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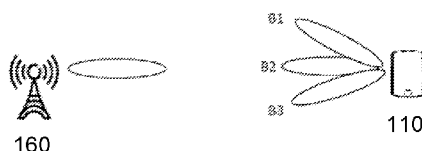
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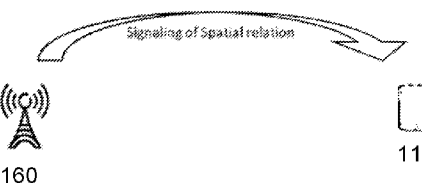
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Fig. 7

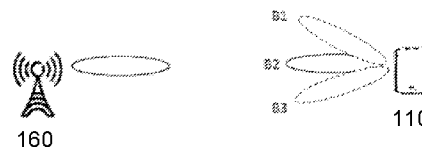
Step1: SRS beam sweep to
determine UE TX beam



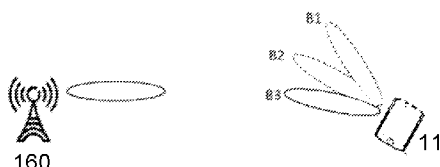
Step2: TRP configure UE with
spatial relation



Step3: UE perform UL
transmission on UE beam 2



Step4: UE determines that it
has rotated and therefore
update UE TX beam from UE
B2 to B3



(57) Abstract: According to some embodiments, a method performed by a wireless device of transmitting in an uplink radio beam comprises: obtaining a spatial domain filter to be used for uplink transmission; determining a spatial orientation of the wireless device has changed after obtaining the spatial domain filter to be used for uplink transmission; updating the spatial domain filter to be used for uplink transmission based on the changed spatial orientation of the wireless device; and transmitting an uplink beam using the updated spatial domain filter.

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FLEXIBLE UPLINK BEAM MANAGEMENT

TECHNICAL FIELD

5 Particular embodiments relate to wireless communication, and more specifically to flexible uplink beam management.

BACKGROUND

10 Generally, all terms used herein are to be interpreted according to their ordinary meaning in the relevant technical field, unless a different meaning is clearly given and/or is implied from the context in which it is used. All references to a/an/the element, apparatus, component, means, step, etc. are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, step, etc., unless explicitly stated otherwise. The steps of any methods disclosed herein do not have to be performed in the exact order disclosed, 15 unless a step is explicitly described as following or preceding another step and/or where it is implicit that a step must follow or precede another step. Any feature of any of the embodiments disclosed herein may be applied to any other embodiment, wherever appropriate. Likewise, any advantage of any of the embodiments may apply to any other embodiments, and vice versa. Other objectives, features, and advantages of the enclosed embodiments will be apparent from 20 the following description.

 The large variety of requirements for the next generation of mobile communications system (i.e., fifth generation (5G) or New Radio (NR)) result in the need for frequency bands at many different carrier frequencies. For example, low bands are used to achieve sufficient coverage and higher bands (e.g., mmW, near and above 30 GHz) are used to reach the required 25 capacity. The propagation properties at mmW frequencies are more challenging, and base stations may use high gain beamforming to achieve sufficient link budget.

 At mmW frequencies, concepts for handling mobility between beams (both within and between transmission reception points (TRPs)) are specified in NR. At these frequencies, where high-gain beamforming is used, each beam is only optimal within a small area. The link 30 budget outside the optimal beam deteriorates quickly. Thus, frequent and fast beam switching

may be needed to maintain high performance. To support such beam switching, NR specifies a beam indication framework. For example, for downlink data transmission (physical downlink shared channel (PDSCH)), the downlink control information (DCI) contains a transmission configuration indicator (TCI) that informs a user equipment (UE) which beam is used so that the UE can adjust its receive beam accordingly. This is beneficial for analog receive (Rx) beamforming where the UE needs to determine and apply the Rx beamforming weights before it can receive the PDSCH.

As used herein, the terminology “spatial filtering weights,” “spatial filtering configuration”, “spatial domain filtering weights,” “spatial domain filtering configuration,” and “spatial domain transmission filter” refer to the antenna weights that are applied at either the transmitter (gNB or UE) and the receiver (UE or gNB) for data/control transmission/reception. The terminology is general in the sense that different propagation environments lead to different spatial filtering weights that match the transmission/reception of a signal to the channel. The spatial filtering weights may not always result in a beam in a strict sense.

Prior to data transmission, a training phase may be used to determine the gNB and UE spatial filtering configurations. An example is illustrated in FIGURE 1.

FIGURE 1 is a block diagram illustrating a beam training phase followed by a data transmission phase. The training phase may be referred to in NR as downlink beam management. In NR, two types of reference signals (RSs) are used for downlink beam management operations, the channel state information RS (CSI-RS) and the synchronization signal/physical broadcast control channel (SS/PBCH) block, or SSB for short. FIGURE 1 illustrates an example where CSI-RS is used to find an appropriate beam pair link (BPL). An appropriate BPL refers to a suitable gNB transmit spatial filtering configuration (gNB Tx beam) plus a suitable UE receive spatial filtering configuration (UE Rx beam) resulting in an acceptable link budget.

For example, gNB 160 may transmit reference signals RS_n to UE 110. During its beam sweep, UE 110 may determine that RS₆ is an appropriate beam.

In the illustrated example, for downlink data/control transmission, gNB 170 indicates to UE 110 that the PDCCH/PDSCH demodulation reference signal (DMRS) is spatially quasi-

co-located (QCL) with RS6—the RS on which UE 110 performs measurements during the UE beam sweep in the beam training phase.

In the gNB Tx beam sweep, gNB 160 configures UE 110 to measure on a set of 5 CSI-RS resources (RS1 ... RS5) which are transmitted with 5 different spatial filtering configurations (Tx beams). The UE is also configured to report back the RS ID and the reference-signal receive power (RSRP) of the CSI-RS corresponding to the maximum measured RSRP.

In the illustrated example, the maximum measured RSRP corresponds to RS4. In this way the gNB learns what is the preferred Tx beam from the UE perspective. In the subsequent UE Rx beam sweep, the gNB transmits a number of CSI-RS resources in different orthogonal frequency division multiplexed (OFDM) symbols all with the same spatial filtering configuration (Tx beam) as was used to transmit RS4 previously. The UE then tests a different Rx spatial filtering configuration (Rx beam) in each OFDM symbol to maximum the received RSRP. The UE remembers the RS ID (RS ID 6 in the illustrated example) and the corresponding spatial filtering configuration that results in the largest RSRP. The network can then refer to this RS ID in the future when downlink data is scheduled to the UE, thus facilitating the UE to adjust its Rx spatial filtering configuration (Rx beam) to receive the PDSCH. As described above, the RS ID is contained in a transmission configuration indicator (TCI) that is carried in a field in the DCI that schedules the PDSCH.

In NR, the term “spatial quasi co-location (QCL)” refers to a relationship between the antenna port(s) of two different downlink reference signals (RSs). If two transmitted downlink RSs are spatially QCL'd at the UE receiver, then the UE may assume that the first and second RSs are transmitted with approximately the same Tx spatial filter configuration. Thus, the UE may use the same Rx spatial filter configuration to receive the second reference signal as it used to receive the first reference signal. Spatial QCL is a term that assists in the use of analog beamforming and formalizes the concept of “same UE Rx beam” over different time instances.

Referring to the downlink data transmission phase illustrated in the bottom left of FIGURE 1, gNB 160 indicates to UE 110 that the PDSCH DMRS is spatially QCL'd with RS6. UE 110 may use the same Rx spatial filtering configuration (Rx beam) to receive the PDSCH as the preferred spatial filtering configuration (Rx beam) determined based on RS6 during the

UE beam sweep in the downlink beam management phase.

While spatial QCL refers to a relationship between two different downlink reference signals from a UE perspective, NR uses the term “spatial relation” to refer to a relationship between an uplink reference signal (SRS or PUCCH/PUSCH DMRS) and another reference signal, which can be either a downlink reference signal (CSI-RS or SSB) or an uplink reference signal (SRS). The spatial relation can also refer to the relationship between PUCCH/PUSCH, i.e., without the explicit mentioning of DMRS, and another reference signal, which can be either a downlink reference signal (CSI-RS or SSB) or an uplink reference signal (SRS). This is also defined from a UE perspective. If the uplink reference signal is spatially related to a downlink reference signal, it means that the UE should transmit the uplink reference signal in the opposite direction from which it received the second reference signal previously. More precisely, the UE should apply the “same” Tx spatial filtering configuration for the transmission of the first reference signal as the Rx spatial filtering configuration it previously used to receive the second reference signal. If the second reference signal is an uplink reference signal, then the UE should apply the same Tx spatial filtering configuration for the transmission of the first reference signal as the Tx spatial filtering configuration it used to transmit the second reference signal previously.

Referring to the uplink data transmission phase illustrated in the bottom right of FIGURE 1, the gNB indicates to the UE that the PUCCH DMRS is spatially related to RS6. This means that the UE should use the “same” Tx spatial filtering configuration (Tx beam) to transmit the PUCCH as the preferred Rx spatial filtering configuration (Rx beam) determined based on RS6 during the UE beam sweep in the downlink beam management phase.

Using downlink reference signals as the source reference signal in a spatial relation is very effective when the UE can transmit the uplink signal in the opposite direction from which it previously received the downlink reference signal, or in other words, if the UE can achieve the same Tx antenna gain during transmission as the antenna gain it achieved during reception. This capability (known as beam correspondence) will not always be perfect. For example, because of imperfect calibration, the uplink Tx beam may point in another direction, resulting in a loss in uplink coverage. To improve the performance in this situation, uplink beam management based on SRS sweeping can be used, as outlined in FIGURE 2.

FIGURE 2 is a block diagram illustrating uplink beam management using a sounding reference signal (SRS) sweep. The signaling of the preferred SRS resource can be performed using different signaling methods, such as radio resource control (RRC), media access control (MAC) control element (CE) or DCI, depending on which channel is indicated.

To achieve optimum performance, the procedure illustrated in FIGURE 2 may be repeated as soon as the UEs Tx beam changes. The scheduling assignment that triggers the PUSCH transmission in the third step points to the most recent transmission of the indicated SRS resource. For every subsequent scheduling assignment, the UE uses the Tx beam used for the corresponding SRS transmission.

In the first step, UE 110 transmits a series of uplink signals (SRS resources) using different Tx beams and gNB 160 performs measurements for each of the SRS transmissions and determines which SRS transmission was received with the best quality, or highest signal quality. Then gNB 160 signals the preferred SRS resource to UE 110. Subsequently UE 110 transmits the PUSCH in the same beam where it transmitted the preferred SRS resource.

Beams and/or beam directions may be described using coordinate systems. A coordinate system, as illustrated in FIGURE 3, may be defined by x, y, z axes, spherical angles, and spherical unit vectors.

FIGURE 3 illustrates spherical angles and spherical unit vectors in a Cartesian coordinate system. In the illustrated example, $\hat{n}$ is the given direction, $\hat{\theta}$ and $\hat{\phi}$ are the spherical basis vectors. FIGURE 3 also defines the zenith angle θ and the azimuth angle ϕ in a Cartesian coordinate system. Note that $\theta = 0$ points to the zenith and $\theta = 90^\circ$ points to the horizon. The field component in the direction of $\hat{\theta}$ is given by F_θ and the field component in the direction of $\hat{\phi}$ is given by F_ϕ .

Coordinate systems include local and global coordinate systems. A Global Coordinate System (GCS) is defined for a system comprising multiple base stations (BSs) and user terminals (UTs). An array antenna for a BS or a UT can be defined in a Local Coordinate System (LCS). An LCS is used as a reference to define the vector far-field that is pattern and polarization, of each antenna element in an array. It is assumed that the far-field is known in the LCS by formulae. The placement of an array within the GCS is defined by the translation between the GCS and a LCS. The orientation of the array with respect to the GCS is defined in

general by a sequence of rotations. Because this orientation is in general different from the GCS orientation, it is necessary to map the vector fields of the array elements from the LCS to the GCS. This mapping depends only on the orientation of the array and may be specified by equations. Any arbitrary mechanical orientation of the array can be achieved by rotating the
 5 LCS with respect to the GCS.

An LCS may be transformed to a GCS. A GCS with coordinates $(x, y, z, \theta, \varphi)$ and unit vectors $(\hat{\theta}, \hat{\varphi})$ and an LCS with "primed" coordinates $(x', y', z', \theta', \varphi')$ and "primed" unit vectors $(\hat{\theta}', \hat{\varphi}')$ are defined with a common origins in FIGURES 4 and 5. FIGURE 4 illustrates the sequence of rotations that relate the GCS (solid lines labeled x, y, z) and the LCS (dashed lines
 10 labeled x, y, z with a single dot over the letters). FIGURE 5 illustrates the coordinate direction and unit vectors of the GCS (solid lines labeled x, y, z) and the LCS (solid lines labeled $x', y',$ and z'). The vector fields of the array antenna elements are defined in the LCS.

FIGURE 4 illustrates an arbitrary 3D-rotation of the LCS with respect to the GCS given by the angles α, β, γ . The set of angles α, β, γ can also be termed as the orientation of the array
 15 antenna with respect to the GCS.

The transformation from a LCS to a GCS depends only on the angles α, β, γ . The angle α is referred to as the bearing angle, β is referred to as the down tilt angle and γ is referred to as the slant angle.

Let $A'(\theta', \varphi')$ denote an antenna element pattern in the LCS and $A(\theta, \varphi)$ denote the
 20 same antenna element pattern in the GCS. Then the two are related simply by

$$A(\theta, \varphi) = A'(\theta', \varphi') \quad (7.1-1)$$

with θ' and φ' given by (7.1-7) and (7.1-8).

The polarized field components in the LCS are denoted by $F'_{\theta'}(\theta', \varphi')$, $F'_{\varphi'}(\theta', \varphi')$ and in the GCS by $F_{\theta}(\theta, \varphi)$, $F_{\varphi}(\theta, \varphi)$. Then they are related by equation (7.1-11).

Any arbitrary three-dimensional (3D) rotation can be specified by at most 3 elemental
 25 rotations, and following the framework of FIGURE 4, a series of rotations about the $z, \dot{y}$ and $\ddot{x}$ axes are assumed, in that order. The dotted and double-dotted marks indicate that the rotations are intrinsic, which means that they are the result of one ($\cdot$) or two ($\ddot{\cdot}$) intermediate rotations. In other words, the $\dot{y}$ axis is the original y axis after the first rotation about z , and the $\ddot{x}$ axis is
 30 the original x axis after the first rotation about z and the second rotation about $\dot{y}$. A first rotation

of α about z sets the antenna bearing angle (i.e., the sector pointing direction for a BS antenna element). The second rotation of β about y sets the antenna down tilt angle. Finally, the third rotation of γ about x sets the antenna slant angle. The orientation of the x , y and z axes after all three rotations can be denoted as $\ddot{x}$, $\ddot{y}$ and $\ddot{z}$. These triple-dotted axes represent the final orientation of the LCS, and for notational purposes denoted as the x' , y' and z' axes (local or "primed" coordinate system).

To establish the equations for transformation of the coordinate system and the polarized antenna field patterns between the GCS and the LCS, it is necessary to determine the composite rotation matrix that describes the transformation of point (x, y, z) in the GCS into point (x', y', z') in the LCS. This rotation matrix is computed as the product of three elemental rotation matrices. The matrix to describe rotations about the z , y and x axes by the angles α , β and γ respectively and in that order is defined as

$$R = R_z(\alpha)R_y(\beta)R_x(\gamma) = \begin{pmatrix} +\cos \alpha & -\sin \alpha & 0 \\ +\sin \alpha & +\cos \alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} +\cos \beta & 0 & +\sin \beta \\ 0 & 1 & 0 \\ -\sin \beta & 0 & +\cos \beta \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & +\cos \gamma & -\sin \gamma \\ 0 & +\sin \gamma & +\cos \gamma \end{pmatrix} \quad (7.1-2)$$

The reverse transformation is given by the inverse of R , which is also equal to the transpose of R since it is orthogonal.

$$R^{-1} = R_x(-\gamma)R_y(-\beta)R_z(-\alpha) = R^T \quad (7.1-3)$$

The simplified forward and reverse composite rotation matrices are given by

$$R = \begin{pmatrix} \cos \alpha \cos \beta & \cos \alpha \sin \beta \sin \gamma - \sin \alpha \cos \gamma & \cos \alpha \sin \beta \cos \gamma + \sin \alpha \sin \gamma \\ \sin \alpha \cos \beta & \sin \alpha \sin \beta \sin \gamma + \cos \alpha \cos \gamma & \sin \alpha \sin \beta \cos \gamma - \cos \alpha \sin \gamma \\ -\sin \beta & \cos \beta \sin \gamma & \cos \beta \cos \gamma \end{pmatrix} \quad (7.1-4)$$

and

$$R^{-1} = \begin{pmatrix} \cos \alpha \cos \beta & \sin \alpha \cos \beta & -\sin \beta \\ \cos \alpha \sin \beta \sin \gamma - \sin \alpha \cos \gamma & \sin \alpha \sin \beta \sin \gamma + \cos \alpha \cos \gamma & \cos \beta \sin \gamma \\ \cos \alpha \sin \beta \cos \gamma + \sin \alpha \sin \gamma & \sin \alpha \sin \beta \cos \gamma - \cos \alpha \sin \gamma & \cos \beta \cos \gamma \end{pmatrix} \quad (7.1-5)$$

These transformations can be used to derive the angular and polarization relationships

between the two coordinate systems.

To establish the angular relationships, consider a point (x, y, z) on the unit sphere defined by the spherical coordinates $(\rho=1, \theta, \phi)$, where ρ is the unit radius, θ is the zenith angle measured from the +z-axis, and ϕ is the azimuth angle measured from the +x-axis in the x-y plane. The Cartesian representation of that point is given by

$$\hat{\rho} = \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \sin \theta \cos \phi \\ \sin \theta \sin \phi \\ \cos \theta \end{pmatrix} \quad (7.1-6)$$

The zenith angle is computed as $\arccos(\hat{\rho} \cdot \hat{z})$ and the azimuth angle as $\arg(\hat{x} \cdot \hat{\rho} + j\hat{y} \cdot \hat{\rho})$, where $\hat{x}$, $\hat{y}$ and $\hat{z}$ are the Cartesian unit vectors. If this point represents a location in the GCS defined by θ and ϕ , the corresponding position in the LCS is given by $R^{-1}\hat{\rho}$, from which local angles θ' and ϕ' can be computed. The results are given in equations (7.1-7) and (7.1-8).

$$\theta'(\alpha, \beta, \gamma; \theta, \phi) = \arccos \left(\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}^T R^{-1} \hat{\rho} \right) = \arccos(\cos \beta \cos \gamma \cos \theta + (\sin \beta \cos \gamma \cos(\phi - \alpha) - \sin \gamma \sin(\phi - \alpha)) \sin \theta) \quad (7.1-7)$$

$$\phi'(\alpha, \beta, \gamma; \theta, \phi) = \arg \left(\begin{bmatrix} 1 \\ j \\ 0 \end{bmatrix}^T R^{-1} \hat{\rho} \right) = \arg \left(\begin{pmatrix} (\cos \beta \sin \theta \cos(\phi - \alpha) - \sin \beta \cos \theta) + \\ j(\cos \beta \sin \gamma \cos \theta + (\sin \beta \sin \gamma \cos(\phi - \alpha) + \cos \gamma \sin(\phi - \alpha)) \sin \theta) \end{pmatrix} \right) \quad (7.1-8)$$

These formulae relate the spherical angles (θ, ϕ) of the GCS to the spherical angles (θ', ϕ') of the LCS given the rotation operation defined by the angles (α, β, γ) .

The polarized field components are denoted $F_\theta(\theta, \varphi)$, $F_\phi(\theta, \varphi)$ in the GCS and $F'_{\theta'}(\theta', \varphi')$, $F'_{\phi'}(\theta', \varphi')$ in the LCS. These are related by

$$\begin{pmatrix} F_\theta(\theta, \phi) \\ F_\phi(\theta, \phi) \end{pmatrix} = \begin{pmatrix} \hat{\theta}(\theta, \phi)^T R \hat{\theta}'(\theta', \phi') & \hat{\theta}(\theta, \phi)^T R \hat{\phi}'(\theta', \phi') \\ \hat{\phi}(\theta, \phi)^T R \hat{\theta}'(\theta', \phi') & \hat{\phi}(\theta, \phi)^T R \hat{\phi}'(\theta', \phi') \end{pmatrix} \begin{pmatrix} F'_{\theta'}(\theta', \phi') \\ F'_{\phi'}(\theta', \phi') \end{pmatrix} \quad (7.1-9)$$

In this equation, $\hat{\theta}$ and $\hat{\phi}$ represent the spherical unit vectors of the GCS, and $\hat{\theta}'$ and $\hat{\phi}'$ are the representations in the LCS. The forward rotation matrix R transforms the LCS unit

vectors into the GCS frame of reference. These pairs of unit vectors are orthogonal and can be represented as shown in FIGURE 6.

FIGURE 6 illustrates rotation of the spherical basis vectors by an angle ψ due to the orientation of the LCS with respect to the GCS. Assuming an angular displacement of ψ between the two pairs of unit vectors, the rotation matrix of equation (7.1-9) can be further simplified as:

$$\begin{pmatrix} \hat{\theta}(\theta, \phi)^T R \hat{\theta}'(\theta', \phi') & \hat{\theta}(\theta, \phi)^T R \hat{\phi}'(\theta', \phi') \\ \hat{\phi}(\theta, \phi)^T R \hat{\theta}'(\theta', \phi') & \hat{\phi}(\theta, \phi)^T R \hat{\phi}'(\theta', \phi') \end{pmatrix} = \begin{pmatrix} \cos \psi & \cos(\pi/2 + \psi) \\ \cos(\pi/2 - \psi) & \cos \psi \end{pmatrix} = \begin{pmatrix} +\cos \psi & -\sin \psi \\ +\sin \psi & +\cos \psi \end{pmatrix} \quad (7.1-10)$$

and equation (7.1-9) can be written as:

$$\begin{pmatrix} F_{\theta}(\theta, \phi) \\ F_{\phi}(\theta, \phi) \end{pmatrix} = \begin{pmatrix} +\cos \psi & -\sin \psi \\ +\sin \psi & +\cos \psi \end{pmatrix} \begin{pmatrix} F'_{\theta'}(\theta', \phi') \\ F'_{\phi'}(\theta', \phi') \end{pmatrix} \quad (7.1-11)$$

The angle ψ can be computed in numerous ways from equation (7.1-10), with one such way being

$$\psi = \arg(\hat{\theta}(\theta, \phi)^T R \hat{\theta}'(\theta', \phi') + j \hat{\phi}(\theta, \phi)^T R \hat{\theta}'(\theta', \phi')) \quad (7.1-12)$$

The dot products are readily computed using the Cartesian representation of the spherical unit vectors. The general expressions for these unit vectors are given by

$$\hat{\theta} = \begin{pmatrix} \cos \theta \cos \phi \\ \cos \theta \sin \phi \\ -\sin \theta \end{pmatrix} \quad (7.1-13)$$

and

$$\hat{\phi} = \begin{pmatrix} -\sin \phi \\ +\cos \phi \\ 0 \end{pmatrix} \quad (7.1-14)$$

The angle ψ can be expressed as a function of mechanical orientation (α, β, γ) and spherical position (θ, ϕ), and is given by

$$\psi = \arg \left(\frac{(\sin \gamma \cos \theta \sin(\phi - \alpha) + \cos \gamma (\cos \beta \sin \theta - \sin \beta \cos \theta \cos(\phi - \alpha))) + j(\sin \gamma \cos(\phi - \alpha) + \sin \beta \cos \gamma \sin(\phi - \alpha))}{j(\sin \gamma \cos(\phi - \alpha) + \sin \beta \cos \gamma \sin(\phi - \alpha))} \right) \quad (7.1-15)$$

It can be shown that $\cos \psi$ and $\sin \psi$ can be expressed as:

$$\cos \psi = \frac{\cos \beta \cos \gamma \sin \theta - (\sin \beta \cos \gamma \cos(\phi - \alpha) - \sin \gamma \sin(\phi - \alpha)) \cos \theta}{\sqrt{1 - (\cos \beta \cos \gamma \cos \theta + (\sin \beta \cos \gamma \cos(\phi - \alpha) - \sin \gamma \sin(\phi - \alpha)) \sin \theta)^2}}$$

(7.1-16)

$$\sin \psi = \frac{\sin \beta \cos \gamma \sin(\phi - \alpha) + \sin \gamma \cos(\phi - \alpha)}{\sqrt{1 - (\cos \beta \cos \gamma \cos \theta + (\sin \beta \cos \gamma \cos(\phi - \alpha) - \sin \gamma \sin(\phi - \alpha)) \sin \theta)^2}}$$

(7.1-17)

There currently exist certain challenges. Because of UE rotation, the uplink Tx beam may be rapidly outdated, making it necessary to repeat the SRS sweep and the subsequent signaling. As illustrated in FIGURE 2, this procedure is associated with a significant amount of overhead: the SRS sweep is triggered, the gNB performs the measurement, and the gNB signals the updated Tx beam to the UE.

Each iteration of the procedure for uplink beam management is associated with significant overhead. Because the procedure may need to be frequently repeated because of UE rotation, the resulting total overhead may be substantial.

SUMMARY

As described above, certain challenges currently exist with uplink beam management. Certain aspects of the present disclosure and their embodiments may provide solutions to these or other challenges.

For example, particular embodiments include a flexible spatial relation based on at least an uplink reference signal so that a user equipment (UE) may choose a different transmit (Tx) beam for a subsequent uplink transmission than was previously used in a sounding reference signal (SRS) transmission. The UE may base its decision on other measurements such as measurements on a downlink reference signal or measurements from movement sensors.

According to some embodiments, a method performed by a wireless device of transmitting in an uplink radio beam comprises: obtaining a spatial domain filter to be used for uplink transmission; determining a spatial orientation of the wireless device has changed after obtaining the spatial domain filter to be used for uplink transmission; updating the spatial domain filter to be used for uplink transmission based on the changed spatial orientation of the

wireless device; and transmitting an uplink beam using the updated spatial domain filter. The method may further comprise receiving an indication from a base station that the wireless device may update its spatial domain filter to be used for uplink transmission.

5 In particular embodiments, obtaining the spatial domain filter to be used for uplink transmission comprises receiving a spatial relation from a base station. The spatial relation is based on results of measurements that the base stations performs on a plurality of reference signals transmitted by the wireless device. Obtaining the spatial domain filter to be used for uplink transmission may comprise receiving from a base station a sounding reference signal (SRS) index of a preferred SRS of a plurality of SRS transmitted from the wireless device to
10 the base station.

In particular embodiments, the wireless device comprises acceleration sensors, and determining that the spatial orientation of the wireless device has changed is based on the acceleration sensors. Determining that the spatial orientation of the wireless device has changed may comprise determining that a relationship between the obtained spatial domain
15 filter and a downlink reference signal has changed.

In particular embodiments, updating the spatial domain filter to be used for uplink transmission comprises determining a coordinate difference between an orientation of the wireless device associated with the obtained spatial domain filter and the changed spatial orientation of the wireless device, and selecting a new spatial domain filter based on the
20 coordinate difference. Updating the spatial domain filter to be used for uplink transmission may comprise determining a difference between a relationship between the obtained spatial domain filter and a downlink reference signal associated with the obtained spatial domain filter and a relationship between the changed spatial orientation of the wireless device and the downlink reference signal, and selecting a new spatial domain filter based on the difference.

25 In particular embodiments, updating the spatial domain filter to be used for uplink transmission comprises selecting a spatial domain filter such that an uplink beam transmitted by the wireless device using the selected spatial domain filter is transmitted in a similar direction as an uplink beam transmitted by the wireless device prior to the determined orientation change using the obtained spatial domain filter.

According to some embodiments, a wireless device is capable of transmitting in an uplink radio beam. The wireless device comprises processing circuitry operable to perform any of the wireless device methods described above.

5 According to some embodiments, a method performed by a network node for configuring a wireless device for uplink beam transmission comprises transmitting an indication to a wireless device that the wireless device may autonomously update its spatial domain filter to be used for uplink transmission.

10 In particular embodiments, the method further comprises transmitting a spatial domain filter to be used for uplink transmission to the wireless device and receiving an uplink transmission from the wireless device. The uplink transmission was transmitted using an updated spatial domain filter.

According to some embodiments, a network node is capable of configuring a wireless device for uplink beam transmission. The network node comprises processing circuitry operable to perform any of the network node methods described above.

15 Also disclosed is a computer program product comprising a non-transitory computer readable medium storing computer readable program code, the computer readable program code operable, when executed by processing circuitry to perform any of the methods performed by the wireless device described above.

20 Another computer program product comprises a non-transitory computer readable medium storing computer readable program code, the computer readable program code operable, when executed by processing circuitry to perform any of the methods performed by the network node described above.

Certain embodiments may provide one or more of the following technical advantages. For example, particular embodiments reduce signaling overhead because the uplink beam sweep and associated signaling can be performed less frequently. For a fixed uplink beam sweep frequency, the performance is improved because the UE may base its decisions on other measurements between the uplink beam sweeps.

25

BRIEF DESCRIPTION OF THE DRAWINGS

30 For a more complete understanding of the disclosed embodiments and their features

and advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a block diagram illustrating a beam training phase followed by a data transmission phase;

5 FIGURE 2 is a block diagram illustrating uplink beam management using a sounding reference signal (SRS) sweep;

FIGURE 3 illustrates spherical angles and spherical unit vectors in a Cartesian coordinate system;

10 FIGURE 4 illustrates orienting a local coordinate system (LCS) with a global coordinate system (GCS) by a sequence of 3 rotations: α , β , γ ,

FIGURE 5 illustrates a definition of spherical coordinates and unit vectors in both the GCS and LCS;

FIGURE 6 illustrates rotation of the spherical basis vectors by an angle ψ due to the orientation of the LCS with respect to the GCS;

15 FIGURE 7 illustrates steps for updating a spatial domain filter used for uplink transmission, according to a particular embodiment;

FIGURE 8 is a block diagram illustrating an example wireless network;

FIGURE 9 illustrates an example user equipment, according to certain embodiments;

20 FIGURE 10 is flowchart illustrating an example method in a wireless device, according to certain embodiments;

FIGURE 11 is a flowchart illustrating an example method in a network node, according to certain embodiments;

FIGURE 12 illustrates a schematic block diagram of a wireless device and network node in a wireless network, according to certain embodiments;

25 FIGURE 13 illustrates an example virtualization environment, according to certain embodiments;

FIGURE 14 illustrates an example telecommunication network connected via an intermediate network to a host computer, according to certain embodiments;

30 FIGURE 15 illustrates an example host computer communicating via a base station with a user equipment over a partially wireless connection, according to certain embodiments;

FIGURE 16 is a flowchart illustrating a method implemented, according to certain embodiments;

FIGURE 17 is a flowchart illustrating a method implemented in a communication system, according to certain embodiments;

5 FIGURE 18 is a flowchart illustrating a method implemented in a communication system, according to certain embodiments; and

FIGURE 19 is a flowchart illustrating a method implemented in a communication system, according to certain embodiments.

10 DETAILED DESCRIPTION

As described above, certain challenges currently exist with uplink beam management. Certain aspects of the present disclosure and their embodiments may provide solutions to these or other challenges. Particular embodiments include a flexible spatial relation based on at least an uplink reference signal so that a user equipment (UE) may choose a different transmit (Tx) beam for a subsequent uplink transmission than was previously used in a sounding reference signal (SRS) transmission. The UE may base its decision on other measurements such as measurements on a downlink reference signal or measurements from movement sensors.

Particular embodiments are described more fully with reference to the accompanying drawings. Other embodiments, however, are contained within the scope of the subject matter disclosed herein, the disclosed subject matter should not be construed as limited to only the embodiments set forth herein; rather, these embodiments are provided by way of example to convey the scope of the subject matter to those skilled in the art.

In a general UE Tx beam sweeping procedure, the UE transmits a set of candidate beams, where each beam may be associated with an arbitrary beam pattern, or equivalently, spatial domain Tx filtering setting, including sub-selection of transmission resource such as antennas or antenna panels.

In many cases, each beam i in the set of candidate beams may correspond to a specific spatial direction and may be expressed from the UE perspective as a pair of angles (θ'_i, ϕ'_i) in the UE's local coordinate system (LCS). Based on the uplink beam sweeping procedure, the gNB measures the received power on each beam in the set of candidate beams and feeds back

a selection of the preferred beam. The preferred beam may typically be selected by the gNB such that it illuminates the strongest channel path and can thus be said to be associated with a pair of angles (θ, ϕ) in the global coordinate system (GCS) relative to a position (x_0, y_0, z_0) of the UE (expressed as Cartesian coordinates).

5 In a typical case, if the UE does not change its original position and orientation (x_0, y_0, z_0) , the propagation channel should remain roughly constant and likely the same Tx beam direction will be optimal. However, if the UE is rotated, which may be quite common if the UE is a handheld smartphone, for example, then the optimal Tx beam direction will likely change drastically. This is because the Tx beam direction as seen by the UE is given
10 by the pair of angles in its LCS, which is no longer aligned with the GCS after a rotation is applied. A rotation (which may be expressed with Euler ZYZ angles α, β, γ) has been performed, shifting the LCS relative the GCS. The gNB indicated Tx beam, while corresponding to the same pair of angles in the UEs LCS, now because of the rotation correspond to another pair of angles $(\tilde{\theta}, \tilde{\phi})$ in the GCS than it did before the rotation was
15 applied. The new pair of angles in the GCS may not illuminate any propagation paths of the channel at all and thus applying a Tx beam transmitting in that direction is a poor transmission strategy.

If the UE could change the transmit beam direction in its LCS by compensating for rotation applied relative to the time of the transmission of the uplink reference signal whereon
20 the gNB made the measurement that the Tx beam selection was based on, the UE could change its transmission beam such as to still direct the beam towards the pair of angles (θ, ϕ) in the GCS corresponding to the strongest propagation path (as given by the gNBs initial TX beam indication), a proper beam direction could be maintained without requiring frequent SRS beam sweeps. Particular embodiments include systems and methods that achieve such a procedure.

25 In some embodiments, when a UE is configured with a spatial relation based on an uplink reference signal, the configuration is accompanied by a flag that tells the UE if the UE can use a spatial domain Tx filter different from the spatial domain Tx filter of the previously transmitted uplink reference signal. If the flag is set to 'true', the UE may change its Tx beam based on any input after the latest transmission of the uplink reference signal. An example is
30 illustrated in FIGURE 7.

FIGURE 7 illustrates steps for updating a spatial domain filter used for uplink transmission, according to a particular embodiment. In the first step, UE 110 performs a TX beam sweep by transmitting different SRS resources in different TX beams. The gNB 160 performs measurements on the different SRS resources and determines a preferred SRS resource, which corresponds to a certain UE TX beam.

In Step 2, gNB 160 signals the spatial relation for UE 110, which in this case corresponds to the SRS resource index of the preferred SRS resource. The signaling message may also include a flag that indicates to UE 110 that it is allowed to use a different Tx beam than the Tx beam used for the preferred SRS resource.

In Step 3 (which is optional), UE 110 transmits PUCCH and/or PUSCH in the B2 according to the spatial relation configuration. In Step 4, UE 110 determines that the Tx beam corresponding to the preferred SRS resource is no longer appropriate and decides to use another Tx beam.

In some embodiments, the UE uses its internal acceleration sensors to determine that the orientation of the UE has changed and that the current Tx beam is no longer appropriate. The UE then adjusts its Tx beam only when it is allowed to do so.

In some embodiments, the UE is configured with a spatial relation defined by one or more SRS resources and one or more downlink reference signals. The network may then signal to the UE a preferred SRS resource, which the UE may use in combination with measurements on downlink reference signals to determine its Tx beam.

In some embodiments, the UE uses the latest transmitted or received reference signal from one or more configured uplink reference signals and one or more configured downlink reference signals to determine its spatial domain Tx filter.

FIGURE 8 illustrates an example wireless network, according to certain embodiments. The wireless network may comprise and/or interface with any type of communication, telecommunication, data, cellular, and/or radio network or other similar type of system. In some embodiments, the wireless network may be configured to operate according to specific standards or other types of predefined rules or procedures. Thus, particular embodiments of the wireless network may implement communication standards, such as Global System for Mobile Communications (GSM), Universal Mobile Telecommunications System (UMTS),

Long Term Evolution (LTE), New Radio (NR), and/or other suitable 2G, 3G, 4G, or 5G standards; wireless local area network (WLAN) standards, such as the IEEE 802.11 standards; and/or any other appropriate wireless communication standard, such as the Worldwide Interoperability for Microwave Access (WiMax), Bluetooth, Z-Wave and/or ZigBee standards.

5 Network 106 may comprise one or more backhaul networks, core networks, IP networks, public switched telephone networks (PSTNs), packet data networks, optical networks, wide-area networks (WANs), local area networks (LANs), wireless local area networks (WLANs), wired networks, wireless networks, metropolitan area networks, and other networks to enable communication between devices.

10 Network node 160 and WD 110 comprise various components described in more detail below. These components work together to provide network node and/or wireless device functionality, such as providing wireless connections in a wireless network. In different embodiments, the wireless network may comprise any number of wired or wireless networks, network nodes, base stations, controllers, wireless devices, relay stations, and/or any other
15 components or systems that may facilitate or participate in the communication of data and/or signals whether via wired or wireless connections.

As used herein, network node refers to equipment capable, configured, arranged and/or operable to communicate directly or indirectly with a wireless device and/or with other network nodes or equipment in the wireless network to enable and/or provide wireless access to the
20 wireless device and/or to perform other functions (e.g., administration) in the wireless network.

Examples of network nodes include, but are not limited to, access points (APs) (e.g., radio access points), base stations (BSs) (e.g., radio base stations, Node Bs, evolved Node Bs (eNBs) and NR NodeBs (gNBs)). Base stations may be categorized based on the amount of coverage they provide (or, stated differently, their transmit power level) and may then also be
25 referred to as femto base stations, pico base stations, micro base stations, or macro base stations.

A base station may be a relay node or a relay donor node controlling a relay. A network node may also include one or more (or all) parts of a distributed radio base station such as centralized digital units and/or remote radio units (RRUs), sometimes referred to as Remote
30 Radio Heads (RRHs). Such remote radio units may or may not be integrated with an antenna

as an antenna integrated radio. Parts of a distributed radio base station may also be referred to as nodes in a distributed antenna system (DAS). Yet further examples of network nodes include multi-standard radio (MSR) equipment such as MSR BSs, network controllers such as radio network controllers (RNCs) or base station controllers (BSCs), base transceiver stations (BTSSs), transmission points, transmission nodes, multi-cell/multicast coordination entities (MCEs), core network nodes (e.g., MSCs, MMEs), O&M nodes, OSS nodes, SON nodes, positioning nodes (e.g., E-SMLCs), and/or MDTs.

As another example, a network node may be a virtual network node as described in more detail below. More generally, however, network nodes may represent any suitable device (or group of devices) capable, configured, arranged, and/or operable to enable and/or provide a wireless device with access to the wireless network or to provide some service to a wireless device that has accessed the wireless network.

In FIGURE 8, network node 160 includes processing circuitry 170, device readable medium 180, interface 190, auxiliary equipment 184, power source 186, power circuitry 187, and antenna 162. Although network node 160 illustrated in the example wireless network of FIGURE 8 may represent a device that includes the illustrated combination of hardware components, other embodiments may comprise network nodes with different combinations of components.

It is to be understood that a network node comprises any suitable combination of hardware and/or software needed to perform the tasks, features, functions and methods disclosed herein. Moreover, while the components of network node 160 are depicted as single boxes located within a larger box, or nested within multiple boxes, in practice, a network node may comprise multiple different physical components that make up a single illustrated component (e.g., device readable medium 180 may comprise multiple separate hard drives as well as multiple RAM modules).

Similarly, network node 160 may be composed of multiple physically separate components (e.g., a NodeB component and a RNC component, or a BTS component and a BSC component, etc.), which may each have their own respective components. In certain scenarios in which network node 160 comprises multiple separate components (e.g., BTS and BSC components), one or more of the separate components may be shared among several network

nodes. For example, a single RNC may control multiple NodeB's. In such a scenario, each unique NodeB and RNC pair, may in some instances be considered a single separate network node.

5 In some embodiments, network node 160 may be configured to support multiple radio access technologies (RATs). In such embodiments, some components may be duplicated (e.g., separate device readable medium 180 for the different RATs) and some components may be reused (e.g., the same antenna 162 may be shared by the RATs). Network node 160 may also include multiple sets of the various illustrated components for different wireless technologies integrated into network node 160, such as, for example, GSM, WCDMA, LTE, NR, WiFi, or
10 Bluetooth wireless technologies. These wireless technologies may be integrated into the same or different chip or set of chips and other components within network node 160.

Processing circuitry 170 is configured to perform any determining, calculating, or similar operations (e.g., certain obtaining operations) described herein as being provided by a network node. These operations performed by processing circuitry 170 may include processing
15 information obtained by processing circuitry 170 by, for example, converting the obtained information into other information, comparing the obtained information or converted information to information stored in the network node, and/or performing one or more operations based on the obtained information or converted information, and as a result of said processing making a determination.

20 Processing circuitry 170 may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, software and/or encoded logic operable to provide, either alone or in conjunction with other network node 160 components,
25 such as device readable medium 180, network node 160 functionality.

For example, processing circuitry 170 may execute instructions stored in device readable medium 180 or in memory within processing circuitry 170. Such functionality may include providing any of the various wireless features, functions, or benefits discussed herein. In some embodiments, processing circuitry 170 may include a system on a chip (SOC).

In some embodiments, processing circuitry 170 may include one or more of radio frequency (RF) transceiver circuitry 172 and baseband processing circuitry 174. In some embodiments, radio frequency (RF) transceiver circuitry 172 and baseband processing circuitry 174 may be on separate chips (or sets of chips), boards, or units, such as radio units and digital units. In alternative embodiments, part or all of RF transceiver circuitry 172 and baseband processing circuitry 174 may be on the same chip or set of chips, boards, or units

In certain embodiments, some or all of the functionality described herein as being provided by a network node, base station, eNB, gNB or other such network device may be performed by processing circuitry 170 executing instructions stored on device readable medium 180 or memory within processing circuitry 170. In alternative embodiments, some or all of the functionality may be provided by processing circuitry 170 without executing instructions stored on a separate or discrete device readable medium, such as in a hard-wired manner. In any of those embodiments, whether executing instructions stored on a device readable storage medium or not, processing circuitry 170 can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry 170 alone or to other components of network node 160 but are enjoyed by network node 160 as a whole, and/or by end users and the wireless network generally.

Device readable medium 180 may comprise any form of volatile or non-volatile computer readable memory including, without limitation, persistent storage, solid-state memory, remotely mounted memory, magnetic media, optical media, random access memory (RAM), read-only memory (ROM), mass storage media (for example, a hard disk), removable storage media (for example, a flash drive, a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer-executable memory devices that store information, data, and/or instructions that may be used by processing circuitry 170. Device readable medium 180 may store any suitable instructions, data or information, including a computer program, software, an application including one or more of logic, rules, code, tables, etc. and/or other instructions capable of being executed by processing circuitry 170 and, utilized by network node 160. Device readable medium 180 may be used to store any calculations made by processing circuitry 170 and/or

any data received via interface 190. In some embodiments, processing circuitry 170 and device readable medium 180 may be considered to be integrated.

Interface 190 is used in the wired or wireless communication of signaling and/or data between network node 160, network 106, and/or WDs 110. As illustrated, interface 190 comprises port(s)/terminal(s) 194 to send and receive data, for example to and from network 106 over a wired connection. Interface 190 also includes radio front end circuitry 192 that may be coupled to, or in certain embodiments a part of, antenna 162.

Radio front end circuitry 192 comprises filters 198 and amplifiers 196. Radio front end circuitry 192 may be connected to antenna 162 and processing circuitry 170. Radio front end circuitry may be configured to condition signals communicated between antenna 162 and processing circuitry 170. Radio front end circuitry 192 may receive digital data that is to be sent out to other network nodes or WDs via a wireless connection. Radio front end circuitry 192 may convert the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters 198 and/or amplifiers 196. The radio signal may then be transmitted via antenna 162. Similarly, when receiving data, antenna 162 may collect radio signals which are then converted into digital data by radio front end circuitry 192. The digital data may be passed to processing circuitry 170. In other embodiments, the interface may comprise different components and/or different combinations of components.

In certain alternative embodiments, network node 160 may not include separate radio front end circuitry 192, instead, processing circuitry 170 may comprise radio front end circuitry and may be connected to antenna 162 without separate radio front end circuitry 192. Similarly, in some embodiments, all or some of RF transceiver circuitry 172 may be considered a part of interface 190. In still other embodiments, interface 190 may include one or more ports or terminals 194, radio front end circuitry 192, and RF transceiver circuitry 172, as part of a radio unit (not shown), and interface 190 may communicate with baseband processing circuitry 174, which is part of a digital unit (not shown).

Antenna 162 may include one or more antennas, or antenna arrays, configured to send and/or receive wireless signals. Antenna 162 may be coupled to radio front end circuitry 190 and may be any type of antenna capable of transmitting and receiving data and/or signals wirelessly. In some embodiments, antenna 162 may comprise one or more omni-directional,

sector or panel antennas operable to transmit/receive radio signals between, for example, 2 GHz and 66 GHz. An omni-directional antenna may be used to transmit/receive radio signals in any direction, a sector antenna may be used to transmit/receive radio signals from devices within a particular area, and a panel antenna may be a line of sight antenna used to transmit/receive radio signals in a relatively straight line. In some instances, the use of more than one antenna may be referred to as MIMO. In certain embodiments, antenna 162 may be separate from network node 160 and may be connectable to network node 160 through an interface or port.

Antenna 162, interface 190, and/or processing circuitry 170 may be configured to perform any receiving operations and/or certain obtaining operations described herein as being performed by a network node. Any information, data and/or signals may be received from a wireless device, another network node and/or any other network equipment. Similarly, antenna 162, interface 190, and/or processing circuitry 170 may be configured to perform any transmitting operations described herein as being performed by a network node. Any information, data and/or signals may be transmitted to a wireless device, another network node and/or any other network equipment.

Power circuitry 187 may comprise, or be coupled to, power management circuitry and is configured to supply the components of network node 160 with power for performing the functionality described herein. Power circuitry 187 may receive power from power source 186. Power source 186 and/or power circuitry 187 may be configured to provide power to the various components of network node 160 in a form suitable for the respective components (e.g., at a voltage and current level needed for each respective component). Power source 186 may either be included in, or external to, power circuitry 187 and/or network node 160.

For example, network node 160 may be connectable to an external power source (e.g., an electricity outlet) via an input circuitry or interface such as an electrical cable, whereby the external power source supplies power to power circuitry 187. As a further example, power source 186 may comprise a source of power in the form of a battery or battery pack which is connected to, or integrated in, power circuitry 187. The battery may provide backup power should the external power source fail. Other types of power sources, such as photovoltaic devices, may also be used.

Alternative embodiments of network node 160 may include additional components beyond those shown in FIGURE 8 that may be responsible for providing certain aspects of the network node's functionality, including any of the functionality described herein and/or any functionality necessary to support the subject matter described herein. For example, network node 160 may include user interface equipment to allow input of information into network node 160 and to allow output of information from network node 160. This may allow a user to perform diagnostic, maintenance, repair, and other administrative functions for network node 160.

As used herein, wireless device (WD) refers to a device capable, configured, arranged and/or operable to communicate wirelessly with network nodes and/or other wireless devices. Unless otherwise noted, the term WD may be used interchangeably herein with user equipment (UE). Communicating wirelessly may involve transmitting and/or receiving wireless signals using electromagnetic waves, radio waves, infrared waves, and/or other types of signals suitable for conveying information through air.

In some embodiments, a WD may be configured to transmit and/or receive information without direct human interaction. For instance, a WD may be designed to transmit information to a network on a predetermined schedule, when triggered by an internal or external event, or in response to requests from the network.

Examples of a WD include, but are not limited to, a smart phone, a mobile phone, a cell phone, a voice over IP (VoIP) phone, a wireless local loop phone, a desktop computer, a personal digital assistant (PDA), a wireless cameras, a gaming console or device, a music storage device, a playback appliance, a wearable terminal device, a wireless endpoint, a mobile station, a tablet, a laptop, a laptop-embedded equipment (LEE), a laptop-mounted equipment (LME), a smart device, a wireless customer-premise equipment (CPE), a vehicle-mounted wireless terminal device, etc. A WD may support device-to-device (D2D) communication, for example by implementing a 3GPP standard for sidelink communication, vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-everything (V2X) and may in this case be referred to as a D2D communication device.

As yet another specific example, in an Internet of Things (IoT) scenario, a WD may represent a machine or other device that performs monitoring and/or measurements and

transmits the results of such monitoring and/or measurements to another WD and/or a network node. The WD may in this case be a machine-to-machine (M2M) device, which may in a 3GPP context be referred to as an MTC device. As one example, the WD may be a UE implementing the 3GPP narrow band internet of things (NB-IoT) standard. Examples of such machines or devices are sensors, metering devices such as power meters, industrial machinery, or home or personal appliances (e.g. refrigerators, televisions, etc.) personal wearables (e.g., watches, fitness trackers, etc.).

In other scenarios, a WD may represent a vehicle or other equipment that is capable of monitoring and/or reporting on its operational status or other functions associated with its operation. A WD as described above may represent the endpoint of a wireless connection, in which case the device may be referred to as a wireless terminal. Furthermore, a WD as described above may be mobile, in which case it may also be referred to as a mobile device or a mobile terminal.

As illustrated, wireless device 110 includes antenna 111, interface 114, processing circuitry 120, device readable medium 130, user interface equipment 132, auxiliary equipment 134, power source 136 and power circuitry 137. WD 110 may include multiple sets of one or more of the illustrated components for different wireless technologies supported by WD 110, such as, for example, GSM, WCDMA, LTE, NR, WiFi, WiMAX, or Bluetooth wireless technologies, just to mention a few. These wireless technologies may be integrated into the same or different chips or set of chips as other components within WD 110.

Antenna 111 may include one or more antennas or antenna arrays, configured to send and/or receive wireless signals, and is connected to interface 114. In certain alternative embodiments, antenna 111 may be separate from WD 110 and be connectable to WD 110 through an interface or port. Antenna 111, interface 114, and/or processing circuitry 120 may be configured to perform any receiving or transmitting operations described herein as being performed by a WD. Any information, data and/or signals may be received from a network node and/or another WD. In some embodiments, radio front end circuitry and/or antenna 111 may be considered an interface.

As illustrated, interface 114 comprises radio front end circuitry 112 and antenna 111. Radio front end circuitry 112 comprise one or more filters 118 and amplifiers 116. Radio front

end circuitry 114 is connected to antenna 111 and processing circuitry 120 and is configured to condition signals communicated between antenna 111 and processing circuitry 120. Radio front end circuitry 112 may be coupled to or a part of antenna 111. In some embodiments, WD 110 may not include separate radio front end circuitry 112; rather, processing circuitry 120 may
5 comprise radio front end circuitry and may be connected to antenna 111. Similarly, in some embodiments, some or all of RF transceiver circuitry 122 may be considered a part of interface 114.

Radio front end circuitry 112 may receive digital data that is to be sent out to other network nodes or WDs via a wireless connection. Radio front end circuitry 112 may convert
10 the digital data into a radio signal having the appropriate channel and bandwidth parameters using a combination of filters 118 and/or amplifiers 116. The radio signal may then be transmitted via antenna 111. Similarly, when receiving data, antenna 111 may collect radio signals which are then converted into digital data by radio front end circuitry 112. The digital data may be passed to processing circuitry 120. In other embodiments, the interface may
15 comprise different components and/or different combinations of components.

Processing circuitry 120 may comprise a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application-specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, software, and/or encoded logic
20 operable to provide, either alone or in conjunction with other WD 110 components, such as device readable medium 130, WD 110 functionality. Such functionality may include providing any of the various wireless features or benefits discussed herein. For example, processing circuitry 120 may execute instructions stored in device readable medium 130 or in memory within processing circuitry 120 to provide the functionality disclosed herein.

As illustrated, processing circuitry 120 includes one or more of RF transceiver circuitry 122, baseband processing circuitry 124, and application processing circuitry 126. In other embodiments, the processing circuitry may comprise different components and/or different combinations of components. In certain embodiments processing circuitry 120 of WD 110 may comprise a SOC. In some embodiments, RF transceiver circuitry 122, baseband
25

processing circuitry 124, and application processing circuitry 126 may be on separate chips or sets of chips.

5 In alternative embodiments, part or all of baseband processing circuitry 124 and application processing circuitry 126 may be combined into one chip or set of chips, and RF transceiver circuitry 122 may be on a separate chip or set of chips. In still alternative embodiments, part or all of RF transceiver circuitry 122 and baseband processing circuitry 124 may be on the same chip or set of chips, and application processing circuitry 126 may be on a separate chip or set of chips. In yet other alternative embodiments, part or all of RF transceiver circuitry 122, baseband processing circuitry 124, and application processing circuitry 126 may
10 be combined in the same chip or set of chips. In some embodiments, RF transceiver circuitry 122 may be a part of interface 114. RF transceiver circuitry 122 may condition RF signals for processing circuitry 120.

In certain embodiments, some or all of the functionality described herein as being performed by a WD may be provided by processing circuitry 120 executing instructions stored
15 on device readable medium 130, which in certain embodiments may be a computer-readable storage medium. In alternative embodiments, some or all of the functionality may be provided by processing circuitry 120 without executing instructions stored on a separate or discrete device readable storage medium, such as in a hard-wired manner.

In any of those embodiments, whether executing instructions stored on a device
20 readable storage medium or not, processing circuitry 120 can be configured to perform the described functionality. The benefits provided by such functionality are not limited to processing circuitry 120 alone or to other components of WD 110, but are enjoyed by WD 110, and/or by end users and the wireless network generally.

Processing circuitry 120 may be configured to perform any determining, calculating, or
25 similar operations (e.g., certain obtaining operations) described herein as being performed by a WD. These operations, as performed by processing circuitry 120, may include processing information obtained by processing circuitry 120 by, for example, converting the obtained information into other information, comparing the obtained information or converted information to information stored by WD 110, and/or performing one or more operations based

on the obtained information or converted information, and as a result of said processing making a determination.

Device readable medium 130 may be operable to store a computer program, software, an application including one or more of logic, rules, code, tables, etc. and/or other instructions
5 capable of being executed by processing circuitry 120. Device readable medium 130 may include computer memory (e.g., Random Access Memory (RAM) or Read Only Memory (ROM)), mass storage media (e.g., a hard disk), removable storage media (e.g., a Compact Disk (CD) or a Digital Video Disk (DVD)), and/or any other volatile or non-volatile, non-transitory device readable and/or computer executable memory devices that store information,
10 data, and/or instructions that may be used by processing circuitry 120. In some embodiments, processing circuitry 120 and device readable medium 130 may be integrated.

User interface equipment 132 may provide components that allow for a human user to interact with WD 110. Such interaction may be of many forms, such as visual, audial, tactile, etc. User interface equipment 132 may be operable to produce output to the user and to allow
15 the user to provide input to WD 110. The type of interaction may vary depending on the type of user interface equipment 132 installed in WD 110. For example, if WD 110 is a smart phone, the interaction may be via a touch screen; if WD 110 is a smart meter, the interaction may be through a screen that provides usage (e.g., the number of gallons used) or a speaker that provides an audible alert (e.g., if smoke is detected).

20 User interface equipment 132 may include input interfaces, devices and circuits, and output interfaces, devices and circuits. User interface equipment 132 is configured to allow input of information into WD 110 and is connected to processing circuitry 120 to allow processing circuitry 120 to process the input information. User interface equipment 132 may include, for example, a microphone, a proximity or other sensor, keys/buttons, a touch display,
25 one or more cameras, a USB port, or other input circuitry. User interface equipment 132 is also configured to allow output of information from WD 110, and to allow processing circuitry 120 to output information from WD 110. User interface equipment 132 may include, for example, a speaker, a display, vibrating circuitry, a USB port, a headphone interface, or other output circuitry. Using one or more input and output interfaces, devices, and circuits, of user

interface equipment 132, WD 110 may communicate with end users and/or the wireless network and allow them to benefit from the functionality described herein.

Auxiliary equipment 134 is operable to provide more specific functionality which may not be generally performed by WDs. This may comprise specialized sensors for doing measurements for various purposes, interfaces for additional types of communication such as wired communications etc. The inclusion and type of components of auxiliary equipment 134 may vary depending on the embodiment and/or scenario.

Power source 136 may, in some embodiments, be in the form of a battery or battery pack. Other types of power sources, such as an external power source (e.g., an electricity outlet), photovoltaic devices or power cells, may also be used. WD 110 may further comprise power circuitry 137 for delivering power from power source 136 to the various parts of WD 110 which need power from power source 136 to carry out any functionality described or indicated herein. Power circuitry 137 may in certain embodiments comprise power management circuitry.

Power circuitry 137 may additionally or alternatively be operable to receive power from an external power source; in which case WD 110 may be connectable to the external power source (such as an electricity outlet) via input circuitry or an interface such as an electrical power cable. Power circuitry 137 may also in certain embodiments be operable to deliver power from an external power source to power source 136. This may be, for example, for the charging of power source 136. Power circuitry 137 may perform any formatting, converting, or other modification to the power from power source 136 to make the power suitable for the respective components of WD 110 to which power is supplied.

Although the subject matter described herein may be implemented in any appropriate type of system using any suitable components, the embodiments disclosed herein are described in relation to a wireless network, such as the example wireless network illustrated in FIGURE 8. For simplicity, the wireless network of FIGURE 8 only depicts network 106, network nodes 160 and 160b, and WDs 110, 110b, and 110c. In practice, a wireless network may further include any additional elements suitable to support communication between wireless devices or between a wireless device and another communication device, such as a landline telephone, a service provider, or any other network node or end device. Of the illustrated components,

network node 160 and wireless device (WD) 110 are depicted with additional detail. The wireless network may provide communication and other types of services to one or more wireless devices to facilitate the wireless devices' access to and/or use of the services provided by, or via, the wireless network.

FIGURE 9 illustrates an example user equipment, according to certain embodiments. As used herein, a user equipment or UE may not necessarily have a user in the sense of a human user who owns and/or operates the relevant device. Instead, a UE may represent a device that is intended for sale to, or operation by, a human user but which may not, or which may not initially, be associated with a specific human user (e.g., a smart sprinkler controller). Alternatively, a UE may represent a device that is not intended for sale to, or operation by, an end user but which may be associated with or operated for the benefit of a user (e.g., a smart power meter). UE 200 may be any UE identified by the 3rd Generation Partnership Project (3GPP), including a NB-IoT UE, a machine type communication (MTC) UE, and/or an enhanced MTC (eMTC) UE. UE 200, as illustrated in FIGURE 9, is one example of a WD configured for communication in accordance with one or more communication standards promulgated by the 3rd Generation Partnership Project (3GPP), such as 3GPP's GSM, UMTS, LTE, and/or NR standards. As mentioned previously, the term WD and UE may be used interchangeable. Accordingly, although FIGURE 9 is a UE, the components discussed herein are equally applicable to a WD, and vice-versa.

In FIGURE 9, UE 200 includes processing circuitry 201 that is operatively coupled to input/output interface 205, radio frequency (RF) interface 209, network connection interface 211, memory 215 including random access memory (RAM) 217, read-only memory (ROM) 219, and storage medium 221 or the like, communication subsystem 231, power source 233, and/or any other component, or any combination thereof. Storage medium 221 includes operating system 223, application program 225, and data 227. In other embodiments, storage medium 221 may include other similar types of information. Certain UEs may use all the components shown in FIGURE 9, or only a subset of the components. The level of integration between the components may vary from one UE to another UE. Further, certain UEs may contain multiple instances of a component, such as multiple processors, memories, transceivers, transmitters, receivers, etc.

In FIGURE 9, processing circuitry 201 may be configured to process computer instructions and data. Processing circuitry 201 may be configured to implement any sequential state machine operative to execute machine instructions stored as machine-readable computer programs in the memory, such as one or more hardware-implemented state machines (e.g., in discrete logic, FPGA, ASIC, etc.); programmable logic together with appropriate firmware; one or more stored program, general-purpose processors, such as a microprocessor or Digital Signal Processor (DSP), together with appropriate software; or any combination of the above. For example, the processing circuitry 201 may include two central processing units (CPUs). Data may be information in a form suitable for use by a computer.

In the depicted embodiment, input/output interface 205 may be configured to provide a communication interface to an input device, output device, or input and output device. UE 200 may be configured to use an output device via input/output interface 205.

An output device may use the same type of interface port as an input device. For example, a USB port may be used to provide input to and output from UE 200. The output device may be a speaker, a sound card, a video card, a display, a monitor, a printer, an actuator, an emitter, a smartcard, another output device, or any combination thereof.

UE 200 may be configured to use an input device via input/output interface 205 to allow a user to capture information into UE 200. The input device may include a touch-sensitive or presence-sensitive display, a camera (e.g., a digital camera, a digital video camera, a web camera, etc.), a microphone, a sensor, a mouse, a trackball, a directional pad, a trackpad, a scroll wheel, a smartcard, and the like. The presence-sensitive display may include a capacitive or resistive touch sensor to sense input from a user. A sensor may be, for instance, an accelerometer, a gyroscope, a tilt sensor, a force sensor, a magnetometer, an optical sensor, a proximity sensor, another like sensor, or any combination thereof. For example, the input device may be an accelerometer, a magnetometer, a digital camera, a microphone, and an optical sensor.

In FIGURE 9, RF interface 209 may be configured to provide a communication interface to RF components such as a transmitter, a receiver, and an antenna. Network connection interface 211 may be configured to provide a communication interface to network 243a. Network 243a may encompass wired and/or wireless networks such as a local-area

network (LAN), a wide-area network (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network 243a may comprise a Wi-Fi network. Network connection interface 211 may be configured to include a receiver and a transmitter interface used to communicate with one or more other devices over a communication network according to one or more communication protocols, such as Ethernet, TCP/IP, SONET, ATM, or the like. Network connection interface 211 may implement receiver and transmitter functionality appropriate to the communication network links (e.g., optical, electrical, and the like). The transmitter and receiver functions may share circuit components, software or firmware, or alternatively may be implemented separately.

RAM 217 may be configured to interface via bus 202 to processing circuitry 201 to provide storage or caching of data or computer instructions during the execution of software programs such as the operating system, application programs, and device drivers. ROM 219 may be configured to provide computer instructions or data to processing circuitry 201. For example, ROM 219 may be configured to store invariant low-level system code or data for basic system functions such as basic input and output (I/O), startup, or reception of keystrokes from a keyboard that are stored in a non-volatile memory.

Storage medium 221 may be configured to include memory such as RAM, ROM, programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), magnetic disks, optical disks, floppy disks, hard disks, removable cartridges, or flash drives. In one example, storage medium 221 may be configured to include operating system 223, application program 225 such as a web browser application, a widget or gadget engine or another application, and data file 227. Storage medium 221 may store, for use by UE 200, any of a variety of various operating systems or combinations of operating systems.

Storage medium 221 may be configured to include a number of physical drive units, such as redundant array of independent disks (RAID), floppy disk drive, flash memory, USB flash drive, external hard disk drive, thumb drive, pen drive, key drive, high-density digital versatile disc (HD-DVD) optical disc drive, internal hard disk drive, Blu-Ray optical disc drive, holographic digital data storage (HDDS) optical disc drive, external mini-dual in-line memory

module (DIMM), synchronous dynamic random access memory (SDRAM), external micro-DIMM SDRAM, smartcard memory such as a subscriber identity module or a removable user identity (SIM/RUIM) module, other memory, or any combination thereof. Storage medium 221 may allow UE 200 to access computer-executable instructions, application programs or the like, stored on transitory or non-transitory memory media, to off-load data, or to upload data. An article of manufacture, such as one utilizing a communication system may be tangibly embodied in storage medium 221, which may comprise a device readable medium.

In FIGURE 9, processing circuitry 201 may be configured to communicate with network 243b using communication subsystem 231. Network 243a and network 243b may be the same network or networks or different network or networks. Communication subsystem 231 may be configured to include one or more transceivers used to communicate with network 243b. For example, communication subsystem 231 may be configured to include one or more transceivers used to communicate with one or more remote transceivers of another device capable of wireless communication such as another WD, UE, or base station of a radio access network (RAN) according to one or more communication protocols, such as IEEE 802.2, CDMA, WCDMA, GSM, LTE, UTRAN, WiMax, or the like. Each transceiver may include transmitter 233 and/or receiver 235 to implement transmitter or receiver functionality, respectively, appropriate to the RAN links (e.g., frequency allocations and the like). Further, transmitter 233 and receiver 235 of each transceiver may share circuit components, software or firmware, or alternatively may be implemented separately.

In the illustrated embodiment, the communication functions of communication subsystem 231 may include data communication, voice communication, multimedia communication, short-range communications such as Bluetooth, near-field communication, location-based communication such as the use of the global positioning system (GPS) to determine a location, another like communication function, or any combination thereof. For example, communication subsystem 231 may include cellular communication, Wi-Fi communication, Bluetooth communication, and GPS communication. Network 243b may encompass wired and/or wireless networks such as a local-area network (LAN), a wide-area network (WAN), a computer network, a wireless network, a telecommunications network, another like network or any combination thereof. For example, network 243b may be a cellular

network, a Wi-Fi network, and/or a near-field network. Power source 213 may be configured to provide alternating current (AC) or direct current (DC) power to components of UE 200.

The features, benefits and/or functions described herein may be implemented in one of the components of UE 200 or partitioned across multiple components of UE 200. Further, the features, benefits, and/or functions described herein may be implemented in any combination of hardware, software or firmware. In one example, communication subsystem 231 may be configured to include any of the components described herein. Further, processing circuitry 201 may be configured to communicate with any of such components over bus 202. In another example, any of such components may be represented by program instructions stored in memory that when executed by processing circuitry 201 perform the corresponding functions described herein. In another example, the functionality of any of such components may be partitioned between processing circuitry 201 and communication subsystem 231. In another example, the non-computationally intensive functions of any of such components may be implemented in software or firmware and the computationally intensive functions may be implemented in hardware.

FIGURE 10 is a flowchart illustrating an example method in a wireless device, according to certain embodiments. In particular embodiments, one or more steps of FIGURE 10 may be performed by wireless device 110 described with respect to FIGURE 8.

The method begins at step 1012, where the wireless device (e.g., wireless device 110) obtains a spatial domain filter to be used for uplink transmission. For example, wireless device 110 may receive an RRC configuration from network node 160.

In some embodiments, obtaining the spatial domain filter to be used for uplink transmission comprises receiving a spatial relation from network node 160. The spatial relation may be based on results of measurements that the base station performs on a plurality of reference signals transmitted by wireless device 110. For example, obtaining the spatial domain filter to be used for uplink transmission may comprise receiving from network node 160 an SRS index of a preferred SRS of a plurality of SRS transmitted from wireless device 110 to network node 160.

At step 1014, the wireless device may receive an indication from a base station that the wireless device may update its spatial domain filter to be used for uplink transmission. For

example, wireless device 110 may receive the indication from network node 160 as part of the signaling in step 1012, or wireless device 110 may receive the indication in separate signaling.

At step 1016, the wireless device determines that a spatial orientation of the wireless device has changed after obtaining the spatial domain filter to be used for uplink transmission.

5 For example, the wireless device may comprise acceleration sensors, and determining that the spatial orientation of the wireless device has changed is based on the acceleration sensors. As another example, determining that the spatial orientation of the wireless device has changed may comprise determining that a relationship between the obtained spatial domain filter and a downlink reference signal has changed.

10 In some embodiments, even though a spatial orientation of the wireless device may not have changed, the wireless device may determine that something in its vicinity has changed (e.g., a car or other object is temporarily impairing transmission using the obtained spatial domain filter) and that obtaining spatial domain filter may no longer be optimal.

At step 1018, the wireless device updates the spatial domain filter to be used for uplink
15 transmission based on the changed spatial orientation of the wireless device. For example, wireless device 110 may determine an updated spatial domain filter to compensate for its change in orientation. The wireless device may select a beam based on new local coordinates that best corresponds to the global coordinates of the original spatial domain filter in the original orientation of the wireless device.

20 In particular embodiments, updating the spatial domain filter to be used for uplink transmission comprises determining a coordinate difference between an orientation of the wireless device associated with the obtained spatial domain filter and the changed spatial orientation of the wireless device, and selecting a new spatial domain filter based on the coordinate difference. Updating the spatial domain filter to be used for uplink transmission
25 may comprise determining a difference between a relationship between the obtained spatial domain filter and a downlink reference signal associated with the obtained spatial domain filter and a relationship between the changed spatial orientation of the wireless device and the downlink reference signal, and selecting a new spatial domain filter based on the difference.

In particular embodiments, updating the spatial domain filter to be used for uplink
30 transmission comprises selecting a spatial domain filter such that an uplink beam transmitted

by the wireless device using the selected spatial domain filter is transmitted in a similar direction as an uplink beam transmitted by the wireless device prior to the determined orientation change using the obtained spatial domain filter.

At step 1020, the wireless device transmits an uplink beam using the updated spatial domain filter.

Modifications, additions, or omissions may be made to method 1000 of FIGURE 10. Additionally, one or more steps in the method of FIGURE 10 may be performed in parallel or in any suitable order.

FIGURE 11 is a flowchart illustrating an example method in a network node, according to certain embodiments. In particular embodiments, one or more steps of FIGURE 11 may be performed by network node 160 described with respect to FIGURE 8.

The method may begin at step 1112, where the network node (e.g., network node 160) transmits a spatial domain filter to be used for uplink transmission to a wireless device (e.g., wireless device 110).

At step 1114, the network node transmits an indication that the wireless device may update its spatial domain filter to be used for uplink transmission. For example, network node 160 may inform wireless device 110 that, if wireless device 110 is able to autonomously determine a better spatial domain filter to be used for a future uplink transmission (such as described with respect to FIGURE 10), then wireless device 110 is permitted to do so.

At step 1116, the network node receives an uplink transmission from the wireless device. The uplink transmission was transmitted using an updated spatial domain filter (such as described with respect to FIGURE 10).

Modifications, additions, or omissions may be made to method 1100 of FIGURE 11. Additionally, one or more steps in the method of FIGURE 11 may be performed in parallel or in any suitable order.

FIGURE 12 illustrates a schematic block diagram of two apparatuses in a wireless network (for example, the wireless network illustrated in FIGURE 8). The apparatuses include a wireless device and a network node (e.g., wireless device 110 and network node 160 illustrated in FIGURE 8). Apparatuses 1600 and 1700 are operable to carry out the example methods described with reference to FIGURES 10 and 11, respectively, and possibly any other

processes or methods disclosed herein. It is also to be understood that the methods of FIGURES 10 and 11 are not necessarily carried out solely by apparatus 1600 and/or apparatus 1700. At least some operations of the method can be performed by one or more other entities.

Virtual apparatuses 1600 and 1700 may comprise processing circuitry, which may include one or more microprocessor or microcontrollers, as well as other digital hardware, which may include digital signal processors (DSPs), special-purpose digital logic, and the like. The processing circuitry may be configured to execute program code stored in memory, which may include one or several types of memory such as read-only memory (ROM), random-access memory, cache memory, flash memory devices, optical storage devices, etc. Program code stored in memory includes program instructions for executing one or more telecommunications and/or data communications protocols as well as instructions for carrying out one or more of the techniques described herein, in several embodiments.

In some implementations, the processing circuitry may be used to cause receiving module 1602, determining module 1604, transmitting module 1606, and any other suitable units of apparatus 1600 to perform corresponding functions according one or more embodiments of the present disclosure. Similarly, the processing circuitry described above may be used to cause receiving module 1702, determining module 1704, transmitting module 1706, and any other suitable units of apparatus 1700 to perform corresponding functions according one or more embodiments of the present disclosure.

As illustrated in FIGURE 12, apparatus 1600 includes receiving module 1602 configured to receive an uplink spatial domain filter and an indication the wireless device may update its spatial domain filter, according to any of the embodiments and examples described herein. Apparatus 1600 also includes determining module 1604 configured to determine a spatial orientation of the wireless device has changed, according to any of the embodiments and examples described herein. Transmitting module 1606 is configured to transmit a uplink BEAM, according to any of the embodiments and examples described herein.

As illustrated in FIGURE 12, apparatus 1700 includes receiving module 1702 configured to receive uplink beams, according to any of the embodiments and examples described herein. Apparatus 1700 also includes determining module 1704 configured to determine whether wireless device is permitted to update its spatial domain filter, according to

any of the embodiments and examples described herein. Transmitting module 1706 is configured to transmit an uplink spatial domain filter and an indication the wireless device may update its spatial domain filter, according to any of the embodiments and examples described herein.

5 FIGURE 13 is a schematic block diagram illustrating a virtualization environment 300 in which functions implemented by some embodiments may be virtualized. In the present context, virtualizing means creating virtual versions of apparatuses or devices which may include virtualizing hardware platforms, storage devices and networking resources. As used herein, virtualization can be applied to a node (e.g., a virtualized base station or a virtualized
10 radio access node) or to a device (e.g., a UE, a wireless device or any other type of communication device) or components thereof and relates to an implementation in which at least a portion of the functionality is implemented as one or more virtual components (e.g., via one or more applications, components, functions, virtual machines or containers executing on one or more physical processing nodes in one or more networks).

15 In some embodiments, some or all of the functions described herein may be implemented as virtual components executed by one or more virtual machines implemented in one or more virtual environments 300 hosted by one or more of hardware nodes 330. Further, in embodiments in which the virtual node is not a radio access node or does not require radio connectivity (e.g., a core network node), then the network node may be entirely virtualized.

20 The functions may be implemented by one or more applications 320 (which may alternatively be called software instances, virtual appliances, network functions, virtual nodes, virtual network functions, etc.) operative to implement some of the features, functions, and/or benefits of some of the embodiments disclosed herein. Applications 320 are run in virtualization environment 300 which provides hardware 330 comprising processing circuitry
25 360 and memory 390. Memory 390 contains instructions 395 executable by processing circuitry 360 whereby application 320 is operative to provide one or more of the features, benefits, and/or functions disclosed herein.

Virtualization environment 300, comprises general-purpose or special-purpose network hardware devices 330 comprising a set of one or more processors or processing circuitry 360,
30 which may be commercial off-the-shelf (COTS) processors, dedicated Application Specific

Integrated Circuits (ASICs), or any other type of processing circuitry including digital or analog hardware components or special purpose processors. Each hardware device may comprise memory 390-1 which may be non-persistent memory for temporarily storing instructions 395 or software executed by processing circuitry 360. Each hardware device may
5 comprise one or more network interface controllers (NICs) 370, also known as network interface cards, which include physical network interface 380. Each hardware device may also include non-transitory, persistent, machine-readable storage media 390-2 having stored therein software 395 and/or instructions executable by processing circuitry 360. Software 395 may include any type of software including software for instantiating one or more virtualization
10 layers 350 (also referred to as hypervisors), software to execute virtual machines 340 as well as software allowing it to execute functions, features and/or benefits described in relation with some embodiments described herein.

Virtual machines 340, comprise virtual processing, virtual memory, virtual networking or interface and virtual storage, and may be run by a corresponding virtualization layer 350 or
15 hypervisor. Different embodiments of the instance of virtual appliance 320 may be implemented on one or more of virtual machines 340, and the implementations may be made in different ways.

During operation, processing circuitry 360 executes software 395 to instantiate the hypervisor or virtualization layer 350, which may sometimes be referred to as a virtual machine
20 monitor (VMM). Virtualization layer 350 may present a virtual operating platform that appears like networking hardware to virtual machine 340.

As shown in FIGURE 13, hardware 330 may be a standalone network node with generic or specific components. Hardware 330 may comprise antenna 3225 and may implement some functions via virtualization. Alternatively, hardware 330 may be part of a larger cluster of
25 hardware (e.g. such as in a data center or customer premise equipment (CPE)) where many hardware nodes work together and are managed via management and orchestration (MANO) 3100, which, among others, oversees lifecycle management of applications 320.

Virtualization of the hardware is in some contexts referred to as network function virtualization (NFV). NFV may be used to consolidate many network equipment types onto

industry standard high-volume server hardware, physical switches, and physical storage, which can be located in data centers, and customer premise equipment.

In the context of NFV, virtual machine 340 may be a software implementation of a physical machine that runs programs as if they were executing on a physical, non-virtualized machine. Each of virtual machines 340, and that part of hardware 330 that executes that virtual machine, be it hardware dedicated to that virtual machine and/or hardware shared by that virtual machine with others of the virtual machines 340, forms a separate virtual network elements (VNE).

Still in the context of NFV, Virtual Network Function (VNF) is responsible for handling specific network functions that run in one or more virtual machines 340 on top of hardware networking infrastructure 330 and corresponds to application 320 in FIGURE 14.

In some embodiments, one or more radio units 3200 that each include one or more transmitters 3220 and one or more receivers 3210 may be coupled to one or more antennas 3225. Radio units 3200 may communicate directly with hardware nodes 330 via one or more appropriate network interfaces and may be used in combination with the virtual components to provide a virtual node with radio capabilities, such as a radio access node or a base station.

In some embodiments, some signaling can be effected with the use of control system 3230 which may alternatively be used for communication between the hardware nodes 330 and radio units 3200.

With reference to FIGURE 14, in accordance with an embodiment, a communication system includes telecommunication network 410, such as a 3GPP-type cellular network, which comprises access network 411, such as a radio access network, and core network 414. Access network 411 comprises a plurality of base stations 412a, 412b, 412c, such as NBs, eNBs, gNBs or other types of wireless access points, each defining a corresponding coverage area 413a, 413b, 413c. Each base station 412a, 412b, 412c is connectable to core network 414 over a wired or wireless connection 415. A first UE 491 located in coverage area 413c is configured to wirelessly connect to, or be paged by, the corresponding base station 412c. A second UE 492 in coverage area 413a is wirelessly connectable to the corresponding base station 412a. While a plurality of UEs 491, 492 are illustrated in this example, the disclosed embodiments

are equally applicable to a situation where a sole UE is in the coverage area or where a sole UE is connecting to the corresponding base station 412.

Telecommunication network 410 is itself connected to host computer 430, which may be embodied in the hardware and/or software of a standalone server, a cloud-implemented server, a distributed server or as processing resources in a server farm. Host computer 430 may be under the ownership or control of a service provider or may be operated by the service provider or on behalf of the service provider. Connections 421 and 422 between telecommunication network 410 and host computer 430 may extend directly from core network 414 to host computer 430 or may go via an optional intermediate network 420. Intermediate network 420 may be one of, or a combination of more than one of, a public, private or hosted network; intermediate network 420, if any, may be a backbone network or the Internet; in particular, intermediate network 420 may comprise two or more sub-networks (not shown).

The communication system of FIGURE 14 as a whole enables connectivity between the connected UEs 491, 492 and host computer 430. The connectivity may be described as an over-the-top (OTT) connection 450. Host computer 430 and the connected UEs 491, 492 are configured to communicate data and/or signaling via OTT connection 450, using access network 411, core network 414, any intermediate network 420 and possible further infrastructure (not shown) as intermediaries. OTT connection 450 may be transparent in the sense that the participating communication devices through which OTT connection 450 passes are unaware of routing of uplink and downlink communications. For example, base station 412 may not or need not be informed about the past routing of an incoming downlink communication with data originating from host computer 430 to be forwarded (e.g., handed over) to a connected UE 491. Similarly, base station 412 need not be aware of the future routing of an outgoing uplink communication originating from the UE 491 towards the host computer 430.

FIGURE 15 illustrates an example host computer communicating via a base station with a user equipment over a partially wireless connection, according to certain embodiments. Example implementations, in accordance with an embodiment of the UE, base station and host computer discussed in the preceding paragraphs will now be described with reference to FIGURE 15. In communication system 500, host computer 510 comprises hardware 515

including communication interface 516 configured to set up and maintain a wired or wireless connection with an interface of a different communication device of communication system 500. Host computer 510 further comprises processing circuitry 518, which may have storage and/or processing capabilities. In particular, processing circuitry 518 may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Host computer 510 further comprises software 511, which is stored in or accessible by host computer 510 and executable by processing circuitry 518. Software 511 includes host application 512. Host application 512 may be operable to provide a service to a remote user, such as UE 530 connecting via OTT connection 550 terminating at UE 530 and host computer 510. In providing the service to the remote user, host application 512 may provide user data which is transmitted using OTT connection 550.

Communication system 500 further includes base station 520 provided in a telecommunication system and comprising hardware 525 enabling it to communicate with host computer 510 and with UE 530. Hardware 525 may include communication interface 526 for setting up and maintaining a wired or wireless connection with an interface of a different communication device of communication system 500, as well as radio interface 527 for setting up and maintaining at least wireless connection 570 with UE 530 located in a coverage area (not shown in FIGURE 15) served by base station 520. Communication interface 526 may be configured to facilitate connection 560 to host computer 510. Connection 560 may be direct, or it may pass through a core network (not shown in FIGURE 15) of the telecommunication system and/or through one or more intermediate networks outside the telecommunication system. In the embodiment shown, hardware 525 of base station 520 further includes processing circuitry 528, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. Base station 520 further has software 521 stored internally or accessible via an external connection.

Communication system 500 further includes UE 530 already referred to. Its hardware 535 may include radio interface 537 configured to set up and maintain wireless connection 570 with a base station serving a coverage area in which UE 530 is currently located. Hardware

535 of UE 530 further includes processing circuitry 538, which may comprise one or more programmable processors, application-specific integrated circuits, field programmable gate arrays or combinations of these (not shown) adapted to execute instructions. UE 530 further comprises software 531, which is stored in or accessible by UE 530 and executable by processing circuitry 538. Software 531 includes client application 532. Client application 532 may be operable to provide a service to a human or non-human user via UE 530, with the support of host computer 510. In host computer 510, an executing host application 512 may communicate with the executing client application 532 via OTT connection 550 terminating at UE 530 and host computer 510. In providing the service to the user, client application 532 may receive request data from host application 512 and provide user data in response to the request data. OTT connection 550 may transfer both the request data and the user data. Client application 532 may interact with the user to generate the user data that it provides.

It is noted that host computer 510, base station 520 and UE 530 illustrated in FIGURE 15 may be similar or identical to host computer 430, one of base stations 412a, 412b, 412c and one of UEs 491, 492 of FIGURE 14, respectively. This is to say, the inner workings of these entities may be as shown in FIGURE 15 and independently, the surrounding network topology may be that of FIGURE 14.

In FIGURE 15, OTT connection 550 has been drawn abstractly to illustrate the communication between host computer 510 and UE 530 via base station 520, without explicit reference to any intermediary devices and the precise routing of messages via these devices. Network infrastructure may determine the routing, which it may be configured to hide from UE 530 or from the service provider operating host computer 510, or both. While OTT connection 550 is active, the network infrastructure may further take decisions by which it dynamically changes the routing (e.g., based on load balancing consideration or reconfiguration of the network).

Wireless connection 570 between UE 530 and base station 520 is in accordance with the teachings of the embodiments described throughout this disclosure. One or more of the various embodiments improve the performance of OTT services provided to UE 530 using OTT connection 550, in which wireless connection 570 forms the last segment. More precisely, the teachings of these embodiments may improve the signaling overhead and reduce

latency, and thereby provide benefits such as reduced user waiting time, better responsiveness and extended battery life.

A measurement procedure may be provided for monitoring data rate, latency and other factors on which the one or more embodiments improve. There may further be an optional
5 network functionality for reconfiguring OTT connection 550 between host computer 510 and UE 530, in response to variations in the measurement results. The measurement procedure and/or the network functionality for reconfiguring OTT connection 550 may be implemented in software 511 and hardware 515 of host computer 510 or in software 531 and hardware 535
10 of UE 530, or both. In embodiments, sensors (not shown) may be deployed in or in association with communication devices through which OTT connection 550 passes; the sensors may participate in the measurement procedure by supplying values of the monitored quantities exemplified above or supplying values of other physical quantities from which software 511,
15 531 may compute or estimate the monitored quantities. The reconfiguring of OTT connection 550 may include message format, retransmission settings, preferred routing etc.; the reconfiguring need not affect base station 520, and it may be unknown or imperceptible to base station 520. Such procedures and functionalities may be known and practiced in the art. In certain embodiments, measurements may involve proprietary UE signaling facilitating host computer 510's measurements of throughput, propagation times, latency and the like. The measurements may be implemented in that software 511 and 531 causes messages to be
20 transmitted, in particular empty or 'dummy' messages, using OTT connection 550 while it monitors propagation times, errors etc.

FIGURE 16 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES
25 14 and 15. For simplicity of the present disclosure, only drawing references to FIGURE 16 will be included in this section.

In step 610, the host computer provides user data. In substep 611 (which may be optional) of step 610, the host computer provides the user data by executing a host application. In step 620, the host computer initiates a transmission carrying the user data to the UE. In step
30 630 (which may be optional), the base station transmits to the UE the user data which was

carried in the transmission that the host computer initiated, in accordance with the teachings of the embodiments described throughout this disclosure. In step 640 (which may also be optional), the UE executes a client application associated with the host application executed by the host computer.

5 FIGURE 17 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES 14 and 15. For simplicity of the present disclosure, only drawing references to FIGURE 17 will be included in this section.

10 In step 710 of the method, the host computer provides user data. In an optional substep (not shown) the host computer provides the user data by executing a host application. In step 720, the host computer initiates a transmission carrying the user data to the UE. The transmission may pass via the base station, in accordance with the teachings of the embodiments described throughout this disclosure. In step 730 (which may be optional), the
15 UE receives the user data carried in the transmission.

 FIGURE 18 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES 14 and 15. For simplicity of the present disclosure, only drawing references to FIGURE 18
20 will be included in this section.

 In step 810 (which may be optional), the UE receives input data provided by the host computer. Additionally, or alternatively, in step 820, the UE provides user data. In substep 821 (which may be optional) of step 820, the UE provides the user data by executing a client application. In substep 811 (which may be optional) of step 810, the UE executes a client
25 application which provides the user data in reaction to the received input data provided by the host computer. In providing the user data, the executed client application may further consider user input received from the user. Regardless of the specific manner in which the user data was provided, the UE initiates, in substep 830 (which may be optional), transmission of the user data to the host computer. In step 840 of the method, the host computer receives the user

data transmitted from the UE, in accordance with the teachings of the embodiments described throughout this disclosure.

FIGURE 19 is a flowchart illustrating a method implemented in a communication system, in accordance with one embodiment. The communication system includes a host computer, a base station and a UE which may be those described with reference to FIGURES 14 and 15. For simplicity of the present disclosure, only drawing references to FIGURE 19 will be included in this section.

In step 910 (which may be optional), in accordance with the teachings of the embodiments described throughout this disclosure, the base station receives user data from the UE. In step 920 (which may be optional), the base station initiates transmission of the received user data to the host computer. In step 930 (which may be optional), the host computer receives the user data carried in the transmission initiated by the base station.

The term unit may have conventional meaning in the field of electronics, electrical devices and/or electronic devices and may include, for example, electrical and/or electronic circuitry, devices, modules, processors, memories, logic solid state and/or discrete devices, computer programs or instructions for carrying out respective tasks, procedures, computations, outputs, and/or displaying functions, and so on, as such as those that are described herein.

Modifications, additions, or omissions may be made to the systems and apparatuses disclosed herein without departing from the scope of the invention. The components of the systems and apparatuses may be integrated or separated. Moreover, the operations of the systems and apparatuses may be performed by more, fewer, or other components. Additionally, operations of the systems and apparatuses may be performed using any suitable logic comprising software, hardware, and/or other logic. As used in this document, “each” refers to each member of a set or each member of a subset of a set.

Modifications, additions, or omissions may be made to the methods disclosed herein without departing from the scope of the invention. The methods may include more, fewer, or other steps. Additionally, steps may be performed in any suitable order.

The foregoing description sets forth numerous specific details. It is understood, however, that embodiments may be practiced without these specific details. In other instances, well-known circuits, structures and techniques have not been shown in detail in order not to

obscure the understanding of this description. Those of ordinary skill in the art, with the included descriptions, will be able to implement appropriate functionality without undue experimentation.

References in the specification to “one embodiment,” “an embodiment,” “an example embodiment,” etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to implement such feature, structure, or characteristic in connection with other embodiments, whether or not explicitly described.

Although this disclosure has been described in terms of certain embodiments, alterations and permutations of the embodiments will be apparent to those skilled in the art. Accordingly, the above description of the embodiments does not constrain this disclosure. Other changes, substitutions, and alterations are possible without departing from the scope of this disclosure, as defined by the claims below.

At least some of the following abbreviations may be used in this disclosure. If there is an inconsistency between abbreviations, preference should be given to how it is used above. If listed multiple times below, the first listing should be preferred over any subsequent listing(s).

	1x RTT	CDMA2000 1x Radio Transmission Technology
	3GPP	3rd Generation Partnership Project
	5G	5th Generation
25	5GC	5th Generation Core
	BCCH	Broadcast Control Channel
	BCH	Broadcast Channel
	BWP	Bandwidth Part
	CA	Carrier Aggregation
30	CC	Carrier Component
	CDMA	Code Division Multiplexing Access

	CN	Core Network
	CORESET	Control Resource Set
	CQI	Channel Quality information
	CSI	Channel State Information
5	DCCH	Dedicated Control Channel
	DCI	Downlink Control Information
	DL	Downlink
	DM	Demodulation
	DMRS	Demodulation Reference Signal
10	eNB	E-UTRAN NodeB
	ePDCCH	enhanced Physical Downlink Control Channel
	EPS	Evolved Packet System
	E-SMLC	evolved Serving Mobile Location Center
	E-UTRA	Evolved UTRA
15	E-UTRAN	Evolved UTRAN
	FDD	Frequency Division Duplex
	GERAN	GSM EDGE Radio Access Network
	gNB	Base station in NR
	GSM	Global System for Mobile communication
20	HSPA	High Speed Packet Access
	HRPD	High Rate Packet Data
	ID	Identity/Identifier
	LTE	Long-Term Evolution
	MAC	Medium Access Control
25	MBMS	Multimedia Broadcast Multicast Services
	MBSFN	Multimedia Broadcast multicast service Single Frequency Network
	NPDCCH	Narrowband Physical Downlink Control Channel
	NAS	Non-Access Stratum
30	NGC	Next Generation Core
	NG-RAN	Next Generation RAN
	NPDCCH	Narrowband Physical Downlink Control Channel

	NR	New Radio
	OCNG	OFDMA Channel Noise Generator
	OFDM	Orthogonal Frequency Division Multiplexing
	OFDMA	Orthogonal Frequency Division Multiple Access
5	P-CCPCH	Primary Common Control Physical Channel
	PCell	Primary Cell
	PCFICH	Physical Control Format Indicator Channel
	PDCCH	Physical Downlink Control Channel
	PDSCH	Physical Downlink Shared Channel
10	PGW	Packet Gateway
	PLMN	Public Land Mobile Network
	PMI	Precoder Matrix Indicator
	PRB	Physical Resource Block
	PUCCH	Physical Uplink Control Channel
15	PUSCH	Physical Uplink Shared Channel
	RAN	Radio Access Network
	RAT	Radio Access Technology
	RLM	Radio Link Management
	RNC	Radio Network Controller
20	RRC	Radio Resource Control
	RRM	Radio Resource Management
	RS	Reference Signal
	RSCP	Received Signal Code Power
	RSRP	Reference Symbol Received Power OR
25		Reference Signal Received Power
	RSRQ	Reference Signal Received Quality OR
		Reference Symbol Received Quality
	RSSI	Received Signal Strength Indicator
	SCell	Secondary Cell
30	SGW	Serving Gateway
	SI	System Information
	SNR	Signal to Noise Ratio

	SS	Synchronization Signal
	SSS	Secondary Synchronization Signal
	TDD	Time Division Duplex
	TTI	Transmission Time Interval
5	UE	User Equipment
	UL	Uplink
	UMTS	Universal Mobile Telecommunication System
	UTDOA	Uplink Time Difference of Arrival
	UTRA	Universal Terrestrial Radio Access
10	UTRAN	Universal Terrestrial Radio Access Network
	WCDMA	Wide CDMA
	WLAN	Wide Local Area Network

CLAIMS:

1. A method performed by a wireless device of transmitting in an uplink radio beam, the method comprising:

5 obtaining (1012) a spatial domain filter to be used for uplink transmission;

determining (1016) a spatial orientation of the wireless device has changed after obtaining the spatial domain filter to be used for uplink transmission;

updating (1018) the spatial domain filter to be used for uplink transmission based on the changed spatial orientation of the wireless device; and

10 transmitting (1020) an uplink beam using the updated spatial domain filter.

2. The method of claim 1, further comprising receiving (1014) an indication from a base station that the wireless device may update its spatial domain filter to be used for uplink transmission.

15 3. The method of any one of claims 1-2, wherein obtaining the spatial domain filter to be used for uplink transmission comprises receiving a spatial relation from a base station, wherein the spatial relation is based on results of measurements that the base stations performs on a plurality of reference signals transmitted by the wireless device.

20 4. The method of any one of claims 1-3, wherein obtaining the spatial domain filter to be used for uplink transmission comprises receiving from a base station a sounding reference signal, SRS, index of a preferred SRS of a plurality of SRS transmitted from the wireless device to the base station.

25 5. The method of any one of claims 1-4, wherein the wireless device comprises acceleration sensors, and determining that the spatial orientation of the wireless device has changed is based on the acceleration sensors.

6. The method of any one of claims 1-4, wherein determining that the spatial orientation of the wireless device has changed comprises determining that a relationship between the obtained spatial domain filter and a downlink reference signal has changed.

7. The method of any one of claims 1-6, wherein updating the spatial domain filter to be used for uplink transmission comprises determining a coordinate difference between an orientation of the wireless device associated with the obtained spatial domain filter and the changed spatial orientation of the wireless device, and selecting a new spatial domain filter based on the coordinate difference.

8. The method of any one of claims 1-6, wherein updating the spatial domain filter to be used for uplink transmission comprises determining a difference between a relationship between the obtained spatial domain filter and a downlink reference signal associated with the obtained spatial domain filter and a relationship between the changed spatial orientation of the wireless device and the downlink reference signal, and selecting a new spatial domain filter based on the difference.

9. The method of any one of claims 1-6, wherein updating the spatial domain filter to be used for uplink transmission comprises selecting a spatial domain filter such that an uplink beam transmitted by the wireless device using the selected spatial domain filter is transmitted in a similar direction as an uplink beam transmitted by the wireless device prior to the determined orientation change using the obtained spatial domain filter.

10. A wireless device (110) capable of transmitting in an uplink radio beam, the wireless device comprising processing circuitry (120) operable to:

obtain a spatial domain filter to be used for uplink transmission;

determine a spatial orientation of the wireless device has changed after obtaining the spatial relation to be used for uplink transmission;

update the spatial domain filter to be used for uplink transmission based on the changed spatial orientation of the wireless device; and

transmit an uplink beam using the updated spatial domain filter.

11. The wireless device of claim 10, the processing circuitry further operable to receive an indication from a base station (160) that the wireless device may update its spatial domain filter to be used for uplink transmission.

12. The wireless device of any one of claims 10-11, wherein the processing circuitry is operable to obtain the spatial domain filter to be used for uplink transmission by receiving a spatial relation from a base station, wherein the spatial relation is based on results of measurements that the base stations performs on a plurality of reference signals transmitted by the wireless device.

13. The wireless device of any one of claims 10-12, wherein the processing circuitry is operable to obtain the spatial domain filter to be used for uplink transmission by receiving from a base station a sounding reference signal, SRS, index of a preferred SRS of a plurality of SRS transmitted from the wireless device to the base station.

14. The wireless device of any one of claims 10-13, wherein the wireless device comprises acceleration sensors, and the processing circuitry is operable to determine that the spatial orientation of the wireless device has changed based on the acceleration sensors.

15. The wireless device of any one of claims 10-13, wherein the processing circuitry is operable to determine that the spatial orientation of the wireless device has changed by determining that a relationship between the obtained spatial domain filter and a downlink reference signal has changed.

16. The wireless device of any one of claims 10-15, wherein the processing circuitry is operable to update the spatial domain filter to be used for uplink transmission by determining a coordinate difference between an orientation of the wireless device associated with the

obtained spatial domain filter and the changed spatial orientation of the wireless device, and selecting a new spatial domain filter based on the coordinate difference.

17. The wireless device of any one of claims 10-15, wherein the processing circuitry is operable to update the spatial domain filter to be used for uplink transmission by determining a difference between a relationship between the obtained spatial domain filter and a downlink reference signal associated with the obtained spatial domain filter and a relationship between the changed spatial orientation of the wireless device and the downlink reference signal, and selecting a new spatial domain filter based on the difference.

18. The wireless device of any one of claims 10-15, wherein the processing circuitry is operable to update the spatial domain filter to be used for uplink transmission by selecting a spatial domain filter such that an uplink beam transmitted by the wireless device using the selected spatial domain filter is transmitted in a similar direction as an uplink beam transmitted by the wireless device prior to the determined orientation change using the obtained spatial domain filter.

19. A method performed by a network node for configuring a wireless device for uplink beam transmission, the method comprising:

transmitting (1114) an indication to a wireless device that the wireless device may autonomously update its spatial domain filter to be used for uplink transmission.

20. The method of claim 19, further comprising transmitting (1112) a spatial domain filter to be used for uplink transmission to the wireless device.

21. The method of claim 20, further comprising receiving (1116) an uplink transmission from the wireless device, wherein the uplink transmission was transmitted using an updated spatial domain filter.

22. A network node (160) capable of configuring a wireless device for uplink beam transmission, the network node comprising processing circuitry (170) operable to:

transmit an indication to a wireless device (110) that the wireless device may autonomously update its spatial domain filter to be used for uplink transmission.

5

23. The network node of claim 22, the processing circuitry further operable to transmit a spatial domain filter to be used for uplink transmission to the wireless device.

24. The network node of claim 23, the processing circuitry further operable to
10 receive an uplink transmission from the wireless device, wherein the uplink transmission was transmitted using an updated spatial domain filter.

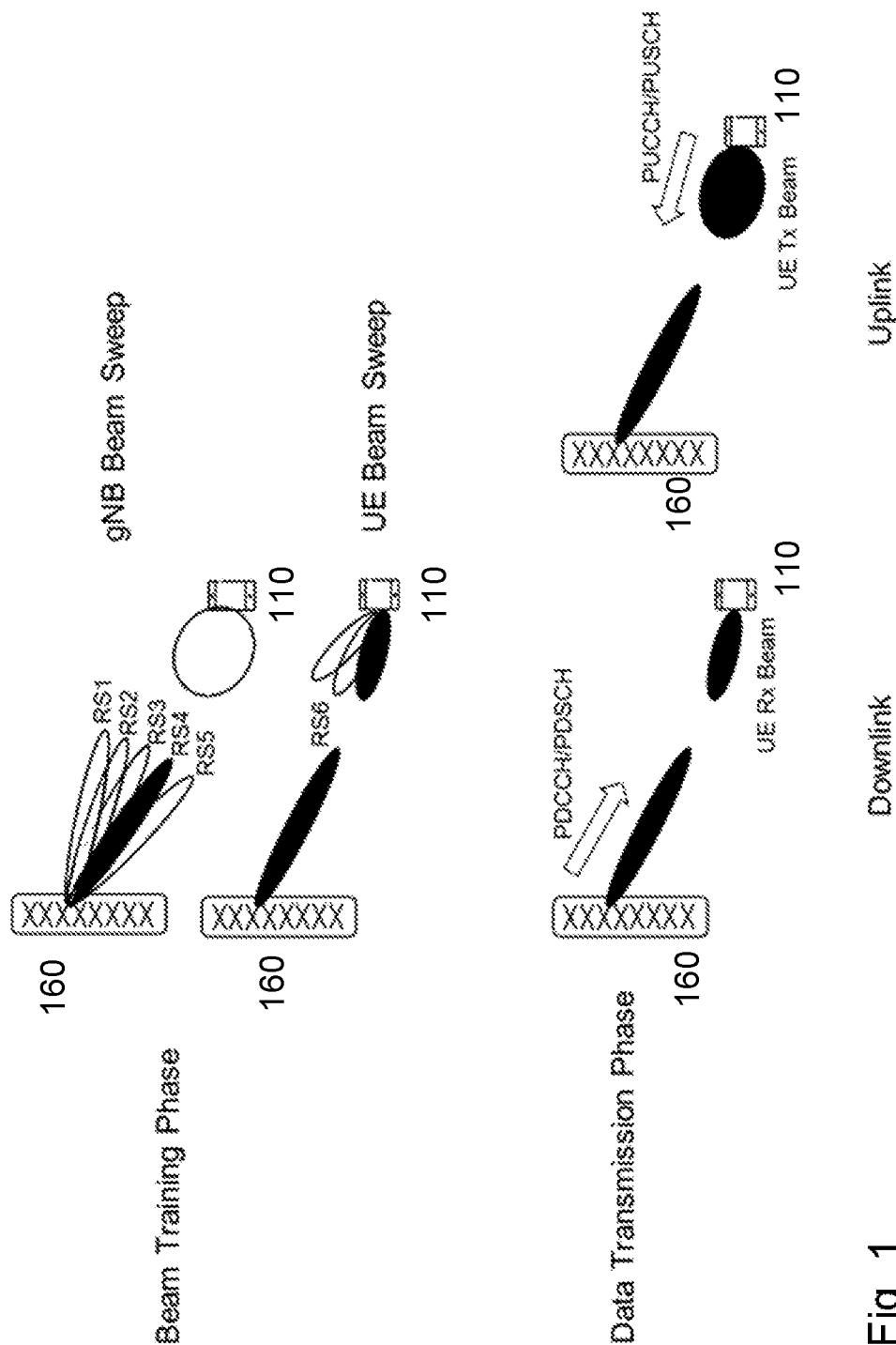


Fig. 1

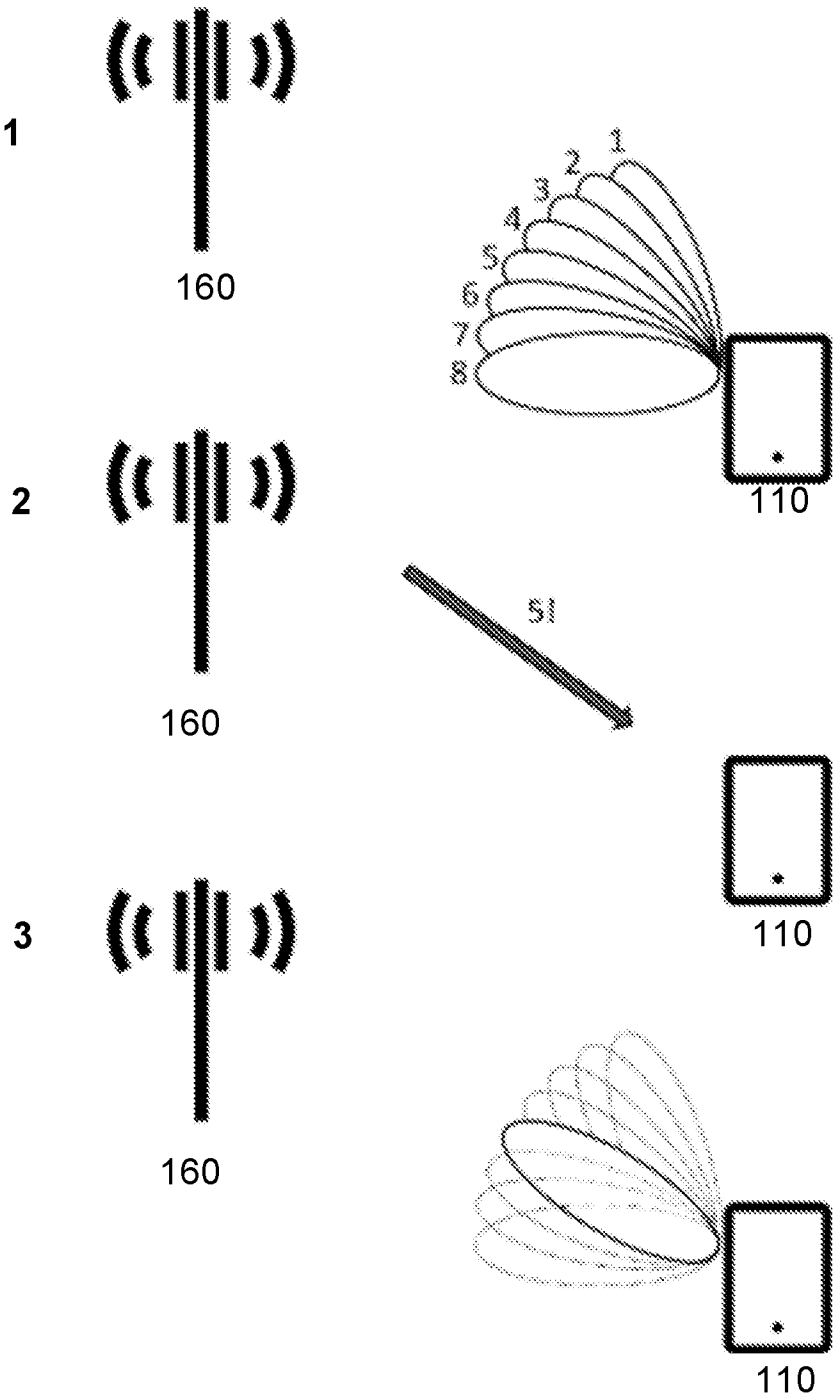


Fig. 2

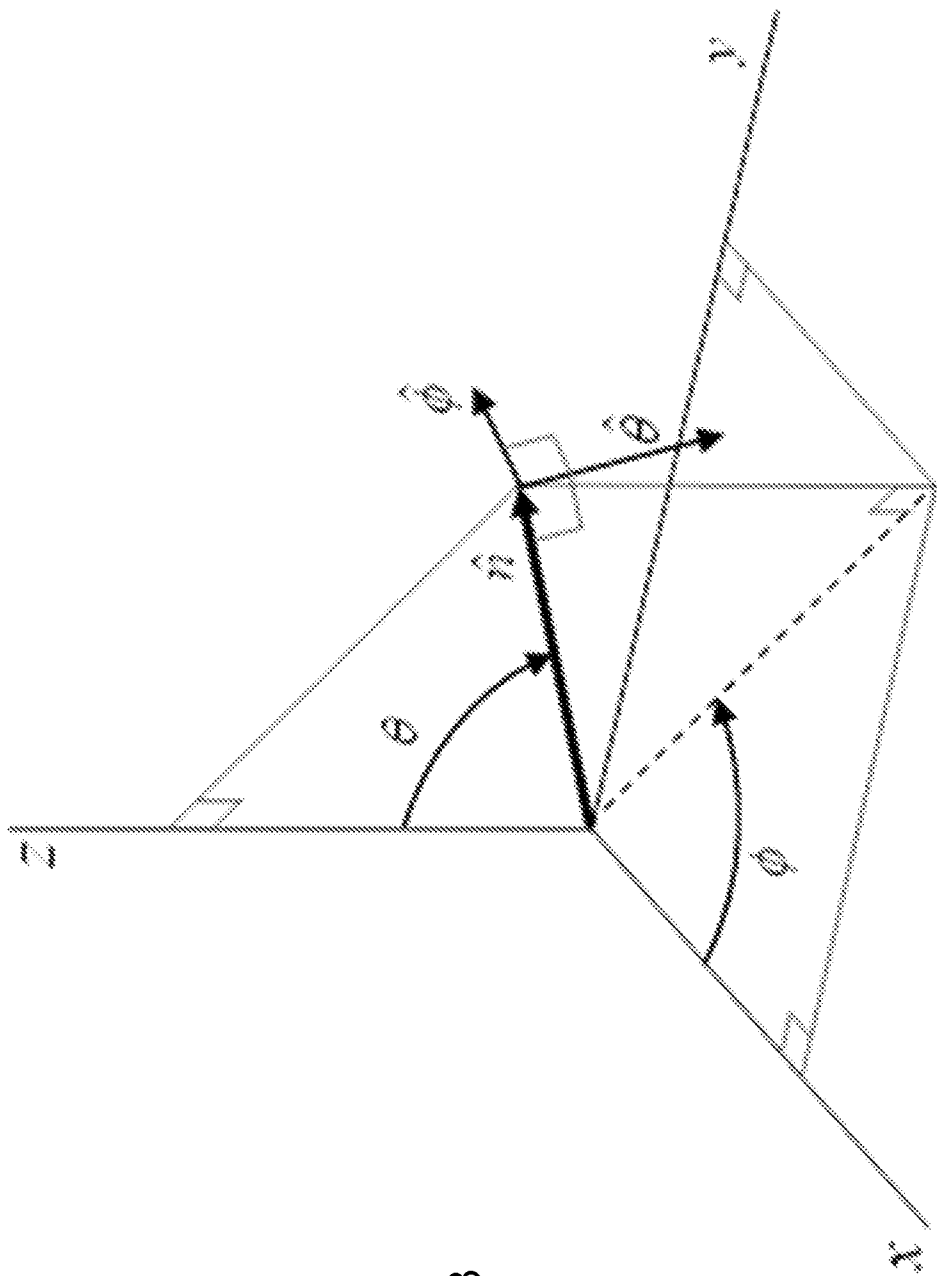


Fig. 3

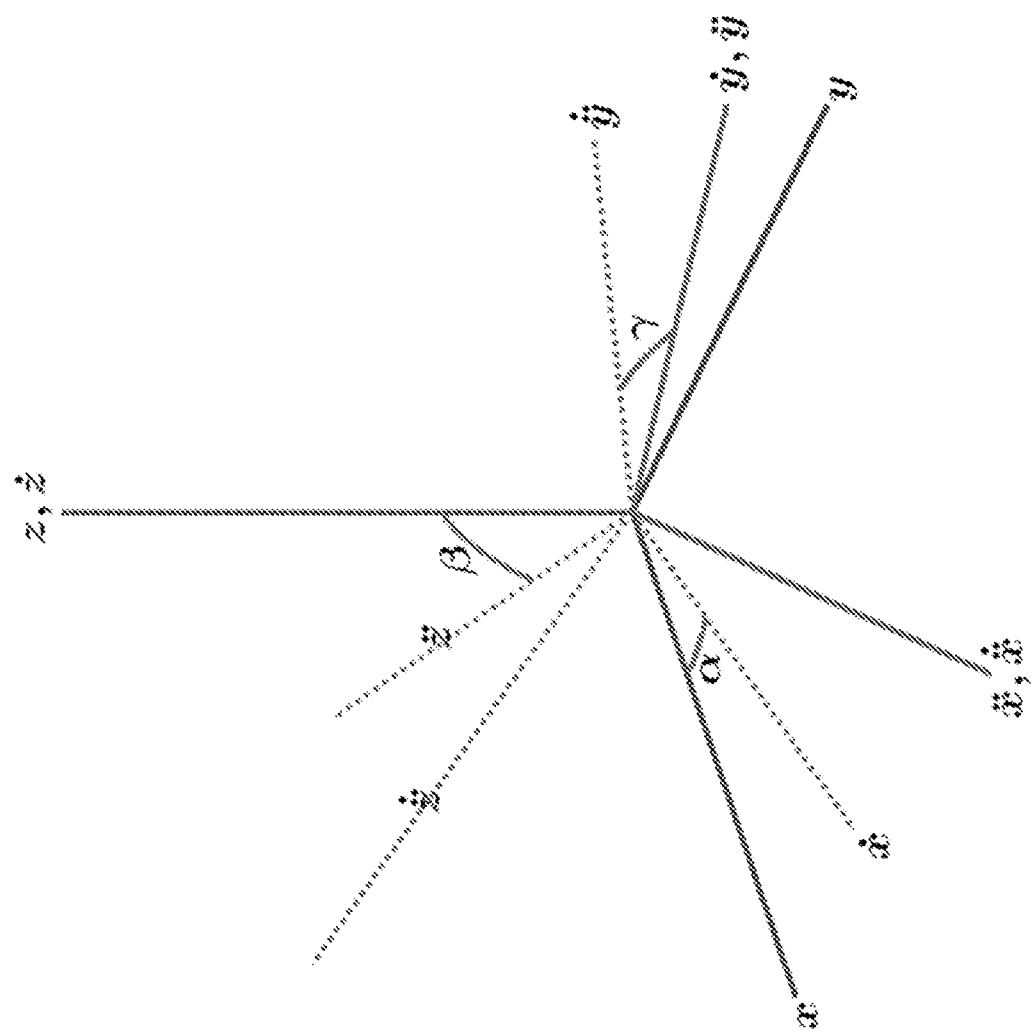


Fig. 4

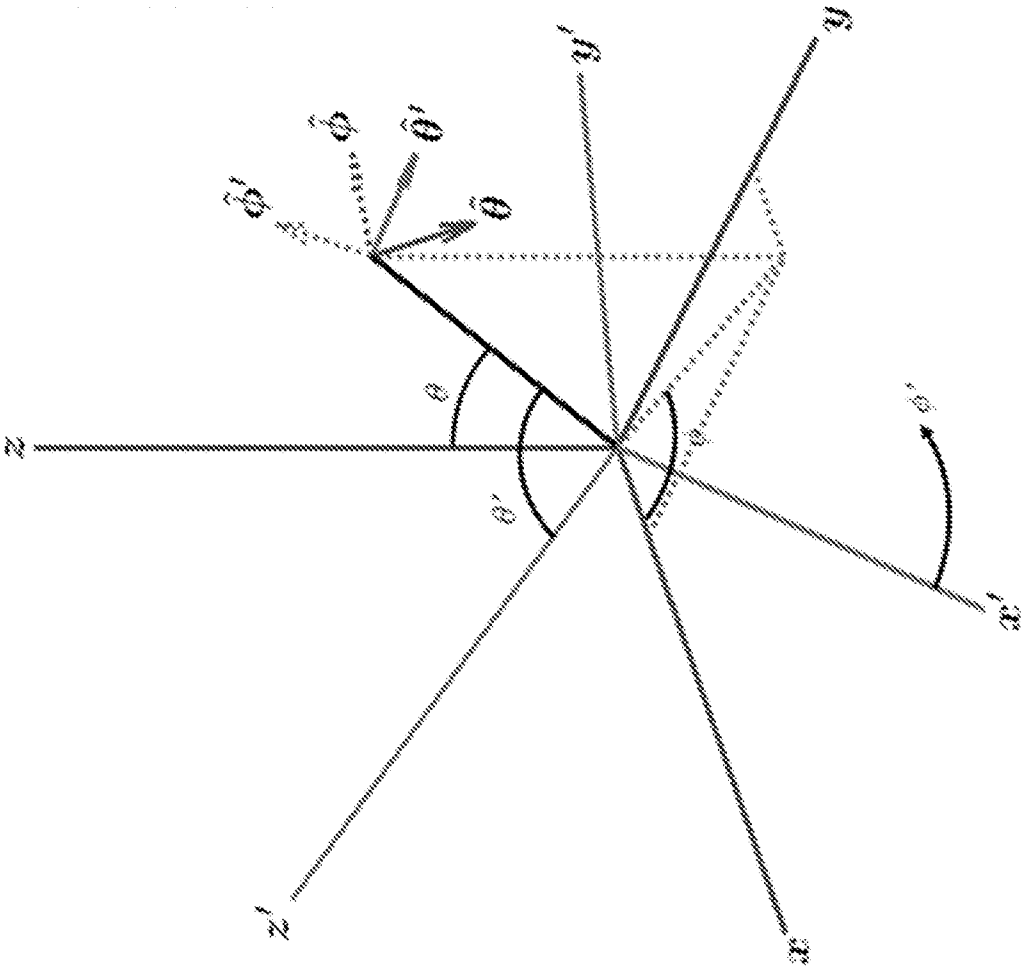


Fig. 5

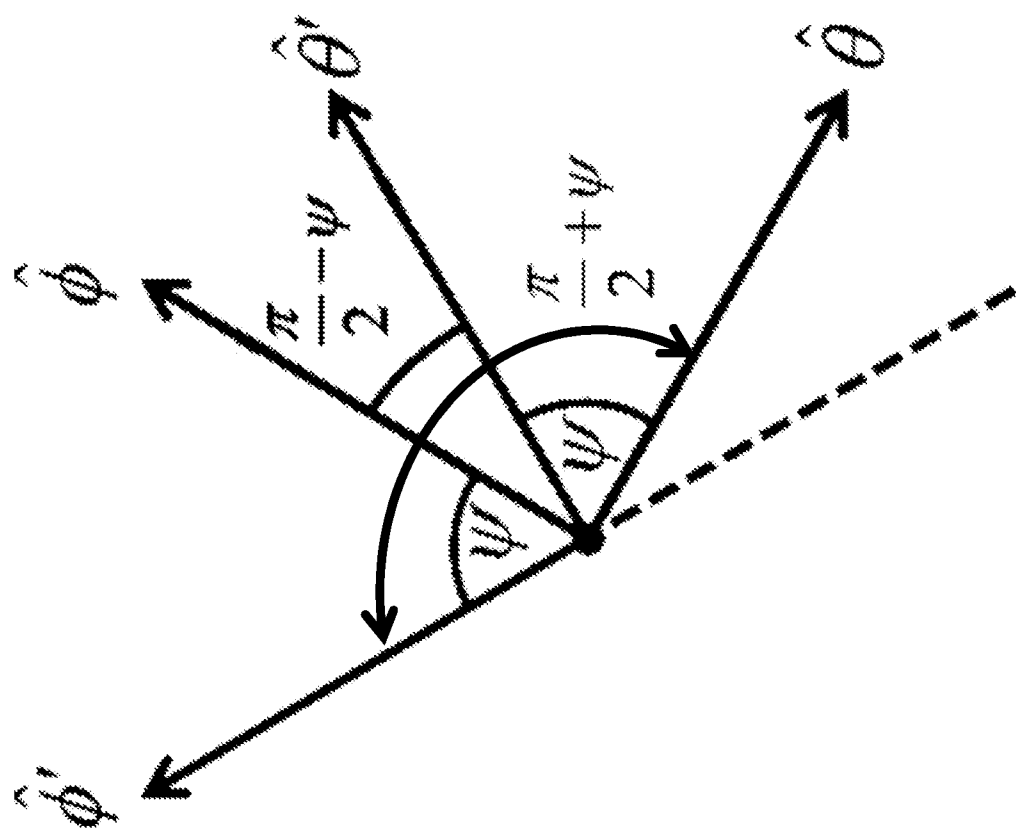


Fig. 6

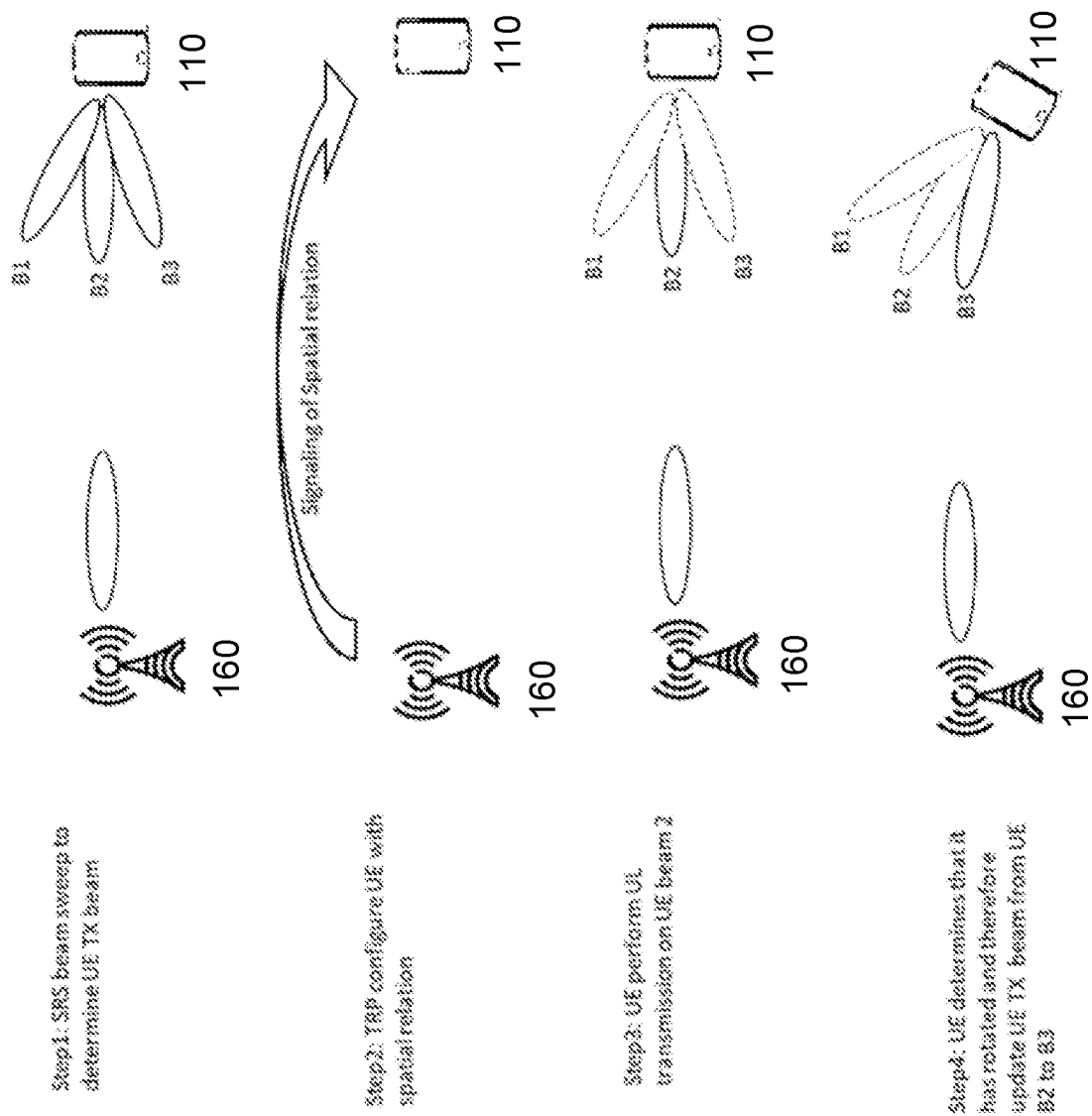


Fig. 7

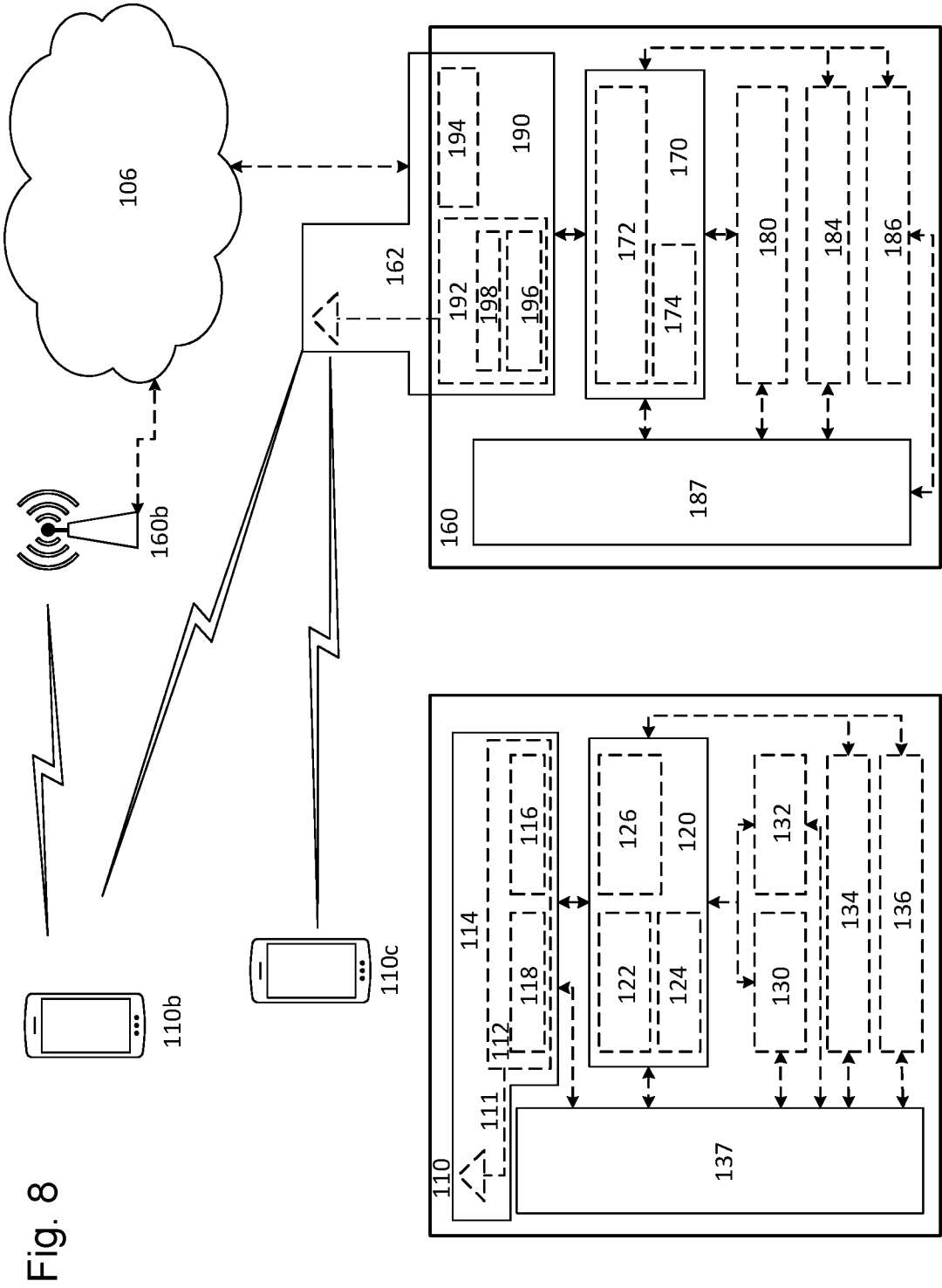
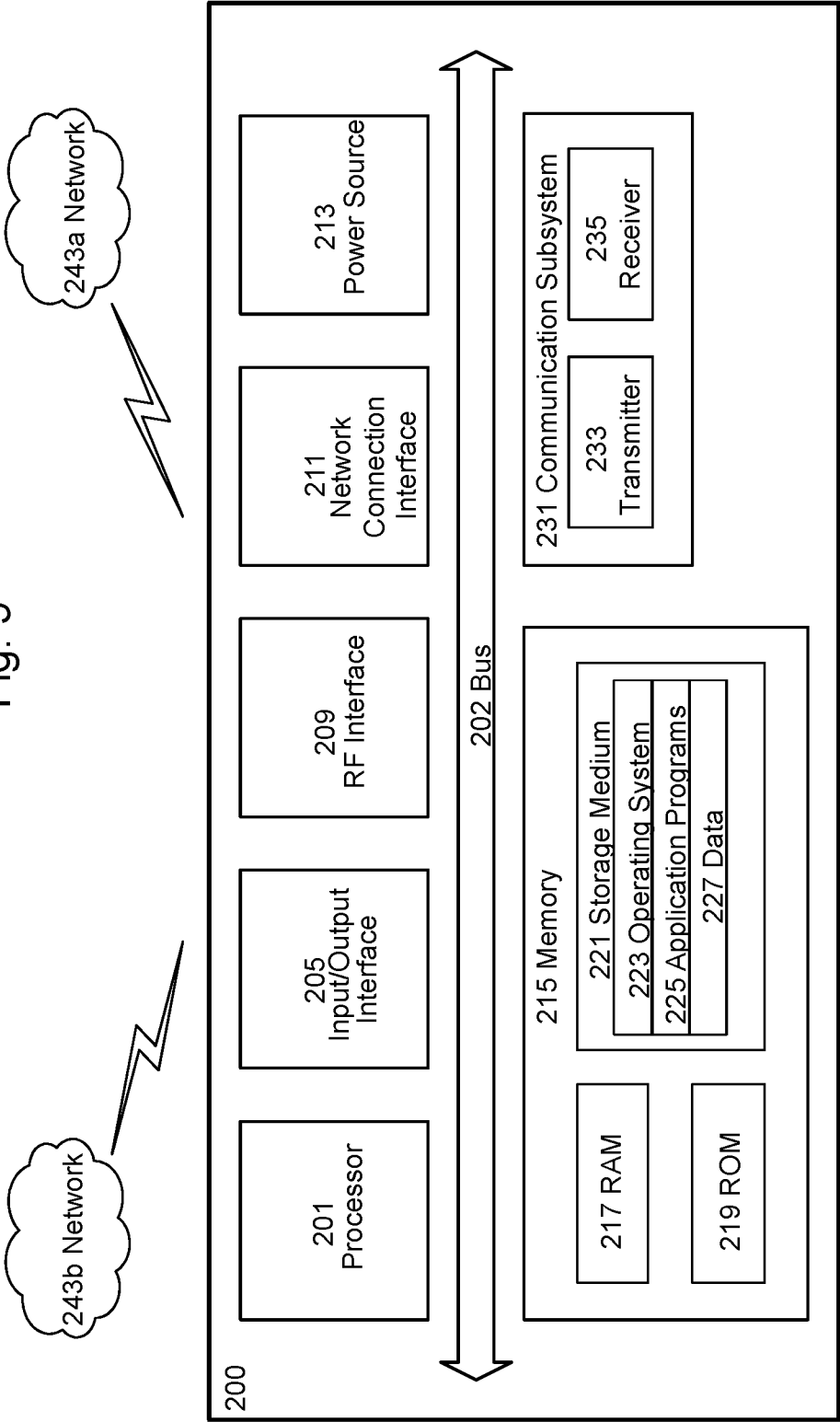


Fig. 9



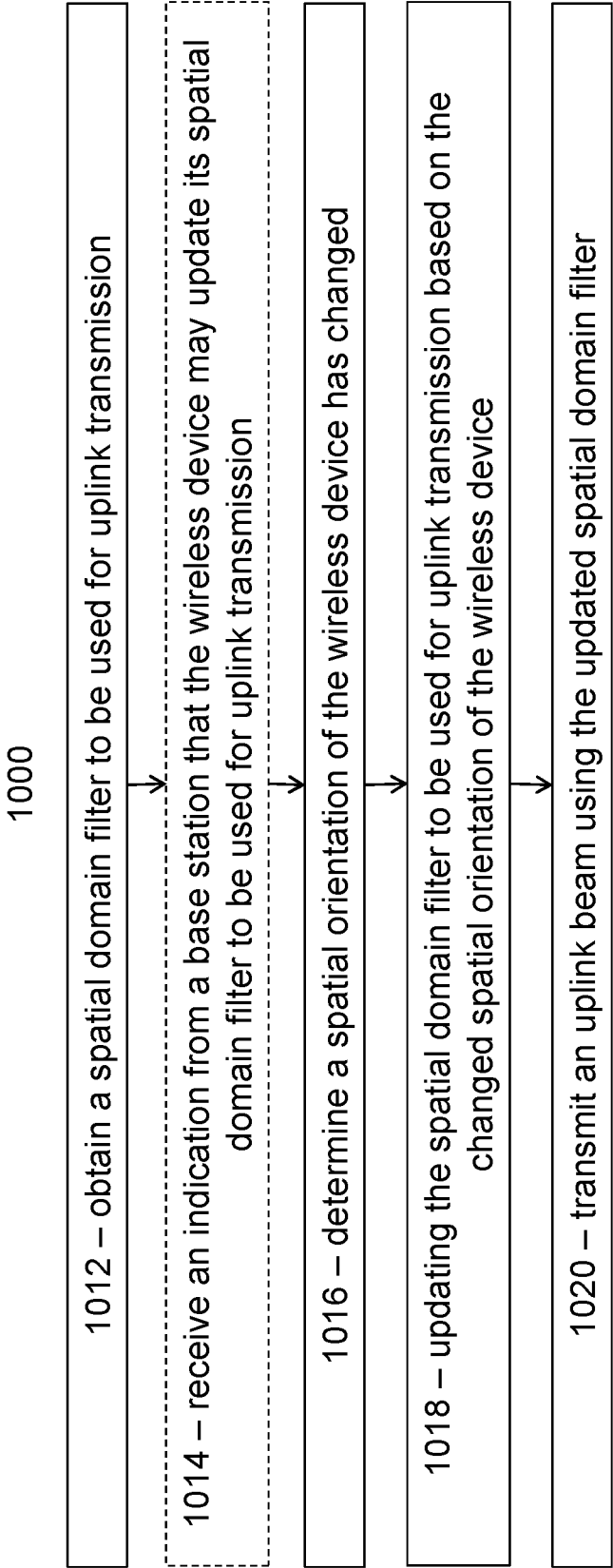


Fig. 10

1100

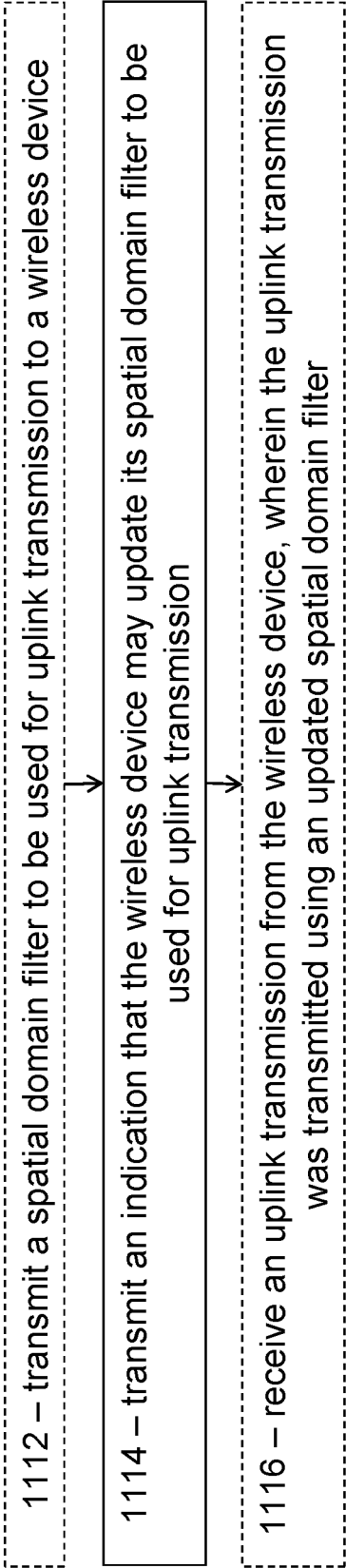


Fig. 11

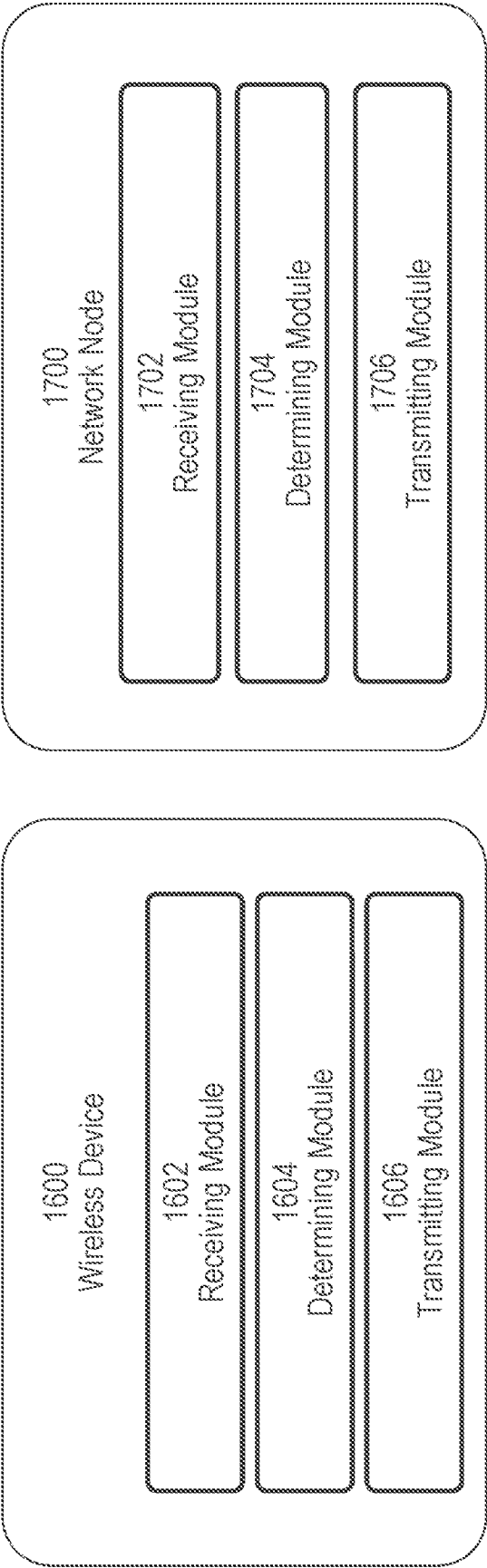


Fig. 12

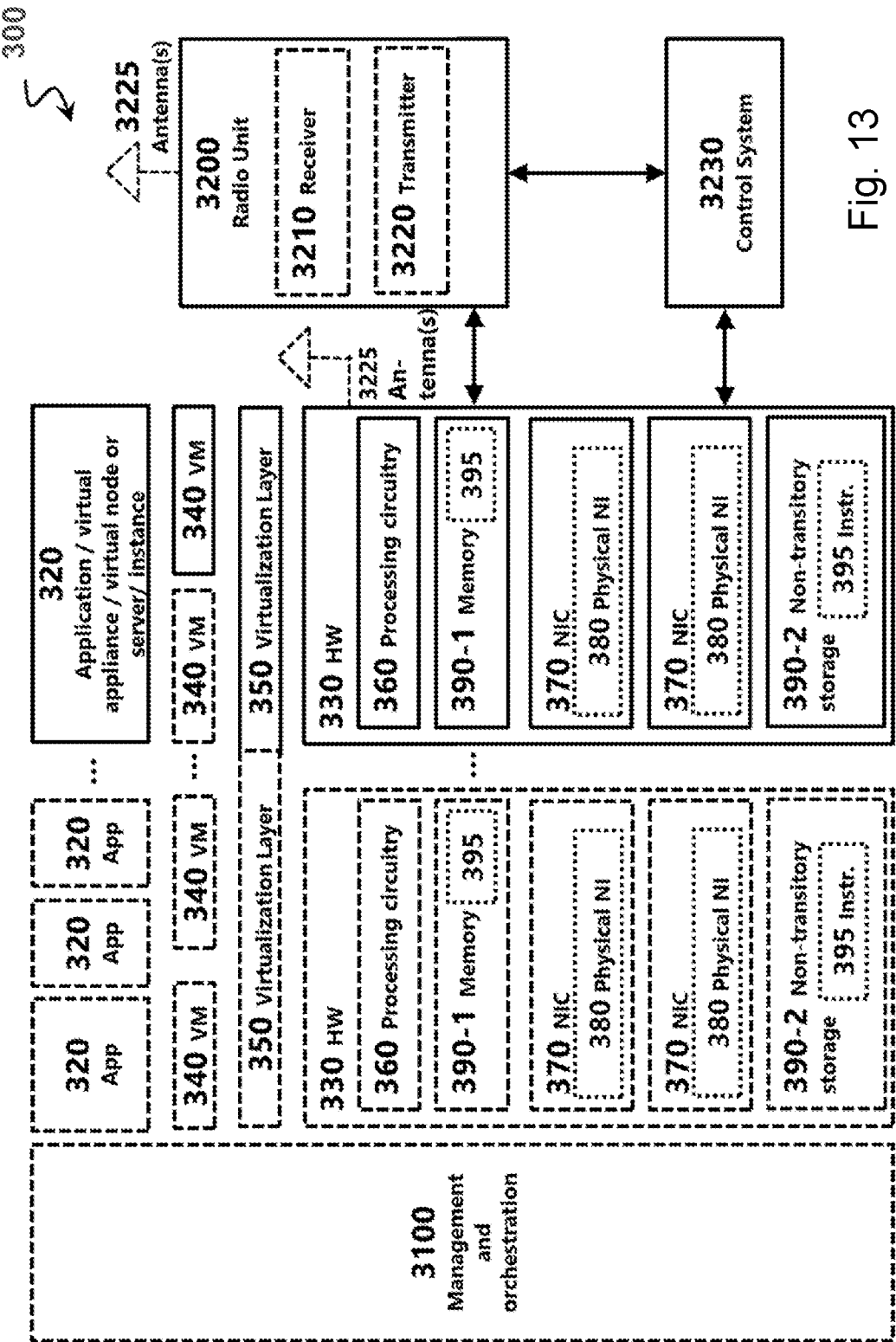


Fig. 13

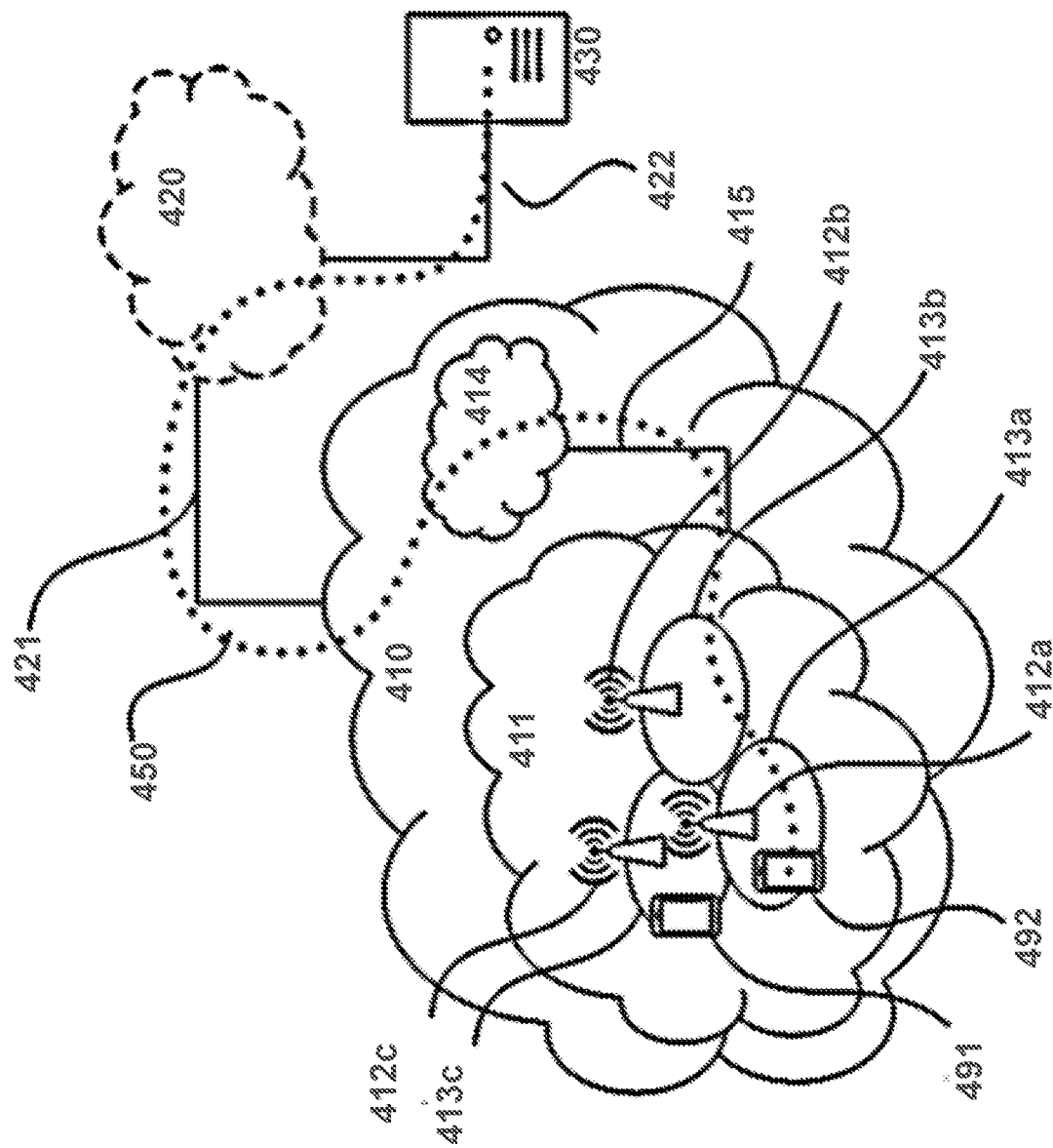


Fig. 14

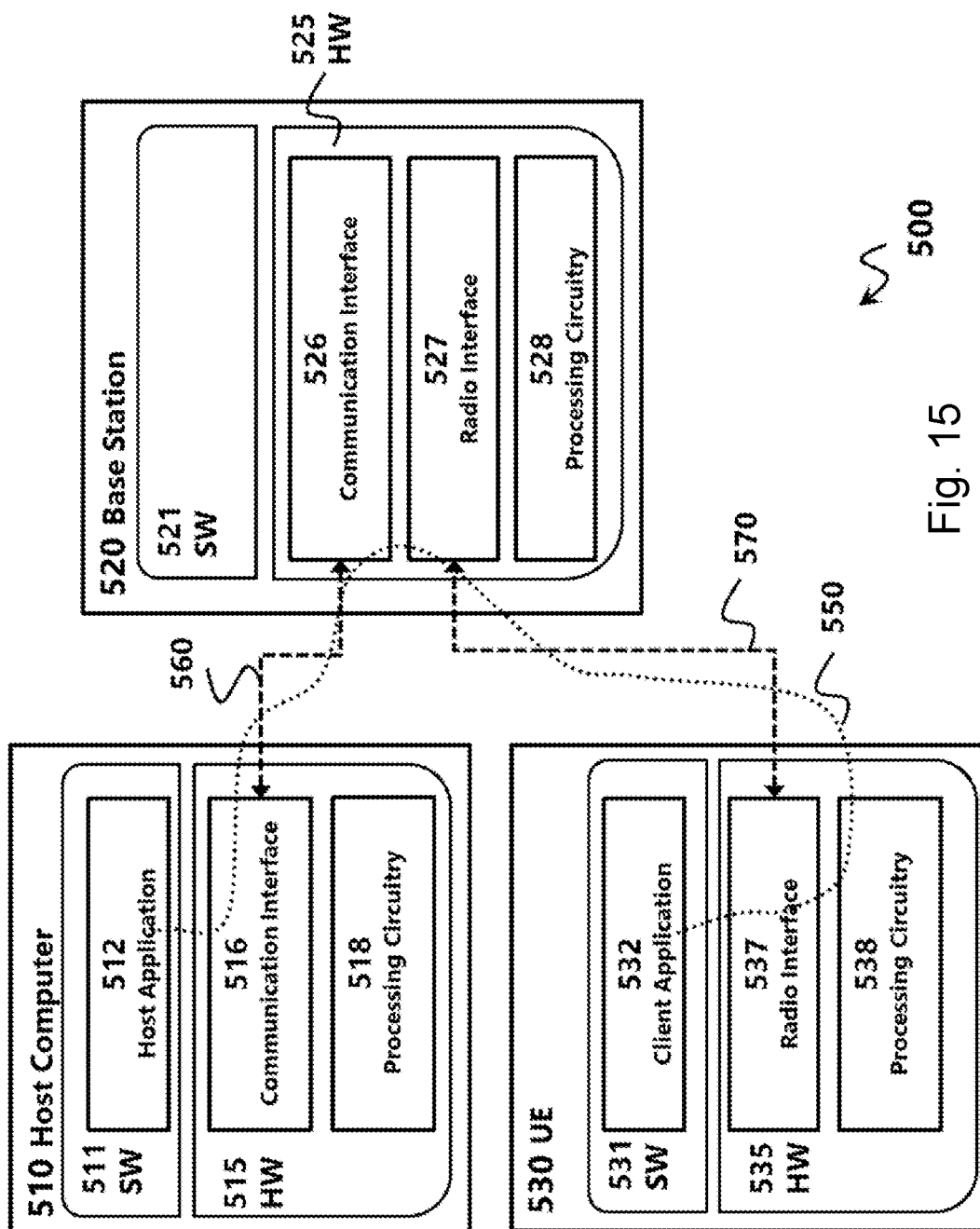


Fig. 15

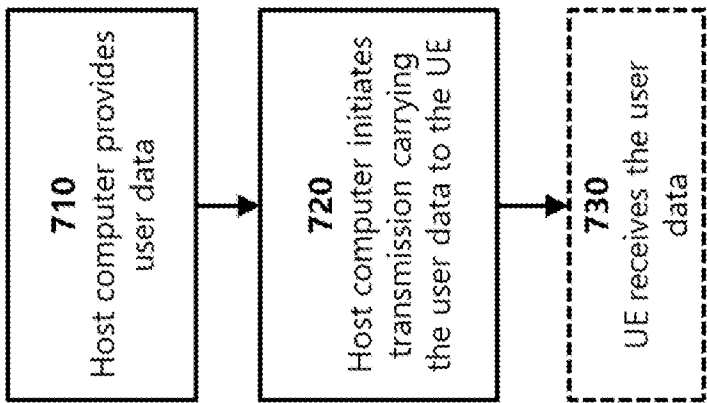


Fig. 17

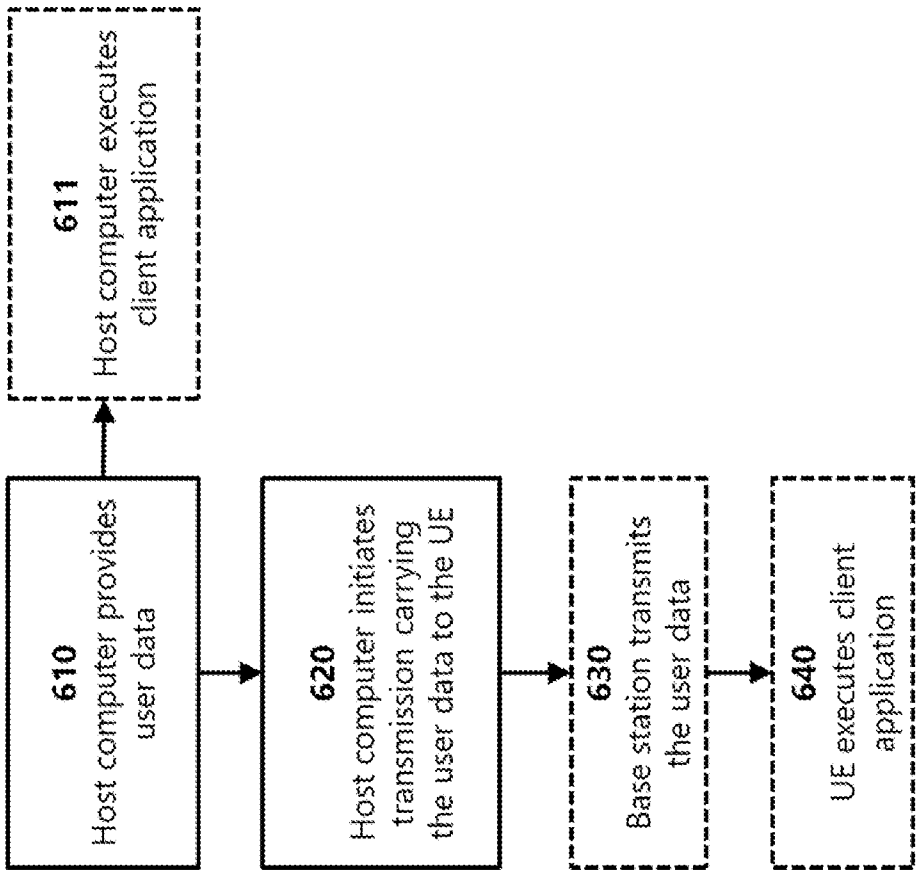


Fig. 16

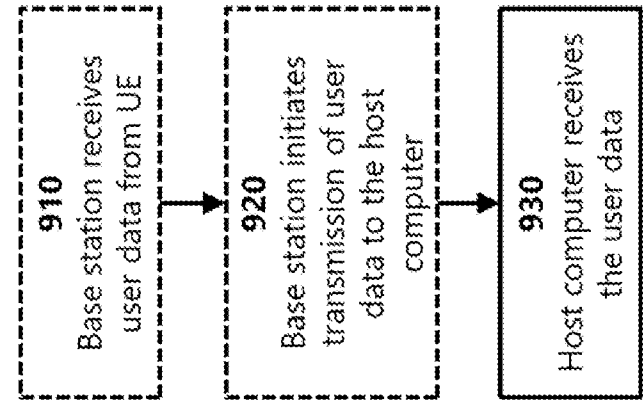


Fig. 19

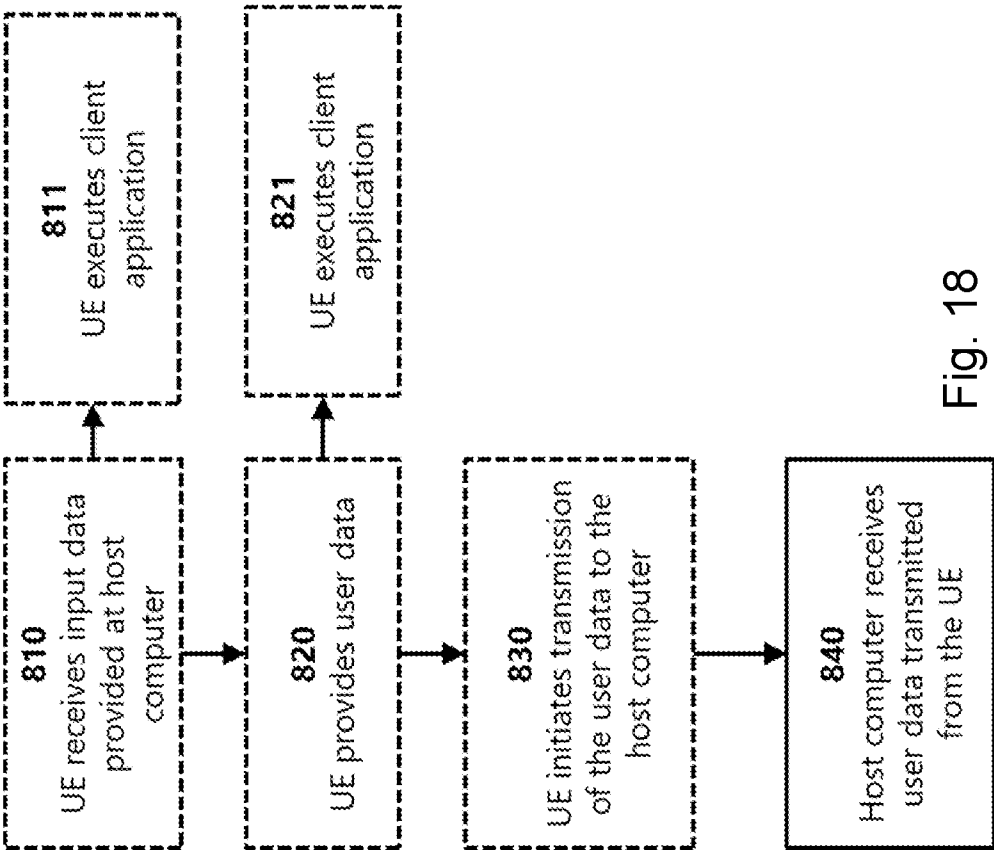


Fig. 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2020/050001

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: H04B, H04W

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data, COMPENDEX, 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 2018204340 A1 (IDAC HOLDING INC ET AL), 8 November 2018 (2018-11-08); paragraphs [0053], [0095], [0107], [0120], [0121], [0156], [0159], [0128], [0129], [0262]	1-5, 10-14, 19-24
A	--	6-9, 15-18
A	WO 2018141204 A1 (HUAWEI TECH CO LTD), 9 August 2018 (2018-08-09); paragraphs [0029]-[0073]	1-24
A	CA 3049490 A1 (HUAWEI TECH CO LTD), 12 July 2018 (2018-07-12); paragraphs [0001], [0003], [0011]-[0013], [0016], [0020], [0241], [0289]	1-24
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"D" document cited by the applicant in the international application	"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
"E" earlier application or patent but published on or after the international filing date	"&" document member of the same patent family
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	
"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	

Date of the actual completion of the international search
16-04-2020

Date of mailing of the international search report
17-04-2020

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INTERNATIONAL SEARCH REPORT

 International application No.
 PCT/SE2020/050001

C (Continuation). 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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P, Y	US 20190281588 A1 (ZHANG YUSHU ET AL), 12 September 2019 (2019-09-12); paragraphs [0027]-[0060] --	1-24
P, Y	WO 2019158186 A1 (ERICSSON TELEFON AB L M), 22 August 2019 (2019-08-22); page 3, line 30 - page 4, line 25 --	1-24
P, Y	WO 2019190377 A1 (ERICSSON TELEFON AB L M), 3 October 2019 (2019-10-03); page 6, line 28 - page 11, line 15 --	1-24
E	WO 2020032737 A1 (LG ELECTRONICS INC), 13 February 2020 (2020-02-13); paragraphs [0236]-[0254] --	1-24
E	CN 110838903 A (CHINA ACAD TELECOM TECHNOLOGY MII ET AL), 25 February 2020 (2020-02-25); whole document; abstract -- -----	1-24

Continuation of: second sheet

International Patent Classification (IPC)

H04B 7/06 (2006.01)

H04B 7/04 (2017.01)

H04W 16/28 (2009.01)

H04W 72/04 (2009.01)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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