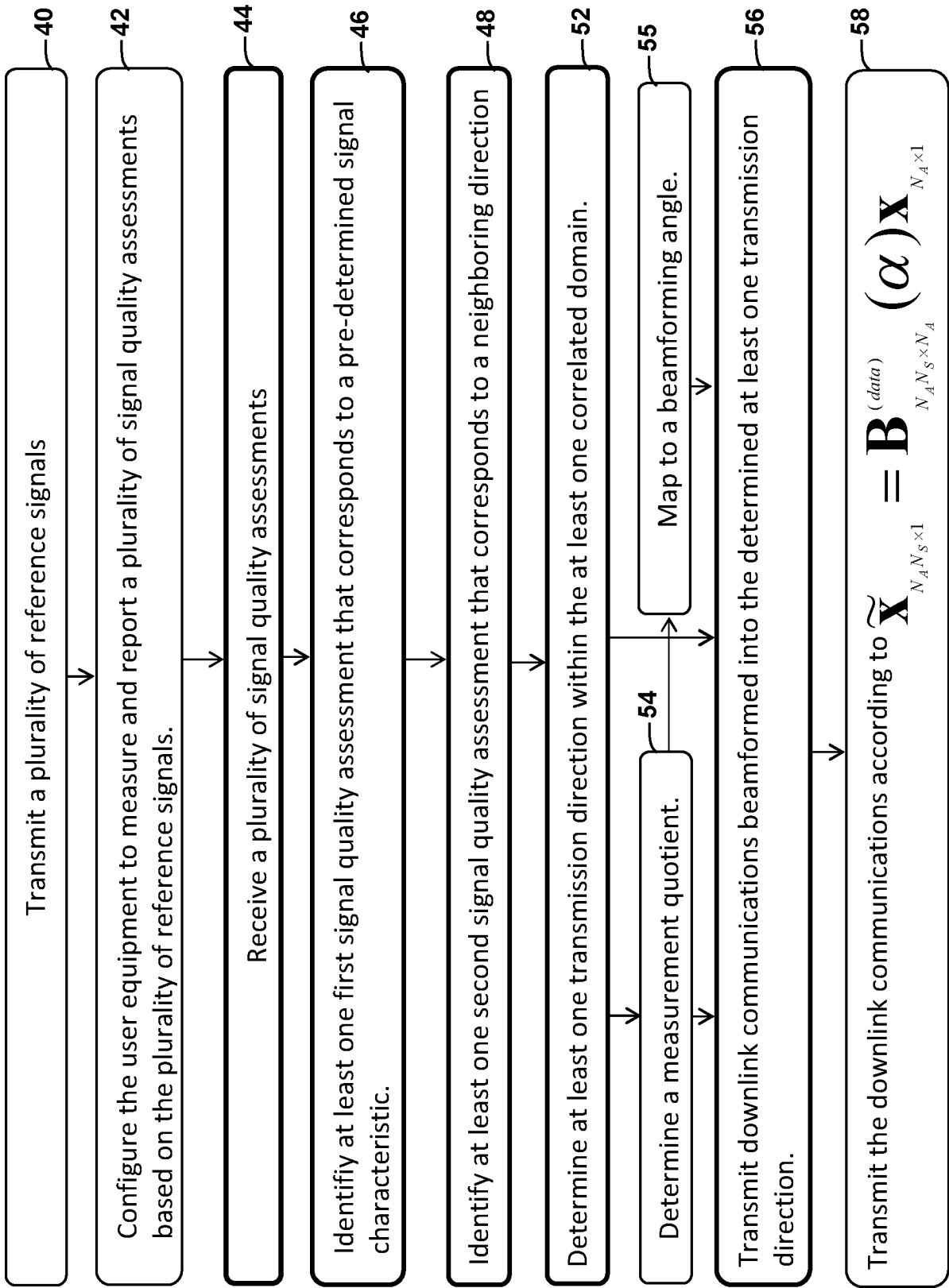


FIGURE 12

INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2012/050624

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06
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

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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98/25362 A1 (MOTOROLA INC [US]) 11 June 1998 (1998-06-11) abstract page 1, lines 5-8 page 3, lines 27-30 page 4, lines 1-7 page 5, lines 5-8, 22-27 page 7, lines 9-31 page 8, lines 4-10, 19-31 pages 9-10 page 11, lines 1-21 ----- -/--	1-28



Further documents are listed in the continuation of Box C.



See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

8 August 2012

Date of mailing of the international search report

14/08/2012

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INTERNATIONAL SEARCH REPORT

International application No

PCT/SE2012/050624

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 02/15432 A1 (FUJITSU LTD [JP]; GUO YINGJIE JAY [GB]) 21 February 2002 (2002-02-21) abstract page 1, lines 3-9 page 3, lines 21-23, 28-36 page 4, lines 1-6, 16-20, 26-36 page 5, lines 14-36 page 6, lines 1-16, 35-36 page 7, lines 1-17 page 8, lines 10-17 page 10, lines 10-36 page 11, lines 20-35 page 12, lines 9-12, 22-27, 36 page 13, lines 1-2, 23-36 page 14, lines 1-21, 28-36 page 15, lines 1-6 page 20, lines 13-20 page 21, lines 26-36 page 22 page 23, lines 1-18 page 24, lines 4-8, 16-36 page 25, lines 9-32 page 26, lines 1-13 page 28, lines 24-30 page 31, lines 14-16 page 34, lines 4-6, 30-36 page 35, lines 1-9 pages 38-39 page 40, lines 9-11 page 43, lines 25-28 page 44, lines 15-36 page 45, lines 19-26 -----	1-28
A	EP 1 267 443 A2 (MOBISPHERE LTD [GB]) 18 December 2002 (2002-12-18) paragraphs [0006] - [0007], [0013], [0020] - [0021], [0023] - [0024]; figure 11 -----	1-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

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