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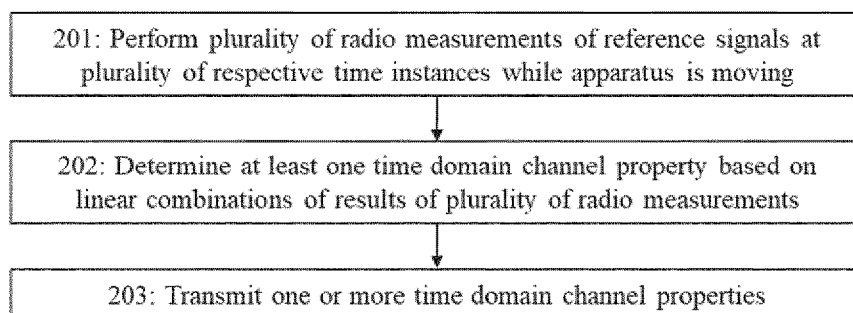


Fig. 2A

(57) Abstract: According to an aspect, there is provided an apparatus for performing the following. The apparatus performs a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path. The apparatus determines at least one time domain channel property based at least on linear combinations of results of the plurality of radio measurements. The at least one time domain channel property comprises at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements or a speed of the apparatus. The apparatus transmits one or more time domain channel properties. The one or more time domain channel properties comprise the at least one time domain channel property.



## PARAMETER ESTIMATION BASED ON VIRTUAL BEAMFORMING

## TECHNICAL FIELD

[0001] Various example embodiments relate to wireless communications.

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## BACKGROUND

[0002] Time domain channel properties (TDCP) have the primary purpose of supporting the access node in determining optimum configurations, e.g., for channel state information reference signals (CSI RSs), sounding reference signals (SRSs), demodulation reference signals (DM-RSs) and/or tracking reference signals (TRSs). The configuration should be the optimal fit for the current radio channel conditions of a certain terminal device. The estimation of Doppler spectrum or the time domain coherence times at terminal device side has been proposed. Based on this information, the maximum Doppler frequency and/or the strongest Doppler frequencies may be reported to the access node as such Doppler information is often a good indicator of the channel variance. However, such Doppler information does not, in general, provide any information about the actual speed of the terminal device itself. This is due to several different factors. Firstly, there is no way to distinguish a change in observed Doppler frequency due to terminal device movements from a change in observed Doppler frequency due to reflections from other moving objects in the environment of the terminal device. Secondly, the maximum Doppler frequency observed at the terminal device depends on the direction of movement of the terminal device relative to the access node position. Thirdly, a frequency offset exists between the local oscillators of the terminal device and the access node. This frequency offset directly adds to the Doppler frequency observed at the terminal device. Thus, there is a need for an improved Doppler-based solutions for estimating time domain channel properties.

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## SUMMARY

[0003] According to an aspect, there is provided the subject matter of the independent claims. Embodiments are defined in the dependent claims.

**[0004]** One or more examples of implementations are set forth in more detail in the accompanying drawings and the description below. Other features will be apparent from the description and drawings, and from the claims.

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## BRIEF DESCRIPTION OF THE DRAWINGS

**[0005]** Figure 1 illustrates a system to which some embodiments may be applied;

**[0006]** Figures 2A and 2B illustrates processes according to some embodiments;

**[0007]** Figure 3 illustrates the basic concept of virtual beamforming for a moving terminal device assuming that there are two reflected multipath components;

10 **[0008]** Figure 4 illustrates two different moving terminal devices forming virtual beamforming array and associated parameters;

**[0009]** Figure 5 shows an exemplary simulated beamsteering pattern according to some embodiments;

15 **[0010]** Figure 6 illustrates the concept of destructive superposition (or interference) of reference signals received by a moving terminal device when the beamformer steering angle is beyond 90°;

**[0011]** Figures 7 and 8 illustrate processes according to some embodiments;

**[0012]** Figure 9 illustrates signalling between a terminal device, an access node and a computing device or system according to some embodiments; and

20 **[0013]** Figure 10 illustrates an apparatus according to some embodiments.

## DETAILED DESCRIPTION OF SOME EMBODIMENTS

25 **[0014]** The following embodiments are only presented as examples. Although the specification may refer to “an”, “one”, or “some” embodiment(s) and/or example(s) in several locations of the text, this does not necessarily mean that each reference is made to the same embodiment(s) or example(s), or that a particular feature only applies to a single

embodiment and/or example. Single features of different embodiments and/or examples may also be combined to provide other embodiments and/or examples.

**[0015]** As used herein, “at least one of the following: <a list of two or more elements>” and “at least one of <a list of two or more elements>” and similar wording, where  
5 the list of two or more elements are joined by “and” or “or”, mean at least any one of the elements, or at least any two or more of the elements, or at least all the elements.

**[0016]** In the following, different exemplifying embodiments will be described using, as an example of an access architecture to which the embodiments may be applied, a radio access architecture based on long term evolution advanced (LTE Advanced, LTE-A) or new  
10 radio (NR, 5G), without restricting the embodiments to such an architecture, however. It is obvious for a person skilled in the art that the embodiments may also be applied to other kinds of communications networks having suitable means by adjusting parameters and procedures appropriately. Some examples of other options for suitable systems are the universal mobile telecommunications system (UMTS) radio access network (UTRAN or E-  
15 UTRAN), long term evolution (LTE, the same as E-UTRA), wireless local area network (WLAN or WiFi), worldwide interoperability for microwave access (WiMAX), Bluetooth®, personal communications services (PCS), ZigBee®, wideband code division multiple access (WCDMA), systems using ultra-wideband (UWB) technology, sensor networks, mobile ad-hoc networks (MANETs) and Internet Protocol multimedia subsystems (IMS) or any  
20 combination thereof.

**[0017]** Figure 1 depicts examples of simplified system architectures only showing some elements and functional entities, all being logical units, whose implementation may differ from what is shown. The connections shown in Figure 1 are logical connections; the actual physical connections may be different. It is apparent to a person skilled in the art that  
25 the system typically comprises also other functions and structures than those shown in Figure 1.

**[0018]** The embodiments are not, however, restricted to the system given as an example but a person skilled in the art may apply the solution to other communication systems provided with necessary properties.

30 **[0019]** The example of Figure 1 shows a part of an exemplifying radio access network.

- [0020]** A communications system typically comprises more than one (e/g)NodeB in which case the (e/g)NodeBs may also be configured to communicate with one another over links, wired or wireless, designed for the purpose. These links may be used for signaling purposes. The (e/g)NodeB is a computing device configured to control the radio resources of communication system it is coupled to. The NodeB may also be referred to as a base station, an access point or any other type of interfacing device including a relay station capable of operating in a wireless environment. The (e/g)NodeB includes or is coupled to transceivers. From the transceivers of the (e/g)NodeB, a connection is provided to an antenna unit that establishes bi-directional radio links to user devices. The antenna unit may comprise a plurality of antennas or antenna elements. The (e/g)NodeB is further connected to core network 110 (CN or next generation core NGC). Depending on the system, the counterpart on the CN side can be a serving gateway (S-GW, routing and forwarding user data packets), packet data network gateway (P-GW), for providing connectivity of user devices (UEs) to external packet data networks, or mobile management entity (MME), etc.
- [0021]** The user device (also called UE, user equipment, user terminal, terminal device, etc.) illustrates one type of an apparatus to which resources on the air interface are allocated and assigned, and thus any feature described herein with a user device may be implemented with a corresponding apparatus, such as a relay node. An example of such a relay node is a layer 3 relay (self-backhauling relay) towards the base station.
- [0022]** The user device typically refers to a portable computing device that includes wireless mobile communication devices operating with or without a subscriber identification module (SIM), including, but not limited to, the following types of devices: a mobile station (mobile phone), smartphone, personal digital assistant (PDA), handset, device using a wireless modem (alarm or measurement device, etc.), laptop and/or touch screen computer, tablet, game console, notebook, and multimedia device. It should be appreciated that a user device may also be a nearly exclusive uplink only device, of which an example is a camera or video camera loading images or video clips to a network. A user device may also be a device having capability to operate in Internet of Things (IoT) network which is a scenario in which objects are provided with the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. The user device (or in some embodiments a layer 3 relay node) is configured to perform one or more of user equipment functionalities. The user device may also be called a subscriber unit, mobile station, remote

terminal, access terminal, user terminal or user equipment (UE) just to mention but a few names or apparatuses.

**[0023]** Various techniques described herein may also be applied to a cyber-physical system (CPS) (a system of collaborating computational elements controlling physical entities). CPS may enable the implementation and exploitation of massive amounts of interconnected ICT devices (sensors, actuators, processors/microcontrollers, etc.) embedded in physical objects at different locations. Mobile cyber physical systems, in which the physical system in question has inherent mobility, are a subcategory of cyber-physical systems. Examples of mobile physical systems include mobile robotics and electronics transported by humans or animals.

**[0024]** It should be understood that, in Figure 1, user devices are depicted to include 2 antennas only for the sake of clarity. The number of reception and/or transmission antennas may naturally vary according to a current implementation.

**[0025]** Additionally, although the apparatuses have been depicted as single entities, different units, processors and/or memory units (not all shown in Figure 1) may be implemented.

**[0026]** 5G enables using multiple input – multiple output (MIMO) antennas, many more base stations or nodes than the LTE (a so-called small cell concept), including macro sites operating in co-operation with smaller stations and employing a variety of radio technologies depending on service needs, use cases and/or spectrum available. 5G mobile communications supports a wide range of use cases and related applications including video streaming, augmented reality, different ways of data sharing and various forms of machine type applications, including vehicular safety, different sensors and real-time control. 5G is expected to have multiple radio interfaces, namely below 6GHz, cmWave and mmWave, and also being integratable with existing legacy radio access technologies, such as the LTE. Integration with the LTE may be implemented, at least in the early phase, as a system, where macro coverage is provided by the LTE and 5G radio interface access comes from small cells by aggregation to the LTE. In other words, 5G is planned to support both inter-RAT operability (such as LTE-5G) and inter-RI operability (inter-radio interface operability, such as below 6GHz – cmWave, below 6GHz – cmWave – mmWave). One of the concepts considered to be used in 5G networks is network slicing in which multiple independent and dedicated virtual sub-networks (network instances) may be created within the same

infrastructure to run services that have different requirements on latency, reliability, throughput and mobility.

**[0027]** The current architecture in LTE networks is fully distributed in the radio and fully centralized in the core network. The low latency applications and services in 5G require to bring the content close to the radio which leads to local break out and multi-access edge computing (MEC). 5G enables analytics and knowledge generation to occur at the source of the data. This approach requires leveraging resources that may not be continuously connected to a network such as laptops, smartphones, tablets and sensors. MEC provides a distributed computing environment for application and service hosting. It also has the ability to store and process content in close proximity to cellular subscribers for faster response time. Edge computing covers a wide range of technologies such as wireless sensor networks, mobile data acquisition, mobile signature analysis, cooperative distributed peer-to-peer ad hoc networking and processing also classifiable as local cloud/fog computing and grid/mesh computing, dew computing, mobile edge computing, cloudlet, distributed data storage and retrieval, autonomic self-healing networks, remote cloud services, augmented and virtual reality, data caching, Internet of Things (massive connectivity and/or latency critical), critical communications (autonomous vehicles, traffic safety, real-time analytics, time-critical control, healthcare applications).

**[0028]** The communication system is also able to communicate with other networks, such as a public switched telephone network or the Internet 112, or utilize services provided by them. The communication network may also be able to support the usage of cloud services, for example at least part of core network operations may be carried out as a cloud service (this is depicted in Figure 1 by “cloud” 114). The communication system may also comprise a central control entity, or a like, providing facilities for networks of different operators to cooperate for example in spectrum sharing.

**[0029]** Edge cloud may be brought into the RAN by utilizing network function virtualization (NFV) and software defined networking (SDN). Using edge cloud may mean access node operations to be carried out, at least partly, in a server, host or node operationally coupled to a remote radio head or unit (RU) or base station comprising radio parts. It is also possible that node operations will be distributed among a plurality of servers, nodes or hosts. Application of cloudRAN architecture enables RAN real time functions being carried out at the RAN side (in a distributed unit, DU 104) and non-real time functions being carried out

in a centralized manner (in a central or centralized unit, CU 108). Thus, in summary, the RAN may comprise at least one distributed access node comprising a central unit, one or more distributed units communicatively connected to the central unit and one or more (remote) radio heads or units, each of which is communicatively connected to at least one of the one or more distributed units.

**[0030]** It should also be understood that the distribution of labor between core network operations and base station operations may differ from that of the LTE or even be non-existent. Some other technology advancements probably to be used are Big Data and all-IP, which may change the way networks are being constructed and managed. 5G (or new radio, NR) networks are being designed to support multiple hierarchies, where MEC servers can be placed between the core and the base station or nodeB (gNB). It should be appreciated that MEC can be applied in 4G networks as well.

**[0031]** 5G may also utilize satellite communication to enhance or complement the coverage of 5G service, for example by providing backhauling. Possible use cases are providing service continuity for machine-to-machine (M2M) or Internet of Things (IoT) devices or for passengers on board of vehicles, or ensuring service availability for critical communications, and future rail-way/maritime/aeronautical communications. Satellite communication may utilize geostationary earth orbit (GEO) satellite systems, but also low earth orbit (LEO) satellite systems, in particular mega-constellations (systems in which hundreds of (nano)satellites are deployed). Each satellite 106 in the mega-constellation may cover several satellite-enabled network entities that create on-ground cells. The on-ground cells may be created through an on-ground relay node 104 or by a gNB located on-ground or in a satellite.

**[0032]** It is obvious for a person skilled in the art that the depicted system is only an example of a part of a radio access system and in practice, the system may comprise a plurality of (e/g)NodeBs, the user device may have an access to a plurality of radio cells and the system may comprise also other apparatuses, such as physical layer relay nodes or other network elements, etc. At least one of the (e/g)NodeBs or may be a Home(e/g)nodeB. Additionally, in a geographical area of a radio communication system a plurality of different kinds of radio cells as well as a plurality of radio cells may be provided. Radio cells may be macro cells (or umbrella cells) which are large cells, usually having a diameter of up to tens of kilometers, or smaller cells such as micro-, femto- or picocells. The (e/g)NodeBs of Figure

1 may provide any kind of these cells. A cellular radio system may be implemented as a multilayer network including several kinds of cells. Typically, in multilayer networks, one access node provides one kind of a cell or cells, and thus a plurality of (e/g)NodeBs are required to provide such a network structure.

5     **[0033]**       For fulfilling the need for improving the deployment and performance of communication systems, the concept of “plug-and-play” (e/g)NodeBs has been introduced. Typically, a network which is able to use “plug-and-play” (e/g)NodeBs, includes, in addition to Home (e/g)NodeBs (H(e/g)nodeBs), a home node B gateway, or HNB-GW (not shown in Figure 1). A HNB Gateway (HNB-GW), which is typically installed within an  
10   operator’s network may aggregate traffic from a large number of HNBs back to a core network.

**[0034]**       6G architecture is targeted to enable easy integration of everything, such as a network of networks, joint communication and sensing, non-terrestrial networks and terrestrial communication. 6G systems are envisioned to encompass machine learning  
15   algorithms as well as local and distributed computing capabilities, where virtualized network functions can be distributed over core and edge computing resources. Far edge computing, where computing resources are pushed to the very edge of the network, will be part of the distributed computing environment, for example in “zero-delay” scenarios. 5G systems may also employ such capabilities. More generally, the actual (radio) communication system is  
20   envisaged to be comprised of one or more computer programs executed within a programmable infrastructure, such as general-purpose computing entities (servers, processors, and like).

**[0035]**       As mentioned above, time domain channel properties have the primary purpose of supporting the access node in determining optimum configurations for various reference  
25   signal such as CSI RSs, SRSs, DMRSs and/or TRSs. The configuration should be the optimal fit for the current radio channel conditions of a certain terminal device. For example, the configuration should correspond to the right repetition rate, the right density in space, frequency and/or time. The estimation of Doppler spectrum or the time domain coherence times at terminal device side has been proposed. Based on this information, the maximum  
30   Doppler frequency and/or the strongest Doppler frequencies (i.e., the strongest Doppler components), for example, may be reported to the access node as such Doppler information is often a good indicator of the channel variance. In other words, the channel variance of the

radio channel may be estimated based on the strongest Doppler frequencies. However, such Doppler information does not, in general, provide any information about the actual speed of the terminal device itself. This is due to several different factors.

**[0036]** Firstly, there is no way to distinguish a change in observed Doppler frequency  
5 due to terminal device movements from a change in observed Doppler frequency due to reflections from other moving objects in the environment of the terminal device.

**[0037]** Secondly, the maximum Doppler frequency observed at the terminal device depends on the direction of movement of the terminal device relative to the access node position. If the terminal device is in a line-of-sight (LOS) scenario and is moving along a  
10 line crossing the location of the access node directly towards the access node or directly away from the access node, the angle of arrival (AoA) is  $0^\circ$  and thus the Doppler frequency will be maximized and can be used directly as a measure of the speed of the terminal device. On the other hand, if the terminal device is moving along a line which does not meet the location of the access node, the observed Doppler frequency depends on the angle of arrival.  
15 If the AoA is equal to  $90^\circ$ , the terminal device will observe under ideal conditions no Doppler shift at all (i.e., Doppler frequency is zero) irrespective of the speed of the terminal device. The related TDCP report will then significantly underestimate the UE speed. If the AoA is between  $0^\circ$  and  $90^\circ$ , the terminal device will observe a Doppler frequency which is between the aforementioned two extremes and which is dependent on the speed of the terminal  
20 device, at least to a certain extent.

**[0038]** Thirdly, a frequency offset exists between the local oscillators of the terminal device and the access node. This frequency offset directly adds to the Doppler frequency observed at the terminal device.

**[0039]** For a network entity (e.g., an access node or other network node) configuring  
25 the reference signal resources (e.g., CSI RS, SRS, or DMRS resources), the Doppler frequency can be a good initial indicator for the radio channel. One disadvantage of relying on the Doppler frequency is that it may change rapidly with a change in movement speed and/or direction of the terminal device. For example, a fast moving terminal device on a rectangular track observing a low Doppler frequency might change its direction so that,  
30 within a relatively short period of time, the terminal device might experience a much higher Doppler frequency. Furthermore, an accurate estimation of velocities of terminal devices would be useful for many other applications such as for optimized radio resource

management (RRM) algorithms, for example, in combination with a digital twin of the wireless communication network. Having a building data map of the environment and knowing the terminal device location as well as the speed of the terminal device, one can easily predict, e.g., the optimal handover points for switching from one radio cell to another.

5     **[0040]**         With respect to 6G and applications like joint communication and sensing or placement of terminal devices within a digital twin, e.g., used for enhanced positioning systems then accurate AoA information of specific Doppler components will be of interest as well.

10     **[0041]**         The embodiments to be discussed below in detail provide methods, apparatuses (e.g., a terminal device, an access node and a computing device or system such as a cloud-based computing system) and software for independently and accurately estimating the speed of the terminal device as well as the associated Doppler frequency. Especially, at least some embodiments enable inferring which part of a given Doppler frequency is due to the movement of the terminal device and which part is due to other moving objects in the environment of the terminal device. In addition, at least some embodiments provide an AoA estimate for the relevant Doppler components relative to the movement direction of the terminal device.

15     **[0042]**         Figure 2A illustrates a process according to embodiments for TDCP estimation based on virtual beamforming according to embodiments. The illustrated process of Figure 20     2A may be performed by an apparatus which may be a terminal device or a part thereof. The terminal device may be one of the terminal device 100, 102 of Figure 1. In the following, the entity performing the process is called simply an apparatus without loss of generality

25     **[0043]**         Referring to Figure 2A, the apparatus performs, in block 201, a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path. The plurality of radio measurements (which are performed at different locations due to the movement of the apparatus) correspond effectively to a radio measurement by a virtual array. The reference signals may be transmitted by the same access node. The performing of the plurality of radio measurements in block 201 may comprise determining (frequency domain sampled) channel transfer functions.

30     **[0044]**         The path of the terminal device may be a (substantially) linear path. In other words, it may be assumed that the terminal device is moving (substantially) along a straight

line. Additionally or alternatively, the radio measurements may be (substantially) periodical radio measurements. In other words, the transmission rate of the reference signals may be constant. The transmission rate  $r$  and the period  $\Delta t$  (equally called sample time) may follow the equation  $r = 1/\Delta t$ . Additionally or alternatively, the speed of the terminal device may  
 5 be assumed to be substantially constant. Thus, the plurality of radio measurements may form a substantially regular linear array of reference signal estimation points in space.

**[0045]** The reference signals measured in block 201 may be (identical) reference signals of the same type. Said type may be, for example, CSI RS or TRS.

**[0046]** The apparatus may perform the plurality of radio measurements in block 201  
 10 using a single antenna element and an antenna array (equally called beamforming array). The antenna array may be tunable or non-tunable, that is, tunability of the antenna array (and thus of the antenna reception beam direction or shape) is not required in most embodiments.

**[0047]** The spatially (and temporally) separated radio measurements performed by the moving apparatus effectively emulate the radio measurements performed by a stationary  
 15 (regular linear) antenna array. Thus, the plurality of radio measurements may be used for virtual beamforming, i.e., for implementing a virtual beamformer or a virtual (tunable) array. The measurements performed in block 201 may be called virtual array based (or virtual beamforming based) radio measurements. The virtual beamformer is characterized by a virtual beamforming vector  $\mathbf{w}(\theta) = [w_1 \ w_2 \ \dots \ w_N]^T = [e^{-i\theta} \ e^{-2i\theta} \ e^{-i\theta N}]^T$ , where  $e$  is  
 20 Euler's number,  $i$  is the imaginary unit,  $T$  is a transpose operation,  $\theta$  is a virtual beamsteering angle and  $N$  is the number of virtual antenna elements in the virtual array which is equal to the number of the plurality of radio measurements (or to the number of measurement time instances or the number of measurement locations).

**[0048]** For performing said virtual beamforming, the terminal device may store results  
 25 of the plurality of radio measurements (e.g., the frequency domain sampled channel transfer functions) into a memory. The results may be, for example, stored to a channel matrix  $\mathbf{H}(f, t + n\Delta t)$ ,  $f = 1 \dots F$ ,  $n = 1 \dots N$  maintained in the memory, where  $f$  is an index for frequency,  $t$  is time,  $F$  is the number of measured frequencies and  $n$  is an index for the virtual elements of the virtual array. The apparatus may proceed to the following step 202 as soon  
 30 as there is a sufficient number  $N$  of time (or spatial) estimates available.

**[0049]** The apparatus determines, in block 202, at least one time domain channel property based at least on linear combinations of results of the plurality of radio measurements. The at least one time domain channel property comprises at least one of (or an indication of at least one of) a Doppler frequency, an angle of arrival associated with a Doppler frequency (or with a Doppler component matching the Doppler frequency), a physical distance between successive radio measurements or a speed of the apparatus. The linear combinations of results of the plurality of radio measurements may correspond to different beamforming configurations of the virtual array. The at least one time domain channel property may be equally called at least one virtual array or virtual beamforming based time domain channel property as they may be derived using virtual beamforming concepts, as will be discussed in connection with Figure 2B.

**[0050]** In some embodiments, the apparatus may determine at least the speed of the apparatus (or at least one parameter derivable based on the speed of the apparatus) in block 202.

**[0051]** The apparatus transmits (or reports), in block 203, one or more time domain channel properties. The one or more time domain channel properties may comprise at least said at least one time domain channel property determined in block 202. The one or more time domain channel properties may be transmitted in block 203 to an access node. The one or more time domain channel properties may be transmitted to the access node directly or via one or more other nodes or devices.

**[0052]** In some embodiments, the one or more time domain channel properties may comprise at least the speed of the apparatus or at least one parameter derivable based on the speed of the apparatus (e.g., a Doppler frequency).

**[0053]** In some embodiments, the one or more virtual array based time domain channel properties may be transmitted in block 203 as uplink control information (UPC).

**[0054]** Figure 2B illustrates another process according to embodiments for TDCP estimation based on virtual beamforming according to embodiments. The illustrated process of Figure 2B may be performed by an apparatus which may be a terminal device or a part thereof. The terminal device may be one of the terminal device 100, 102 of Figure 1. In the following, the entity performing the process is called simply an apparatus without loss of generality

[0055] The process of Figure 2B corresponds to a large extent to the process of Figure 2B. Thus, any of the definitions and features described in connection with Figure 2A may apply, *mutatis mutandis*, also here.

5 [0056] Referring to Figure 2B, the apparatus performs, in block 211, a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path. Block 211 may correspond fully to block 201 of Figure 2A.

10 [0057] Blocks 212 to 213 provide one more detailed implementation of block 202 of Figure 2A. First, the apparatus derives (or generates), in block 212, a beamsteering pattern (being a beamsteering power or amplitude pattern) of the virtual array based on the plurality of radio measurements of the reference signals. Here, the beamsteering pattern of the virtual array may be defined to associate received power or amplitude (e.g., an average or maximum received power or amplitude) when virtual beamforming is employed using the virtual array with a beamsteering angle of the virtual array. In other words, the apparatus may perform  
15 virtual beamforming based on the results of the plurality of radio measurements of the reference signals to form a plurality of beamforming patterns corresponding to, respectively, to a plurality of different beamsteering angles and then combine the plurality of beamforming patterns to form a beamsteering pattern. The beamsteering pattern is a reception beamsteering pattern. In general, the reception beamsteering pattern defines (total)  
20 received power (or electric field amplitude) against the beamsteering angle. The beamsteering angle refers to the direction in which the main lobe of the antenna pattern (of, here, the virtual array) is steered.

[0058] The apparatus determines, in block 213, at least one time domain channel property based on the beamsteering pattern of the virtual array. Similar to Figure 2A, the at  
25 least one time domain channel property comprises at least one of (or an indication of at least one of) a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements (being equal to a spacing between virtual antenna elements of the virtual array) or a speed of the apparatus.

[0059] In some embodiments, the at least one time domain channel property  
30 comprises at least a speed of the apparatus (i.e., a speed of the terminal device). The determination of the speed is based on the principle that, in general, a smaller spacing between antenna elements of an antenna array leads to a wider main lobe of the beamsteering

pattern (i.e., a larger angular separation between main slopes of the beamsteering pattern). This applies also for virtual arrays and virtual beamforming. As here, in the case of the virtual array, the spacing of virtual antenna elements of the virtual array is determined by the speed of the apparatus, it is possible to determine the speed of the apparatus by looking at the (main) slopes of the beamsteering pattern. Thus, the determination of the speed of the apparatus in block 213 may be at least based on the values of the beamsteering angles corresponding to the two main slopes of the beamsteering pattern or the difference thereof.

**[0060]** In some embodiments, the determination of the speed of the apparatus in block 213 may be further (i.e., in addition to the beamsteering pattern or the values of the beamsteering angles corresponding to the two main slopes of the beamsteering pattern or the difference thereof) based on a wavelength ( $\lambda$ ) or radio frequency ( $f$ ) of the reference signals and a period ( $\Delta t$ ) of the plurality of radio measurements.

**[0061]** The apparatus may apply the virtual beamformers  $\mathbf{w}(\theta)$  for different virtual beamsteering angles  $\theta$  to the receive signals in the channel matrix  $\mathbf{H}$ , that is, the apparatus may calculate a beamsteering (power) pattern  $\mathbf{V}(\theta) = \mathbf{H} \mathbf{w}_n(\theta)$  by applying different virtual beamsteering angles  $\theta = -\theta_{\max} \cdots \Delta\theta \cdots \theta_{\max}$ . Due to the steep slopes of the beamsteering pattern powers over  $\theta$  this will allow us to identify the steep slopes as well as their (angular) distance, i.e.,  $\Delta\theta_{\text{slope}} = \theta_{\text{slope,max}} - \theta_{\text{slope,min}}$ , where  $\theta_{\text{slope,min}}$  and  $\theta_{\text{slope,max}}$  are beamsteering angles at which rising and falling slopes appear in the beamsteering pattern (or specifically in its main or predominant lobe). The parameters  $\Delta\theta_{\text{slope}}$ ,  $\theta_{\text{slope,min}}$  and  $\theta_{\text{slope,max}}$  are illustrated for one exemplary beamsteering pattern in Figure 5 to be discussed below in detail. The parameter  $\Delta\theta_{\text{slope}}$  is directly related to the physical distance between two adjacent (or equally successive) radio measurements  $d_v$  defined according to  $d_v = \frac{1}{2} d_\lambda \Delta\theta_{\text{slope}} / 360^\circ$ . Here,  $d_\lambda$  is the wavelength of the reference signals, and  $\Delta\theta_{\text{slope}}$  is assumed to be given in degrees. Knowing the distance  $d_v$ , the speed  $v$  of the apparatus may be calculated as  $v = d_v / \Delta t$ . Notably, this calculation is now independent of any Doppler frequency. It should be noted that, due the rather steep rise at  $\theta_{\text{slope,min}}$  and the sudden drop at  $\theta_{\text{slope,max}}$ , even small multipath component reflections are sufficient to identify the slopes in the beamforming pattern.

**[0062]** In some alternative embodiments, the apparatus may determine the speed of the apparatus by comparing the beamsteering pattern to a plurality of pre-defined reference

beamsteering patterns associated with a respective plurality of known reference speeds. For example, the apparatus may select a speed to equal a reference speed corresponding to the one of the plurality of reference beamsteering patterns most closely matching the beamsteering pattern. Alternative, the apparatus may carry out interpolation between two or more reference speeds corresponding to two or more reference beamsteering pattern most closely matching the beamsteering pattern to acquire the speed of the apparatus. The plurality of pre-defined beamsteering patterns may be maintained in a memory of the apparatus or in an external memory to which the apparatus has access (e.g., via a wireless communications network). The plurality of pre-defined beamsteering patterns associated with a respective plurality of known speeds may have been calculated previously (offline) by a computing device or system and subsequently communicated to the terminal device. The plurality of pre-defined beamsteering patterns and associated speeds may have been calculated using the methodology described above in connection with blocks 212, 213 for determining the beamsteering pattern and the speed of the apparatus. Each or at least some of the plurality of reference beamsteering patterns may be specific to a particular wavelength or radio frequency of the reference signals, a particular physical distance between adjacent radio measurements of the plurality of radio measurements and/or a particular period of the plurality of radio measurements.

**[0063]** In embodiments where the at least one time domain channel property determined in block 212 comprises the physical distance between successive radio measurements  $d_v$ , said physical distance may be determined based on the beamsteering pattern using the equation  $d_v = \frac{1}{2} d_\lambda \Delta\theta_{\text{slope}} / 360^\circ$  (as described above).

**[0064]** It should be noted that the speed of the apparatus (or any other receiver) is related to the Doppler frequency  $f_{\text{Doppler}}$  via the well-known equation:  $f_{\text{Doppler}} = \left(1 \pm \frac{v}{c}\right) f_0$ , where  $c$  is the speed of light in a medium (typically air) and  $f_0$  is the transmission (radio) frequency of the reference signals. Thus, the apparatus may calculate the Doppler frequency due to the movement of the apparatus (or the terminal device) based on the speed of the apparatus (or the terminal device).

**[0065]** In embodiments where the at least one time domain channel property determined in block 212 comprises a Doppler frequency and/or an angle of arrival associated with said Doppler frequency, the Doppler frequency and/or the angle of arrival may be

determined based on the beamsteering angles of the slopes ( $\theta_{\text{slope,min}}$  &  $\theta_{\text{slope,max}}$ ) in the beamsteering pattern and the beamsteering angles of the (Doppler) peaks of the beamsteering pattern. For example, if the beamsteering angles for the slopes and the peaks coincide (as in Figure 5), the angle of arrival is equal to  $\pm 180^\circ$ . As there is a fixed relation between the Doppler frequency and the angle of arrival for a particular speed of the apparatus (or the terminal device), it is possible to identify a deviation of the Doppler frequency based on the angle of arrival. For that purpose, the apparatus may form a virtual beam with a beamsteering angle matching to the direction of the estimated angle of arrival and estimate the Doppler frequency associated with the angle of arrival based on the associated time-domain signal.

10 If there is a difference, the apparatus may that the Doppler frequency is affected by a moving reflector (i.e., a moving object) in the environment of the apparatus.

**[0066]** In some embodiments, the apparatus may determine in block 213, based on results of the plurality of radio measurements and/or the beamsteering pattern, at least one time domain channel property comprising at least one of (or an indication of at least one of):

- 15
  - a strongest Doppler frequency (i.e., a Doppler frequency associated with a Doppler component having the highest amplitude or power),
  - an angle of arrival of the strongest Doppler frequency (i.e., an angle of arrival of a Doppler component having the highest amplitude or power),
  - one or more secondary Doppler frequencies,
- 20
  - one or more angles of arrival of the one or more secondary Doppler frequencies,
  - one or more Doppler frequencies associated with one or more moving objects in an environment of the apparatus or
  - one or more angles of arrival associated with the one or more moving objects in the environment of the apparatus.

25 Here, the secondary Doppler frequencies may be any Doppler frequencies other than the strongest Doppler frequencies. In some embodiments, said at least one time domain channel property determined based on the results of the plurality of radio measurements and/or the beamsteering pattern may comprise a frequency offset of a local oscillator of the apparatus (see discussion in connection with block 910 to 911 of Figure 9). In some embodiments, said

30 at least one time-domain channel property determined based on the results of the plurality of radio measurements and/or the beamsteering pattern may comprise a list of moving objects in the vicinity of the apparatus.

**[0067]** The apparatus transmits (or reports), in block 214, one or more time domain channel properties (e.g., to an access node). Block 214 may correspond to block 203 of Figure 2A.

**[0068]** In some embodiments, the one or more time domain channel properties transmitted in block 214 may further comprise said at least one further time domain channel property parameter as defined above or a subset thereof.

**[0069]** Figure 3 illustrates the basic concept of virtual beamforming for a non-line-of-sight (NLOS) channel between an access node 301 and a moving terminal device 302. Figure 3 shows two multipath components reflected from obstructions 303, 304. In the example of Figure 3, the terminal device performs radio measurements of reference signals at locations 1, 2, ...,  $L$ . The virtual receive beamformer is generated by applying a beamforming vector  $w(\theta) = e^{-i\theta n}$  with  $n = 1, 2, \dots, N$ . Here, the parameter  $\theta$  is the virtual beam steering angle. In Figure 3, the beam angle  $\Phi_{\text{beam}}$  is defined as  $\Phi_{\text{beam}} = \arcsin\left(\frac{d_\lambda}{d_v} \theta / 360^\circ\right)$ , where the beamsteering angle  $\theta$  is given in degrees.

**[0070]** Figure 4 illustrates operation of the virtual beamformer (i.e., virtual array used for beamforming). Top and bottom parts of Figure 4 show, respectively, two terminal devices moving at two different speeds  $v_1$  and  $v_2$ , where the upper terminal device is moving about half as fast as the lower terminal device (i.e.,  $v_1 = 0.5v_2$ ). Figure 4 illustrates the measurement positions of the two terminal devices with oval shapes. Correspondingly, and under the assumption of the same time  $\Delta t$  between two radio measurements (i.e., the same reference signal rate  $1/\Delta t$ ), the distance  $d_v$  between two measurement points will be for the faster (bottom) terminal device about twice that of the lower speed (top) terminal device. The virtual beamforming vector  $w(\theta) = e^{-i\theta n}$  defines the virtual beam steering angle  $\Phi_{\text{beam}}(\theta) = \arcsin(d_s/d_v)$ , where  $\theta$  is defined as  $\theta = d_s/d_\lambda 360^\circ$ , with  $d_\lambda$  being the wavelength of the reference signal. One challenge here is that there is an ambiguity between the beam reception angle  $\Phi_{\text{beam}}$  (i.e., the beamsteering angle) and the distance  $d_v$  which a terminal device is moving between two measurement points, i.e., between the receive angle of the strongest Doppler frequency and the mobile speed  $v$ . Therefore, it is not directly possible to infer the distance  $d_v$  – and then the terminal device velocity  $\hat{v}$  – from a known  $\theta$  mapped, e.g., to the strongest Doppler frequency component.

- [0071] Overcoming the problem described in the previous paragraph according to embodiments is based on taking advantage of the particular shape of the beamsteering (power) pattern and its properties, as previously described in connection with Figure 1. Namely, the measured beamsteering pattern of a virtual beamformer is known to have sharp edges (i.e., steep slopes) at either side of the (central) angle  $\theta = 0^\circ$ . Figure 5 illustrates one exemplary simulated beamsteering power pattern and the beamwidth  $\Delta\theta$  characterized by steep edges/slopes of the beamsteering pattern. The vertical axis in Figure 5 corresponds to (normalized) power in dB. In the illustrated example, the beamwidth  $\Delta\theta$  is equal to  $30^\circ$ . The beamsteering pattern is symmetric so that  $\theta_{\text{slope,min}} = -15^\circ$  and  $\theta_{\text{slope,max}} = +15^\circ$ .
- [0072] The reason for the sharp edges/steep slopes in the beamsteering pattern such as the one in Figure 5 may be understood based on Figure 6. Figure 6 illustrates a terminal device moving at speeds  $v_2$  and making radio measurements of reference signals at the locations indicated with oval shapes, similar to bottom part of Figure 4. However, in Figure 6, the beam reception angle has been increased to  $90^\circ$  so that the distance  $d_s$  is larger than the distance  $d_v$  between two adjacent measurement points. In such a case, the elements of the virtual precoder become  $d_s(n) = n(d_v + \Delta d_v)$ . This leads to increasing relative phase offsets for the virtual antenna elements of the virtual beamformer and, on average, to a destructive superposition of the signal components.
- [0073] As mostly only the shape and location of the (primary) slopes/edges of the beamsteering pattern is of interest in view of embodiments, in some embodiments, processing complexity may be reduced by oversampling the beamsteering pattern in the vicinity of said edges/slopes (i.e., close to beamsteering angles  $\theta_{\text{slope,min}}$  and  $\theta_{\text{slope,max}}$ ) compared to other sections of the beamsteering pattern. In other words, in the context of Figure 2B, the deriving of the beamsteering pattern of the virtual array in block 212 may comprise oversampling (primary) slopes of the beamsteering pattern relative to other sections of the beamsteering pattern.
- [0074] Figure 7 illustrates a process according to embodiments for use of (virtual array based) time domain channel property estimation results according to embodiments. The illustrated process of Figure 7 may be performed by an apparatus which may be an access node (e.g., a distributed or a non-distributed access node) or a part thereof. The access node may be the access node 104 of Figure 1. The process of Figure 7 corresponds to a process carried out at the access node side following the carrying out of the process of Figure 2A or

2B at the terminal device side. In the following, the entity performing the process is called simply an apparatus without loss of generality.

**[0075]** Referring to Figure 7, the apparatus receives, in block 701, one or more (virtual array based) time domain channel properties (TDCP) of a terminal device. The one or more  
5 time domain channel properties may be received from the terminal device itself. The one or more time domain channel properties comprise at least one of (or an indication of at least one of) a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device or a speed of the terminal device. In some embodiments, the one or more time domain  
10 channel properties may comprise at least a speed of the terminal device or at least one parameter derivable based on the speed of the terminal device. The transmission received in block 701 may correspond to the transmission of block 203 of Figure 2A or of block 204 of Figure 2B and thus any of the related features and definitions provided in connection with Figure 2A and/or 2B (and/or any of Figures 3 to 6) may apply here. For example, in some  
15 embodiments, the one or more time domain channel properties may be received in block 701 as uplink control information (UPC), similar to as discussed above.

**[0076]** Before the reception in block 701, the apparatus or some other access node may have transmitted periodically reference signals which may have been measured by the terminal device. The one or more time domain channel properties received in block 701 may  
20 have been determined based on these radio measurements, similar to as discussed, e.g., in connection with Figures 2A, 2B and 3 to 5.

**[0077]** The apparatus updates, in block 702, one or more radio resource management (RRM) algorithms based on the one or more time domain channel properties.

**[0078]** In some embodiments, the updating of the one or more RRM algorithms in  
25 block 702 may comprise configuring at least one of a CSI-RS, a TRS, an SRS or a DM-RS based on the one or more time domain channel properties (e.g., based on at least the speed of the terminal device or at least one speed-related parameter).

**[0079]** In some embodiments, the updating of the one or more RRM algorithms in block 702 may comprise defining (or preparing) a primary (default) pattern of the CSI-RS  
30 and a secondary (or fallback) pattern of the CSI-RS based on the one or more time domain channel properties (or at least some of them). Here, the defining of the primary and

secondary patterns may be based at least on the strongest Doppler frequency (or one or more strongest Doppler frequencies) determined based on the beamsteering pattern and/or the speed of the terminal device and/or the maximum terminal device mobility (i.e., the largest feasible speed value). Here, the primary pattern and the secondary pattern may be optimized  
5 (by the apparatus), respectively, for a current strongest Doppler frequency (i.e., the Doppler frequency associated with the highest amplitude/power) and for a pre-defined Doppler frequency corresponding to a highest feasible terminal device mobility. Thus, the secondary pattern may correspond to a worst case scenario of terminal device mobility, i.e., highest possible Doppler frequency for the given highest speed of the terminal device which is  
10 realistic in a typical communication scenario. Here, the highest Doppler frequency of the terminal device may not be the absolute highest Doppler frequency possible, but a Doppler frequency which is assumed to be exceeded very rarely (i.e., which has a certain pre-defined non-zero probability of occurring). The access may initially cause configuring, as a part of the execution of the one or more RRM algorithms, the terminal device to use the primary  
15 CSI-RS pattern. The access node may subsequently, also as a part of the execution of the one or more RRM algorithms, cause configuring the terminal device to use the secondary CSI-RS pattern in response to certain pre-defined conditions being satisfied. For example, the pre-defined conditions may correspond to detecting that the terminal device has changed its direction (of movement) or is affected by new reflection(s) potentially leading to the  
20 highest feasible Doppler frequency. This embodiment enables combining a low CSI-RS overhead to high reliability.

**[0080]** The apparatus transmits (or reports), in block 703, the one or more (virtual array based) time domain channel properties (or the at least some of them, e.g., at least the speed of the terminal device) to a computing system or device comprised in or connected to  
25 a core network. The computing system may be a (computing) cloud-based computing system.

**[0081]** In some embodiments, block 703 may be omitted.

**[0082]** In some embodiments, the apparatus may perform actions pertaining to blocks 701 to 702 with a plurality of terminal devices and report one or more (virtual array based)  
30 time domain channel properties of the plurality of terminal device at the same time to the computing device or system.

**[0083]** Figure 8 illustrates a process according to embodiments for use of (virtual array based) time domain channel properties estimation results according to embodiments. The illustrated process of Figure 8 may be performed by an apparatus which may be a computing device or system or a part thereof. The computing device or system may be comprised in or communicatively connected to a core network. The computing device or system may be the server node 112 of Figure 1. The computing device or system may be a cloud-based system. The process of Figure 8 corresponds to a process carried out by the computing device or system following the carrying out of the process of Figure 7 by the access node. In the following, the entity performing the process is called simply an apparatus without loss of generality.

**[0084]** Referring to Figure 8, the apparatus receives, in block 801, one or more time domain channel properties of one or more terminal devices. The one or more time domain channel properties may be received from an access node. The one or more time domain channel properties comprise, per terminal device, at least one of (or an indication of at least one of) a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by a terminal device or a speed of the terminal device. In general, the one or more (virtual array based) time domain channel properties may be defined as described in connection with Figure 2A or 2B.

**[0085]** The apparatus updates, in block 802, a digital twin of a wireless communication network (or a radio access network) comprising the one or more terminal devices based on the one or more time domain channel properties of the one or more terminal devices.

**[0086]** A digital twin in wireless communications may be defined, in general, as a virtual replica or representation of a physical wireless communication system or network. A digital twin may be a digital model that mimics the behavior, characteristics, and performance of the real-world wireless system. The digital twin in wireless communications may be used, for example, for gaining insights, optimizing performance of the wireless communication network and/or making more informed decisions regarding the operation and/or configuration of the wireless communication network.

**[0087]** In embodiments, the digital twin may comprise, for example, a data map of the physical environment of the wireless communication network, information on the current states of the terminal devices in the wireless communication network (e.g., movements of

the terminal device, speed of the terminal devices) and information on stationary and/or moving objects in the environment of the terminal devices.

**[0088]** In some embodiments, the digital twin may form a part of the metaverse.

**[0089]** The apparatus executes, in block 803, one or more RRM algorithms using the digital twin. For example, the executing of the one or more RRM algorithms may involve predicting optimal handover points for switching terminal devices from one radio cell to another. Additionally or alternatively, the executing of the one or more RRM algorithms in block 803 may comprise applying load balancing and/or multiuser (MU) scheduling over time based on terminal device to cell connections expected in the near future (i.e., within a certain pre-defined time). Channel estimation and prediction may benefit from known terminal device channel conditions at specific digital twin locations.

**[0090]** This prediction may be carried out in a more accurate manner compared to previous solutions thanks to the additional information provided by the one or more virtual array based time domain channel properties of the one or more terminal devices.

**[0091]** Figures 9 illustrates signalling between a terminal device, an access node and a computing device/system (e.g., cloud-based system). The terminal device may correspond to any of the terminal devices 100, 102 of Figure 1, the access node may correspond to the access node 104 of Figure 1 and/or the computing device/system may correspond to the server 112 of Figure 1.

**[0092]** The processes illustrated in Figure 9 correspond to a large extent to the processes discussed previously in connection with Figures 2A, 2B, 7 and 8. Any of the features and definitions provided in connection with any of Figures 2A, 2B and 3 to 8 may apply also here. The following discussion on Figure 9 is concentrated on the features not previously discussed in connection with Figures 2A, 2B and 3 to 8.

**[0093]** Referring to Figure 9, the computing device/system initially transmits, in message 901, a request for one or more (virtual array based) time domain channel properties of one or more terminal devices to the access node. Here, the one or more terminal devices may comprise at least the terminal device illustrated in Figure 9. Message 901 may not define the one or more time domain channel properties themselves but merely indicate that virtual array based time domain channel properties of one or more terminal devices are requested.

The time domain channel properties are called, in Figure 9, virtual beamforming time domain channel properties (VB TDCP).

**[0094]** The access node receives, in block 902, the request. In response to the reception of the request, the access node verifies, also in block 902, a capability of the terminal device (or, in general, of one or more terminal devices) for supporting virtual array based time domain channel properties (or the VB TDCP method in general). In other words, the access node verifies, in block 902, whether or not at least the terminal device supports the process for obtaining virtual array based (or virtual beamforming based) time domain channel properties (e.g., the process of Figure 2A or 2B) in general. The verifying in block 902 may be based on terminal device capability information on one or more terminal devices served by the access node maintained in a memory of the access node.

**[0095]** In response to the verification being successful at least for the illustrated terminal device, the access node transmits, in message 903, a (positive) acknowledgment back to the computing system or device. In response to the verification being unsuccessful for all terminal devices served by the access node, the access node may transmit a negative acknowledgment back to the computing system or device (not shown in Figure 9). In some alternative embodiments, no acknowledgment may be transmitted by the access node.

**[0096]** The positive acknowledgment is received, in block 904, by the computing device or system. Thereafter, the computing device/system transmits, in message 905, information defining the one or more (virtual array based) time domain channel properties to be employed. Here, the one or more time domain channel properties may comprise, for example, at least one of (or an indication of at least one of):

- a speed of the terminal device,
- a strongest Doppler frequency (i.e., a Doppler frequency associated with a Doppler component having the highest amplitude or power),
- an angle of arrival of the strongest Doppler frequency (i.e., an angle of arrival of a Doppler component having the highest amplitude or power),
- one or more secondary Doppler frequencies,
- one or more angles of arrival of the one or more secondary Doppler frequencies,
- one or more Doppler frequencies associated with one or more moving objects in an environment of the terminal device,

- one or more angles of arrival associated with the one or more moving objects in the environment of the terminal device,
- a frequency offset of a local oscillator of the terminal device or
- a list of moving objects in the vicinity of the terminal device.

5 In some embodiments, the one or more time domain channel properties may comprise at least the speed of the terminal device (or a parameter derived directly based thereon).

**[0097]** The access node receives, in block 906, the information defining the one or more time domain channel properties to be employed.

10 **[0098]** In some embodiments, messages 901, 905 may be combined into a single message.

**[0099]** The access node transmits, in message 907, a request (or a command) for configuring the terminal device to measure (or determine) and report the one or more time domain channel properties (defined in message 905). The terminal device receives, in block 908, the request and configures itself according to the request also in block 908.

15 **[00100]** The access node transmits, in messages 909, a plurality of reference signals (e.g., CSI-RSs) to the terminal device. The transmission in messages 909 is performed periodically. The transmission may be defined, e.g., as described in connection with block 201 of Figure 2A.

20 **[00101]** The terminal device measures, in block 910, the plurality of reference signals at a plurality of respective time instances while the terminal device is moving along a (linear) path, similar to block 201 of Figure 2A.

**[00102]** The terminal device determines, in block 911, a frequency offset of a local oscillator of the apparatus (relative to a frequency of the access node). To give a non-limiting example of a typical frequency offset value, the frequency offset may be, for example, 16  
25 Hz. Then, the terminal device applies, in block 912, a phase correction term to virtual antenna elements of the virtual array in the plurality of radio measurements to correct for the frequency offset. Namely, as the frequency offset causes phase drift over time, the different radio measurements occurring at different time instances suffer from a different degree of phase drift which may significantly reduce the accuracy of the radio measurement results. In  
30 a beamsteering pattern, this frequency offset/phase drift may be observed as an asymmetric

shape of the beamsteering pattern. Using the notation of Figure 5, this may mean that  $\theta_{\text{slope,min}} \neq -\theta_{\text{slope,max}}$  in contrast to the symmetrical case (such as the one shown in Figure 5) where  $\theta_{\text{slope,min}} = -\theta_{\text{slope,max}}$ .

5 **[00103]** In some embodiments, the determining of the frequency offset (block 911) may be performed earlier, e.g., before measuring the reference signals in block 910.

**[00104]** The terminal device determines, in block 913, one or more (virtual beamforming based) time domain channel properties based on the plurality of corrected radio measurements. This block may correspond to block 202 of Figure 2A or blocks 212 to 213 of Figure 2B (though with the frequency offset correction).

10 **[00105]** The following steps depicted in Figure 9 may also be performed as described in connection with Figures 2A, 2B, 7 and 8 and are thus not repeated here for brevity. Namely, elements 914 may correspond to block 203 of Figure 2A or block 214 of Figure 2B, elements 916 to 917 may correspond to blocks 701 to 703 of Figure 8 and elements 918 to 920 may correspond to blocks 801 to 803 of Figure 8.

15 **[00106]** In some embodiments, the frequency offset determined in block 911 may be included in the one or more time domain channel properties reported in message 914 back to the access node (and in message 917 to the computing system or device).

**[00107]** While Figure 9 shows only a single terminal device and single access node, in practice, the procedure of Figure 9 may be carried out for a plurality of access nodes each of which serves a plurality of terminal devices.

**[00108]** It should be noted that actions relating to blocks 903, 911, 912 may be considered optional. Thus, block 903 and/or blocks 911, 912 may be omitted in some embodiments. In some embodiments, the configuration functionalities described in connection with elements 901 to 908 may be omitted.

25 **[00109]** At least some embodiments provide the following technical advantages (or at least some of them):

- Accurate estimation of the speed of a terminal device independent of the terminal device trajectory relative to the access node.
- Accurate estimation of the AoA of the strongest Doppler frequencies. By combining the AoA of the Doppler component with the known speed of the terminal device and

30

with a direct estimate of the strongest Doppler frequency in the time domain, it is possible to distinguish Doppler domain components, which are due to the terminal device movement itself from those due to other moving objects in the environment.

- When used for RRM configurations, the virtual beamforming may be applied relatively seldomly (e.g., every second or minute) and based on cell specific CSI RRs (or other reference signals) so that the overall overhead can be moderate. One might even use or include tracking reference signals (TRS) for the estimation of the virtual beamformer power shape.
- Generally, the main processing may be done at the terminal device side so that the reporting over the uplink control information (UCI) channel can be very efficient. For example, only the speed of the terminal device, AoA of strongest and/or specific Doppler frequencies and AoA for some moving objects in the environment (if applicable) may be communicated to the access node.

**[00110]** The blocks, related functions, and information exchanges described above by means of Figures 2A, 2B and 3 to 9 are in no absolute chronological order, and some of them may be performed simultaneously or in an order differing from the given one. Other functions can also be executed between them or within them, and other information may be sent, and/or other rules applied. Some of the blocks or part of the blocks or one or more pieces of information can also be left out or replaced by a corresponding block or part of the block or one or more pieces of information.

**[00111]** Figure 10 provides an apparatus 1001 according to some embodiments. Specifically, the apparatus 1001 may be a terminal device or a part thereof or an access node or a part thereof or a computing device or system or a part thereof.

**[00112]** The apparatus 1001 may comprise one or more communication control circuitry 1020, such as at least one processor, and at least one memory 1040, including one or more algorithms 1031 (instructions), such as a computer program code (software) wherein the at least one memory and the computer program code (software) are configured, with the at least one processor, to cause the apparatus to carry out any one of the exemplified functionalities of the terminal device, the access node or the computing device or system described above. Said at least one memory 1040 may also comprise at least one database 1032.

**[00113]** When the one or more communication control circuitry 1020 comprises more than one processor, the apparatus 1001 may be a distributed device wherein processing of tasks takes place in more than one physical unit. Each of the at least one processor may comprise one or more processor cores. A processing core may comprise, for example, a Cortex-A10 processing core manufactured by ARM Holdings or a Zen processing core designed by Advanced Micro Devices Corporation. The one or more control circuitry 1020 may comprise at least one Qualcomm Snapdragon and/or Intel Atom processor. The one or more control circuitry 1020 may comprise at least one application-specific integrated circuit (ASIC). The one or more control circuitry 1020 may comprise at least one field-programmable gate array (FPGA).

**[00114]** Referring to Figure 10, the one or more communication control circuitry 1020 of the apparatus 1001 is configured to carry out functionalities described above by means of any of Figures 2A, 2B and 3 to 9 using one or more individual circuitries. It is also feasible to use specific integrated circuits, such as ASIC (Application Specific Integrated Circuit) or other components and devices for implementing the functionalities in accordance with different embodiments.

**[00115]** Referring to Figure 10, the apparatus 1001 may further comprise different interfaces 1010 such as one or more communication interfaces comprising hardware and/or software for realizing communication connectivity according to one or more communication protocols. Specifically when the apparatus 1001 is a terminal device, the one or more communication interfaces 1010 may comprise, for example, communication interfaces providing a connection at least to one or more access nodes. Specifically when the apparatus 1001 is an access node, the one or more communication interfaces 1010 may comprise, for example, communication interfaces providing a connection to one or more terminal devices and/or to one or more core network nodes and/or to the computing device or system. Specifically when the apparatus 1001 is a computing device or system, the one or more communication interfaces 1010 may comprise, for example, communication interfaces providing a connection to one or more access nodes. The one or more communication interfaces 1010 may comprise standard well-known components such as an amplifier, filter, frequency-converter, (de)modulator, and encoder/decoder circuitries, controlled by the corresponding controlling units, and one or more antennas. The apparatus 1001 may also comprise one or more user interfaces.

**[00116]** Referring to Figure 10, the memory 1040 may be implemented using any suitable data storage technology, such as semiconductor based memory devices, flash memory, magnetic memory devices and systems, optical memory devices and systems, fixed memory and removable memory.

5 **[00117]** As used in this application, the term ‘circuitry’ may refer to one or more or all of the following: (a) hardware-only circuit implementations, such as implementations in only analog and/or digital circuitry, and (b) combinations of hardware circuits and software (and/or firmware), such as (as applicable): (i) a combination of analog and/or digital hardware circuit(s) with soft-ware/firmware and (ii) any portions of hardware processor(s)  
10 with software, including digital signal processor(s), software, and memory(ies) that work together to cause an apparatus, such as a terminal device or an access node, to perform various functions, and (c) hardware circuit(s) and processor(s), such as a microprocessor(s) or a portion of a microprocessor(s), that requires software (e.g. firmware) for operation, but the software may not be present when it is not needed for operation. This definition of ‘circuitry’  
15 applies to all uses of this term in this application, including any claims. As a further example, as used in this application, the term ‘circuitry’ also covers an implementation of merely a hard-ware circuit or processor (or multiple processors) or a portion of a hardware circuit or processor and its (or their) accompanying software and/or firmware.

**[00118]** In an embodiment, at least some of the processes described in connection with  
20 Figures 2A, 2B and 3 to 9 may be carried out by an apparatus comprising corresponding means for carrying out at least some of the described processes. Some example means for carrying out the processes may include at least one of the following: detector, processor (including dual-core and multiple-core processors), digital signal processor, controller, receiver, transmitter, encoder, decoder, memory, RAM, ROM, software, firmware, display,  
25 user interface, display circuitry, user interface circuitry, user interface software, display software, circuit, filter (low-pass, high-pass, bandpass and/or bandstop), sensor, circuitry, inverter, capacitor, inductor, resistor, operational amplifier, diode and transistor. In an embodiment, the at least one processor, the memory, and the computer program code form processing means or comprises one or more computer program code portions for carrying  
30 out one or more operations according to any one of the embodiments of Figures 3 to 7 or operations thereof. In some embodiments, at least some of the processes may be implemented using discrete components.

**[00119]** According to an embodiment, there is provided an apparatus (being, e.g., a terminal device or a part thereof) comprising means for performing:

performing a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path;

5 determining at least one time domain channel property based at least on linear combinations of results of the plurality of radio measurements, wherein the at least one time domain channel property comprises an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements or a speed of the apparatus; and

10 transmitting one or more time domain channel properties, wherein the one or more time domain channel properties comprise the at least one time domain channel property.

**[00120]** According to an embodiment, there is provided an apparatus (being, e.g., an access node or a part thereof) comprising means for performing:

receiving one or more time domain channel properties of a terminal device, wherein the  
15 one or more time domain channel properties comprise an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device; and

updating one or more radio resource management algorithms based on the one or more  
20 time domain channel properties.

**[00121]** According to an embodiment, there is provided an apparatus (being, e.g., computing device or system or a part thereof) comprising means for performing:

receiving one or more time domain channel properties of one or more terminal devices, wherein the one or more time domain channel properties comprise, per terminal device, an  
25 indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device;

updating a digital twin of a wireless communications network comprising the one or more terminal devices based on the one or more time domain channel properties; and

30 executing one or more radio resource management algorithms using the digital twin.

**[00122]** Embodiments as described may also be carried out, fully or at least in part, in the form of a computer process defined by a computer program or portions thereof. Embodiments of the methods described in connection with Figures 2A, 2B and 3 to 9 may be carried out by executing at least one portion of a computer program comprising

corresponding instructions. The computer program may be provided as a computer readable medium comprising program instructions stored thereon or as a non-transitory computer readable medium comprising program instructions stored thereon. The computer program may be in source code form, object code form, or in some intermediate form, and it may be stored in some sort of carrier, which may be any entity or device capable of carrying the program. For example, the computer program may be stored on a computer program distribution medium readable by a computer or a processor. The computer program medium may be, for example but not limited to, a record medium, computer memory, read-only memory, electrical carrier signal, tele-communications signal, and software distribution package, for example. The computer program medium may be a non-transitory medium. Coding of software for carrying out the embodiments as shown and described is well within the scope of a person of ordinary skill in the art

**[00123]** The term “non-transitory”, as used herein, is a limitation of the medium itself (that is, tangible, not a signal) as opposed to a limitation on data storage persistency (for example, RAM vs. ROM).

**[00124]** According to an embodiment, there is provided a non-transitory computer readable medium having stored thereon instructions that, when executed by a computing device for a network device, cause the computing device to perform:

performing a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path;

determining at least one time domain channel property based at least on linear combinations of results of the plurality of radio measurements, wherein the at least one time domain channel property comprises an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements or a speed of the apparatus; and

transmitting one or more time domain channel properties, wherein the one or more time domain channel properties comprise the at least one time domain channel property.

**[00125]** According to an embodiment, there is provided a non-transitory computer readable medium having stored thereon instructions that, when executed by a computing device, cause the computing device to perform:

receiving one or more time domain channel properties of a terminal device, wherein the one or more time domain channel properties comprise an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical

distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device; and

updating one or more radio resource management algorithms based on the one or more time domain channel properties.

5 **[00126]** According to an embodiment, there is provided a non-transitory computer readable medium having stored thereon instructions that, when executed by a computing device, cause the computing device to perform:

receiving one or more time domain channel properties of one or more terminal devices, wherein the one or more time domain channel properties comprise, per terminal device, an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device;

updating a digital twin of a wireless communications network comprising the one or more terminal devices based on the one or more time domain channel properties; and

15 executing one or more radio resource management algorithms using the digital twin.

**[00127]** Reference throughout this specification to one embodiment or an embodiment means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present solution. Thus, appearances of the phrases “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily all referring to the same embodiment.

**[00128]** As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary. In addition, various embodiments and example of the present solution may be referred to herein along with alternatives for the various components thereof. It is understood that such embodiments, examples, and alternatives are not to be construed as de facto equivalents of one another, but are to be considered as separate and autonomous representations of the present solution.

**[00129]** Even though embodiments have been described above with reference to examples according to the accompanying drawings, it is clear that the embodiments are not restricted thereto but can be modified in several ways within the scope of the appended

claims. Therefore, all words and expressions should be interpreted broadly and they are intended to illustrate, not to restrict, the embodiment. It will be obvious to a person skilled in the art that, as technology advances, the inventive concept can be implemented in various ways. Further, it is clear to a person skilled in the art that the described embodiments may,  
5 but are not required to, be combined with other embodiments in various ways.

#### INDUSTRIAL APPLICABILITY

**[00130]** At least some embodiments find industrial application in wireless communications.

## CLAIMS

1. An apparatus comprising:  
5       at least one processor; and  
      at least one memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to perform:  
      performing a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path;  
10       determining at least one time domain channel property based at least on linear combinations of results of the plurality of radio measurements, wherein the at least one time domain channel property comprises an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements or a speed of the apparatus; and  
15       transmitting one or more time domain channel properties, wherein the one or more time domain channel properties comprise the at least one time domain channel property.
2. The apparatus of claim 1, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to transmit the one or more  
20   time domain channel properties to an access node.
3. The apparatus of claim 1 or 2, wherein the path is a substantially linear path and the plurality of radio measurements are substantially periodical radio measurements.
- 25       4. The apparatus according to any preceding claim, wherein the plurality of radio measurements correspond to a radio measurement by a virtual array, the determining of the at least one time domain channel property comprises:  
      deriving a beamsteering pattern of the virtual array based on the plurality of radio measurements of the reference signals, wherein the beamsteering pattern of the virtual array  
30       associates received power or amplitude when virtual beamforming is employed using the virtual array with a beamsteering angle of the virtual array; and  
      determining the at least one time domain channel property based at least on the beamsteering pattern of the virtual array.

5. The apparatus of claim 4, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to determine the at least one time domain channel property based on an angular distance between two slopes of the beamsteering pattern.

5

6. The apparatus of claim 5, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to determine the distance between the successive radio measurements further based on the wavelength or radio frequency of the reference signals; and/or

10 determine the speed of the apparatus further based on the wavelength or radio frequency of the reference signals and the period of the plurality of radio measurements.

7. The apparatus according to any of claims 4 to 6, wherein the deriving of the beamsteering pattern of the virtual array comprises:

15 oversampling slopes of the beamsteering pattern relative to other sections of the beamsteering pattern.

8. The apparatus according to any of claims 4 to 7, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to perform:

20

determining a frequency offset of a local oscillator of the apparatus; and

applying, before the deriving of the beamsteering pattern, a phase correction term to virtual antenna elements of the virtual array in the plurality of radio measurements to correct for the frequency offset causing a phase drift over time; and/or

25 including the frequency offset in the one or more time domain channel properties.

9. The apparatus according to any preceding claim, wherein the at least one time domain channel property comprises an indication of at least one of:

a strongest Doppler frequency,

30 an angle of arrival associated with the strongest Doppler frequency,

one or more secondary Doppler frequencies,

one or more angles of arrival associated with the one or more secondary Doppler frequencies,

one or more Doppler frequencies associated with one or more moving objects in an environment of the apparatus,

one or more angles of arrival associated with the one or more moving objects in the environment of the apparatus.

5

10. The apparatus according to any preceding claim, wherein the reference signals are identical signals of one of the following types: a channel state information reference signal and/or a tracking reference signal.

10

11. The apparatus according to any preceding claim, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to transmit the one or more time domain channel properties as uplink control information.

15

12. An apparatus comprising:

at least one processor; and

at least one memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to perform:

20

receiving one or more time domain channel properties of a terminal device, wherein the one or more time domain channel properties comprise an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device; and

updating one or more radio resource management algorithms based on the one or more time domain channel properties.

25

13. The apparatus of claim 12, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to perform:

transmitting the one or more time domain channel properties.

30

14. The apparatus of claim 13, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to

receive the one or more time domain channel properties from the terminal device and/or

transmit the one or more time domain channel properties to a computing system or device comprised in or connected to a core network.

15        15. The apparatus according to any of claims 12 to 14, wherein the updating of the one or more radio resource management algorithms comprises configuring at least one of a channel state information reference signal, a tracking reference signal, a sounding reference signal or a demodulation reference signal based on the one or more time domain channel properties.

10        16. The apparatus according to any of claims 12 to 15, wherein the updating of the one or more radio resource management algorithms comprises defining a primary pattern of the channel state information reference signal and a secondary pattern of the channel state information reference signal based on the one or more time domain channel properties, the primary pattern and the secondary pattern being optimized, respectively, for a current  
15        strongest Doppler frequency and for a pre-defined Doppler frequency corresponding to a highest feasible terminal device mobility.

17. The apparatus according to any of claims 12 to 16, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the  
20        apparatus to receive the one or more time domain channel properties as uplink control information.

18. An apparatus comprising:  
at least one processor; and  
25        at least one memory storing instructions that, when executed by the at least one processor, cause the apparatus at least to perform:

receiving one or more time domain channel properties of one or more terminal devices, wherein the one or more time domain channel properties comprise, per terminal device, an indication of at least one of a Doppler frequency, an angle of arrival associated  
30        with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device;

updating a digital twin of a wireless communications network comprising the one or more terminal devices based on the one or more time domain channel properties; and  
executing one or more radio resource management algorithms using the digital twin.

19. The apparatus of claim 18, wherein the at least one memory and the instructions are configured, with the at least one processor, to cause the apparatus to receive the one or more time domain channel properties from an access node.

5

20. A method comprising:

performing a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path;

determining at least one time domain channel property based at least on linear combinations of results of the plurality of radio measurements, wherein the at least one time domain channel property comprises an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements or a speed of the apparatus; and

transmitting one or more time domain channel properties, wherein the one or more time domain channel properties comprise the at least one time domain channel property.

21. A method comprising:

receiving one or more time domain channel properties of a terminal device, wherein the one or more time domain channel properties comprise an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device; and

updating one or more radio resource management algorithms based on the one or more time domain channel properties.

25

22. A method comprising:

receiving one or more time domain channel properties of one or more terminal devices, wherein the one or more time domain channel properties comprise, per terminal device, an indication of at least one of a Doppler frequency, an angle of arrival associated with a Doppler frequency, a physical distance between successive radio measurements performed by the terminal device while moving or a speed of the terminal device;

updating a digital twin of a wireless communications network comprising the one or more terminal devices based on the one or more time domain channel properties; and

executing one or more radio resource management algorithms using the digital twin.

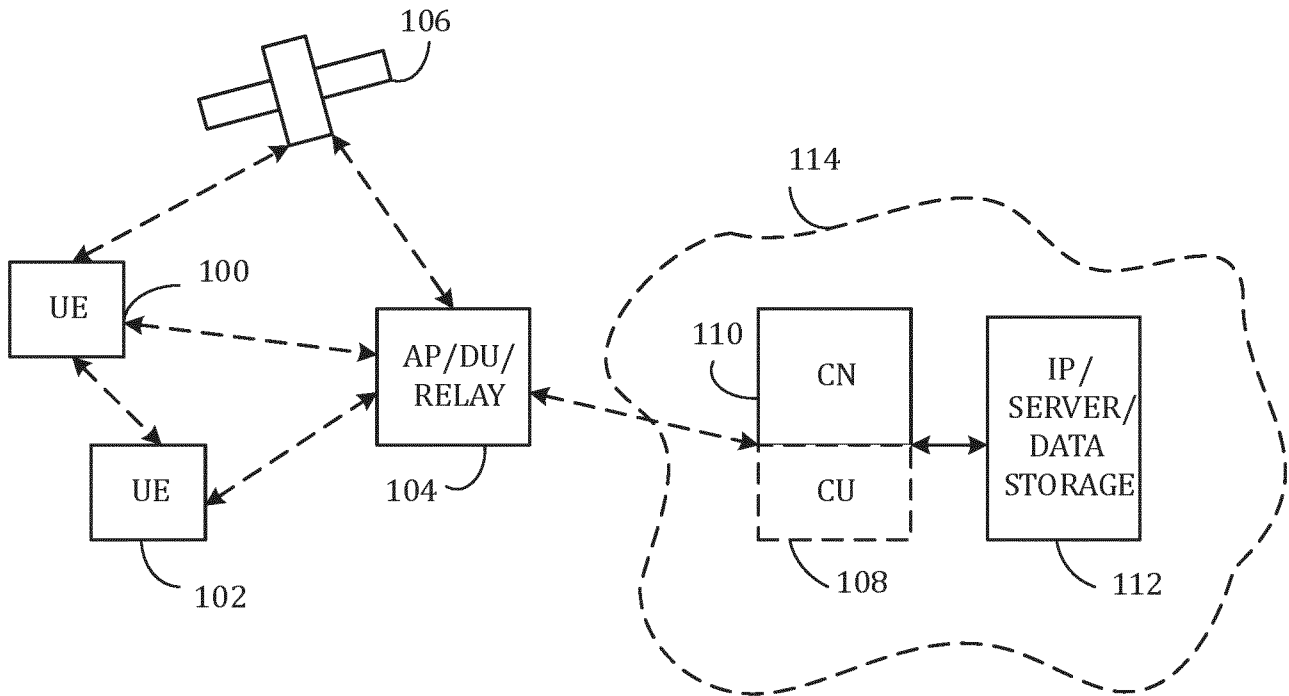


Fig. 1

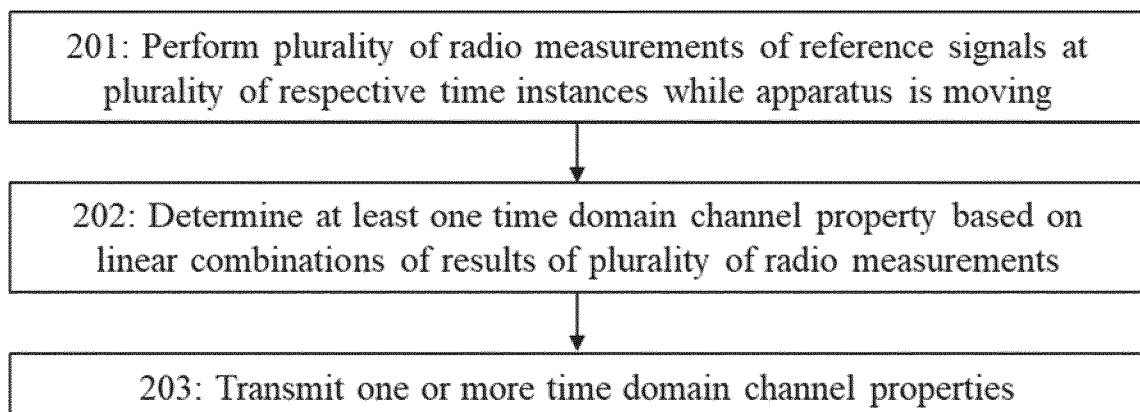


Fig. 2A

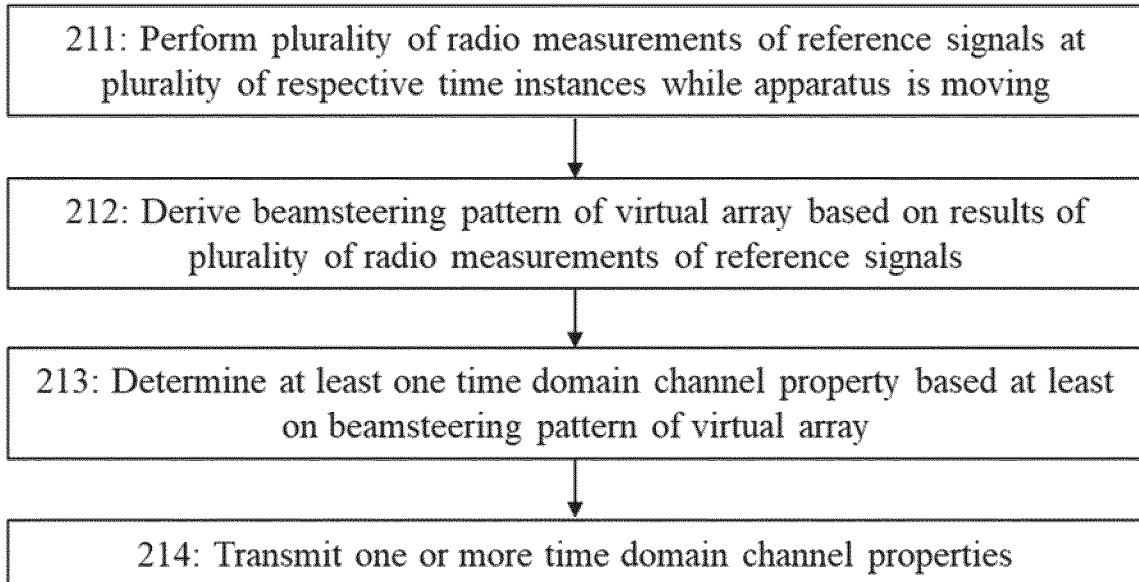


Fig. 2B

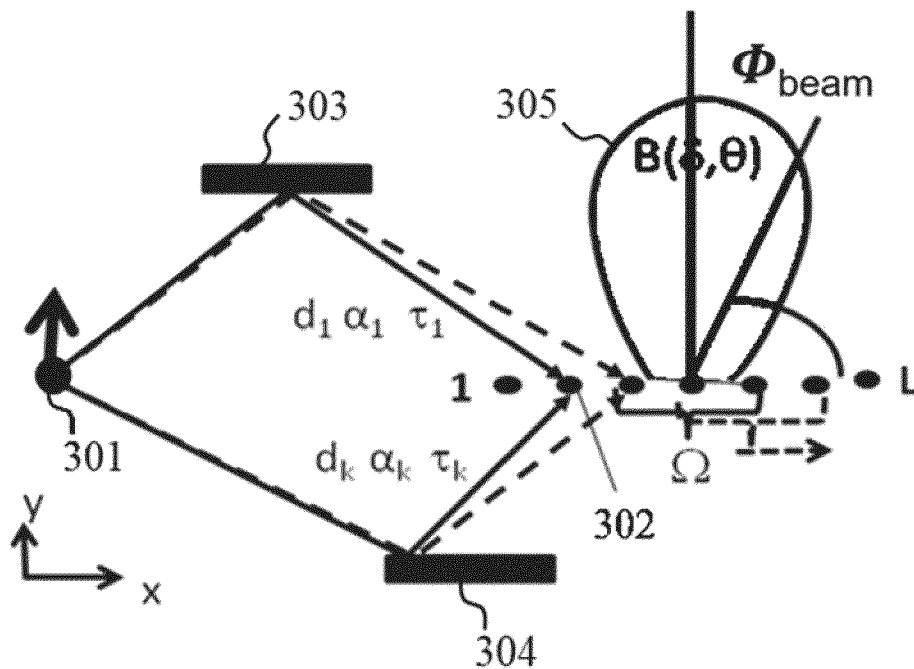


Fig. 3

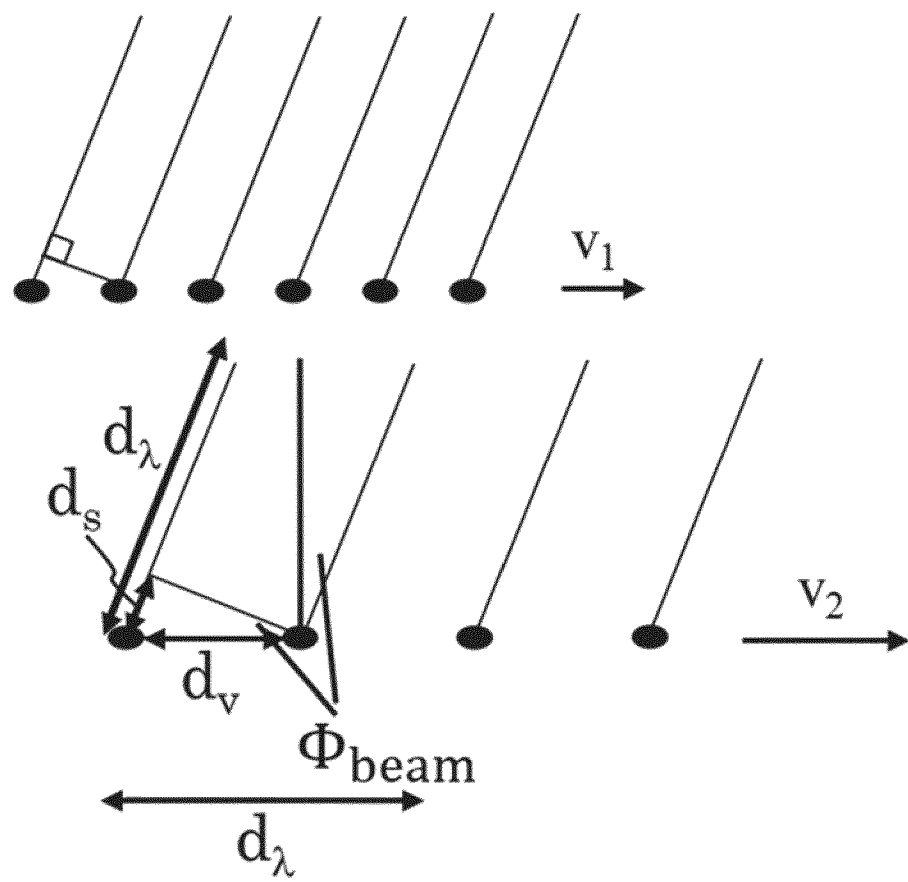


Fig. 4

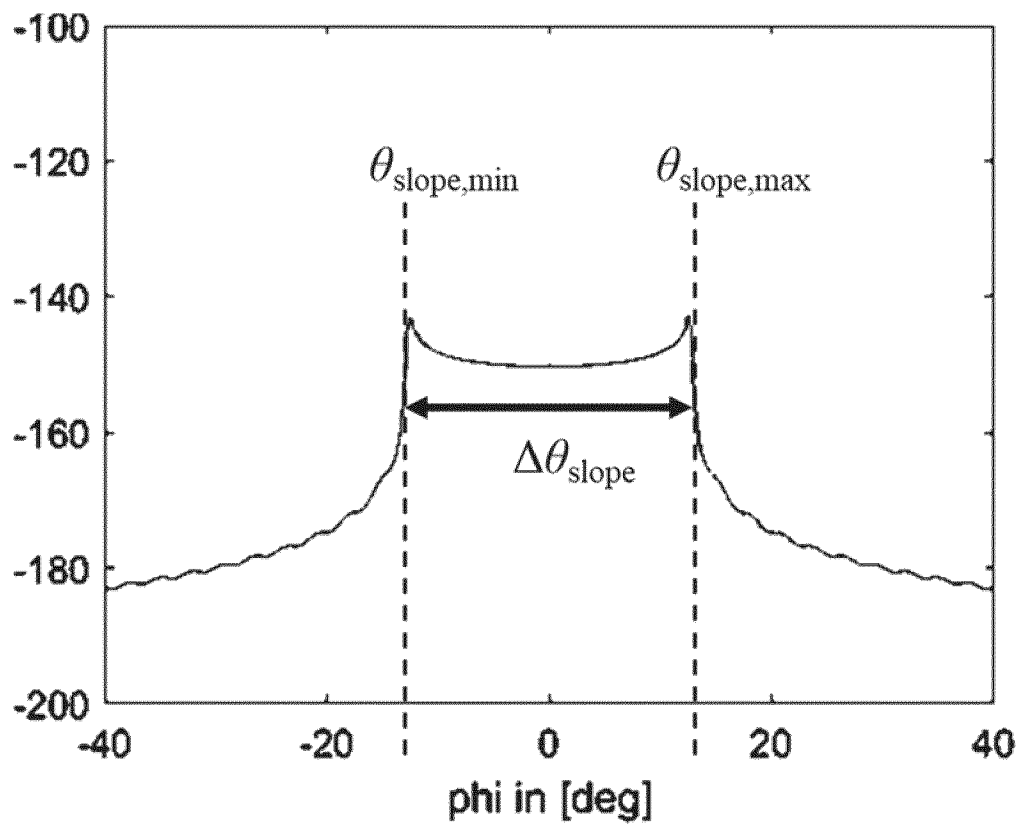


Fig. 5

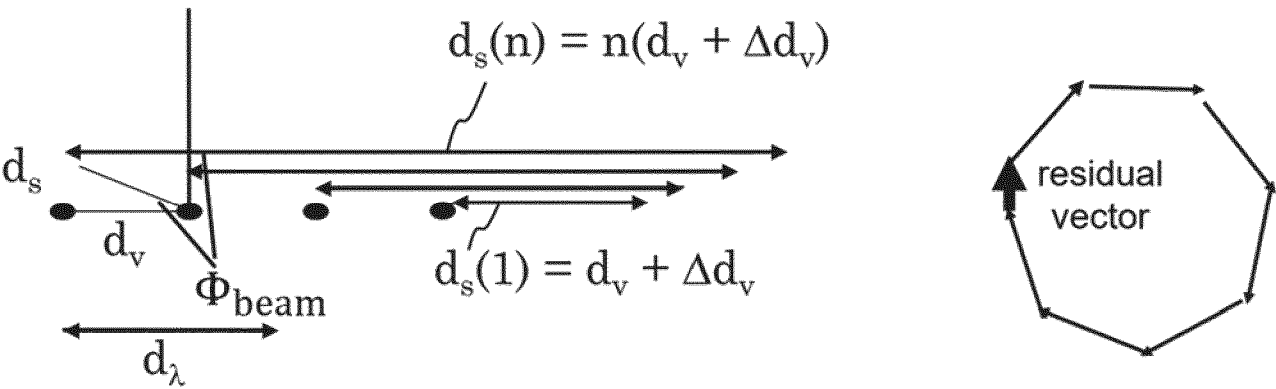


Fig. 6

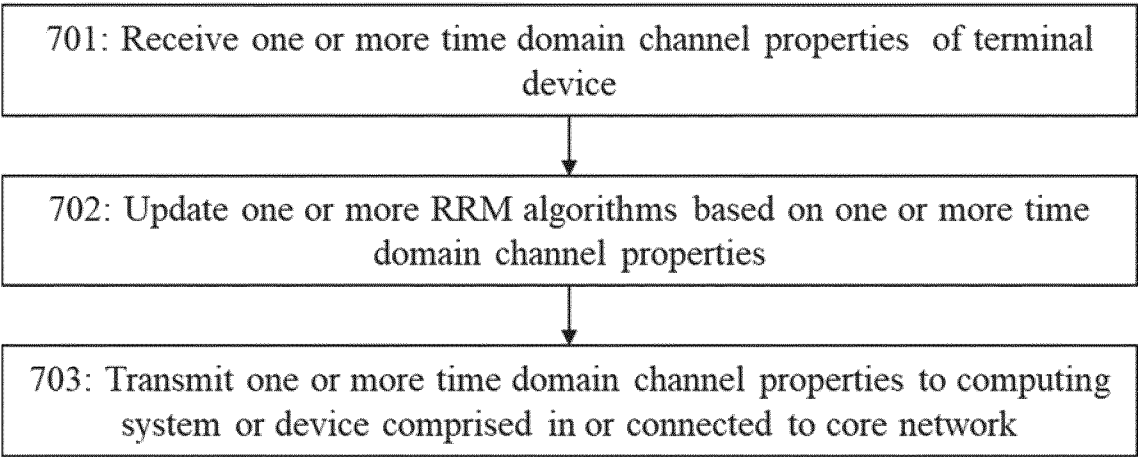


Fig. 7

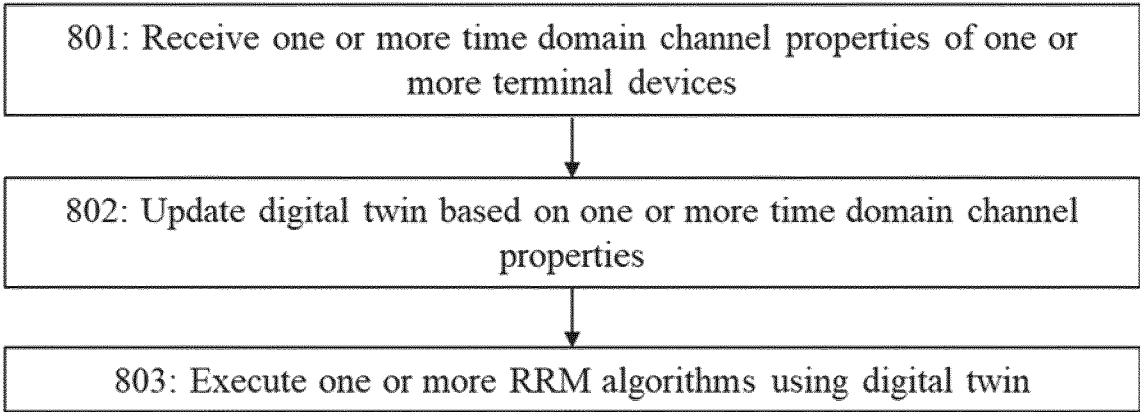


Fig. 8

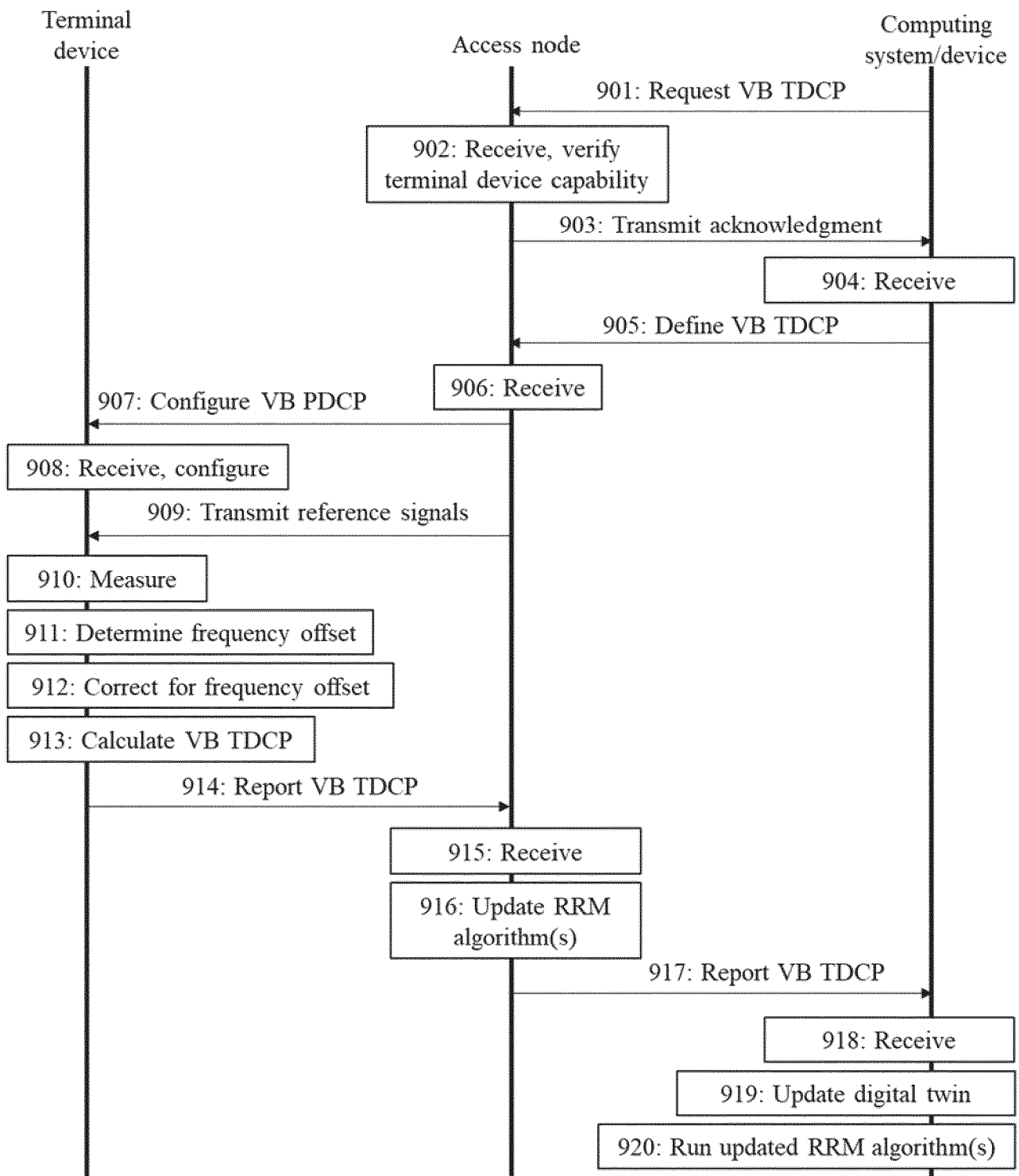


Fig. 9

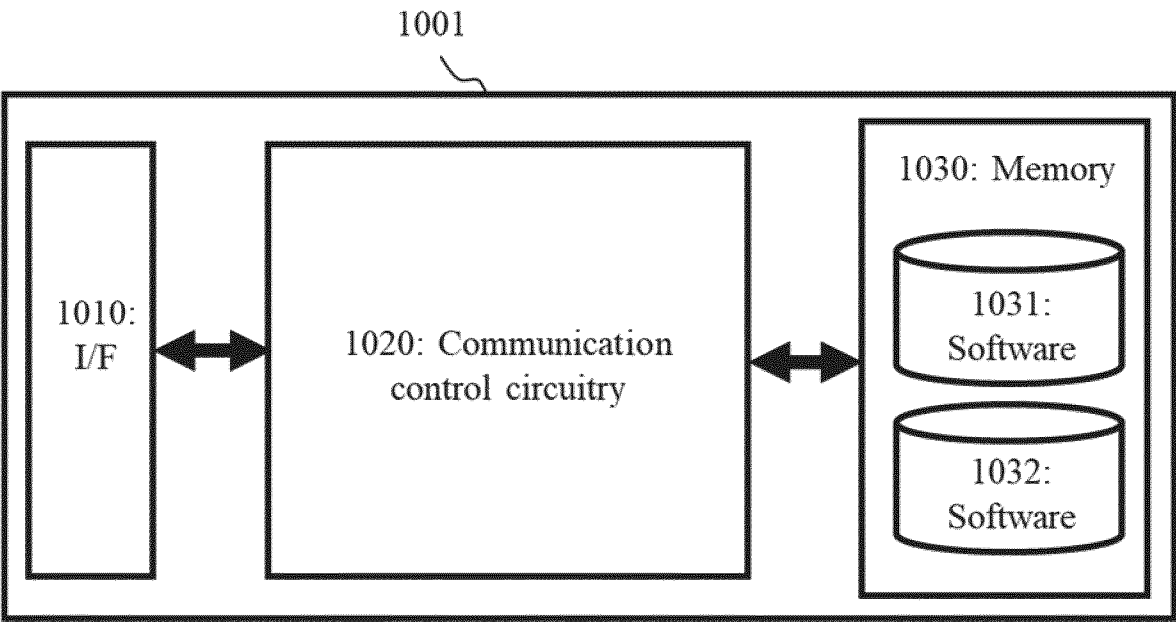


Fig. 10

## INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2024/061502

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>INV. H04B7/08 H04L5/00 H04L25/02<br>ADD.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                             |
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                             |
| <b>B. FIELDS SEARCHED</b><br>Minimum documentation searched (classification system followed by classification symbols)<br>H04B H04L<br><br>Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched<br><br>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br><br>EPO-Internal                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                             |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                             |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                                                             | Relevant to claim No.                                                       |
| X<br>A<br><br>X<br>A<br><br>X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | CN 106 788 804 A (UNIV BEIJING JIAOTONG)<br>31 May 2017 (2017-05-31)<br>paragraphs [0013] - [0023]; figure 5<br>-----<br>WO 2021/128751 A1 (HUAWEI TECH CO LTD<br>[CN]) 1 July 2021 (2021-07-01)<br>paragraphs [0118] - [0132], [0208]<br>-----<br>US 2016/205677 A1 (KIM KITAE [KR] ET AL)<br>14 July 2016 (2016-07-14)<br>paragraphs [0008] - [0010], [0083],<br>[0106], [0111] - [0113]; figures 16, 19<br>-----<br>- / - - | 1-3,<br>9-11,20<br>4-8<br><br>1-3,<br>9-11,20<br>4-8<br><br>12-19,<br>21,22 |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                             |
| <p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"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</p> <p>"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</p> <p>"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</p> <p>"&amp;" document member of the same patent family</p> |                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                             |
| Date of the actual completion of the international search<br><br>3 September 2024                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                | Date of mailing of the international search report<br><br>18/09/2024        |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                | Authorized officer<br><br>El Hajj Shehadeh, Y                               |

## INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/061502

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                       |
|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Relevant to claim No. |
| X                                                    | <p>QUALCOMM INCORPORATED: "CSI enhancements for high/medium UE velocities and Coherent-JT",<br/>3GPP DRAFT; R1-2207217, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE</p> <p>,<br/>vol. RAN WG1, no. Toulouse, France;<br/>20220822 - 20220826<br/>12 August 2022 (2022-08-12), XP052275154,<br/>Retrieved from the Internet:<br/>URL:https://ftp.3gpp.org/tsg_ran/WG1_RL1/TSGR1_110/Docs/R1-2207217.zip<br/>R1-2207217.docx<br/>[retrieved on 2022-08-12]<br/>section 4</p> <p>-----</p>                     | 12-19,<br>21,22       |
| A                                                    | <p>NVIDIA: "Evaluation of AI and ML for CSI feedback enhancement",<br/>3GPP DRAFT; R1-2305160, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE</p> <p>,<br/>vol. RAN WG1, no. Incheon, Korea; 20230522 - 20230526<br/>21 May 2023 (2023-05-21), XP052394108,<br/>Retrieved from the Internet:<br/>URL:https://ftp.3gpp.org/Meetings_3GPP_SYN C/RAN1/Docs/R1-2305160.zip R1-2305160<br/>Evaluation of AI and ML for CSI feedback enhancement.docx<br/>[retrieved on 2023-05-21]<br/>section 2.3</p> <p>-----</p> | 18,19,22              |
| A                                                    | <p>WO 2023/089593 A1 (ERICSSON TELEFON AB L M [SE]) 25 May 2023 (2023-05-25)<br/>paragraphs [0208] - [0213]; figure 16</p> <p>-----</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 18,19,22              |

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/EP2024/061502

## Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims;; it is covered by claims Nos.:

### Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

## FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-11, 20

Performing a plurality of radio measurements of reference signals at a plurality of respective time instances while the apparatus is moving along a path; and determining the at least one time domain channel property based at least on linear combinations of results of the plurality of radio measurements. The determining the at least one time domain channel property comprises: deriving a beamsteering pattern of the virtual array based on the plurality of radio measurements of the reference signals, wherein the plurality of radio measurements correspond to a radio measurement by a virtual array, and wherein the beamsteering pattern of the virtual array associates received power or amplitude when virtual beamforming is employed using the virtual array with a beamsteering angle of the virtual array; and determining the at least one time domain channel property based at least on the beamsteering pattern of the virtual array.

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2. claims: 12-19, 21, 22

Updating one or more radio resource management algorithms based on the one or more time domain channel properties. The updating comprises: defining a primary pattern of the channel state information reference signal and a secondary pattern of the channel state information reference signal based on the one or more time domain channel properties, the primary pattern and the secondary pattern being optimized, respectively, for a current strongest Doppler frequency and for a pre-defined Doppler frequency corresponding to a highest feasible terminal device mobility.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No  
PCT/EP2024/061502

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