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(71) Applicant: **TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)** [SE/SE]; SE-164 83 Stockholm (SE).

(72) Inventors: **KAROUT, Johnny**; Klaravägen 24, SE-417 29 Göteborg (SE). **FODOR, Gabor**; Astrakangatan 124, SE-165 52 Hässelby (SE). **SEIFI, Nima**; Oppegårdsstråket 5A 3tr, SE-191 60 Sollentuna (SE).

(74) Agent: **BOU FAICAL, Roger**; Ericsson AB, Patent Unit Kista RAN1, SE-164 80 Stockholm (SE).

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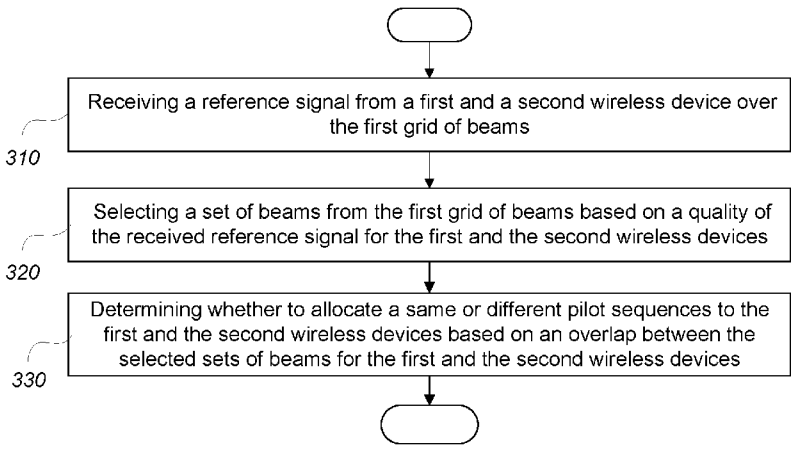


FIG. 3A

(57) Abstract: The disclosure relates to a method in a network node for determining reuse of pilot sequences for wireless devices of a wireless communication network. The network node provides wireless coverage through a grid of beams. The method comprises receiving (310) a reference signal from a first wireless device and a second wireless device respectively over the grid of beams, and selecting (320) a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices respectively. The method further comprises determining (330) whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

METHODS AND APPARATUS FOR PILOT SEQUENCE ALLOCATION

TECHNICAL FIELD

The disclosure generally relates to pilot sequence allocation, and particularly relates to methods and apparatus for determining reuse of pilot sequences when allocating the pilot sequences to different wireless devices.

BACKGROUND

The 3rd Generation Partnership Project (3GPP) is responsible for the standardization of Universal Mobile Telecommunication System (UMTS), and Long Term Evolution (LTE). LTE is also sometimes referred to as Evolved Universal Terrestrial Access Network (E-UTRAN). LTE is a technology for realizing high-speed packet-based communication that can reach high data rates both in the downlink and in the uplink, and is a next generation wireless communication system relative to UMTS. LTE brings significant improvements in capacity and performance over previous radio access technologies.

The Universal Terrestrial Radio Access Network (UTRAN) is the radio access network of a UMTS and E-UTRAN is the radio access network of an LTE system. In an UTRAN and an E-UTRAN, a wireless device, also called a User Equipment (UE), is wirelessly connected to a Radio Base Station (RBS) commonly referred to as a NodeB (NB) in UMTS, and as an evolved NodeB (eNB or eNodeB) in LTE. An RBS is a general term for a radio network node capable of transmitting radio signals to the UE and receiving signals transmitted by the UE. The area served by one or sometimes several RBSs may be referred to as a cell.

The ever increasing end-user demands are a significant challenge to the operators. Separating multiple UEs spatially by means of precoding and/or beamforming and serving them over the same time-frequency resources is one way to improve the performance of a wireless system. Multiple Input Multiple Output (MIMO) systems up to 8 or 16 antennas are supported by existing standards as so called MIMO transmission modes. However, the use of very large antenna arrays (also called massive or Full Dimension MIMO systems) in commercial cellular systems has only recently been proposed. 3GPP is currently working on the implications of supporting up to 64

transceiver units (TXRU) to serve many UEs or users simultaneously, commonly called multi-user MIMO, and to provide both energy efficiency and beamforming gain by creating narrow pencil beams when serving the scheduled UEs. See 3GPP TR: 36.897: Study on Elevation Beamforming/Full-Dimension, FD, MIMO for LTE: version 0.2.1.

The expectation of full dimension MIMO systems is to boost the spectral efficiency and capacity, as well as to provide a uniform user experience in a cell as opposed to large variations in the received UE bit rate or quality of service between cell center and cell edge areas in conventional MIMO systems. The underlying theory of full dimension MIMO systems is that under the assumption of perfect channel estimation, the vector channel of a served UE grows orthogonal to other UEs and thereby intra-cell and inter-cell interference can be virtually eliminated.

Downlink and uplink transmission methods rely on knowledge of the channel at the transmitting RBS, or, more precisely, the availability of estimates of the channels between the RBS antennas and the UEs' antenna(s) to which this RBS is transmitting information. This channel state information (CSI) is then used to "precode" the information intended for each of the UEs prior to transmission in such a way that each UE is able to decode the signals of its own interest. One of the most important challenges for successful implementation of full dimension MIMO systems is CSI acquisition. In full dimension MIMO systems the number of antennas at the network node (which may be in the order of 100-1000) is assumed to be much larger than the total number of the antennas of the served UEs (which may be in the order of 10-20). Therefore, to limit the CSI acquisition overhead and complexity, full dimension MIMO was originally proposed for time-division duplexing (TDD) systems in which the CSI acquisition overhead is proportional to the total number of antennas of all UEs rather than the number of antennas at the network node. CSI acquisition in TDD systems is done through transmission of uplink pilot sequences, i.e., known signature waveforms, by the UEs and the estimation of the channels based on the received pilot sequences by the RBS.

However, pilot sequences represent a limited resource. This is due to the fact that the length, in number of symbols, of pilot sequences is limited by the coherence time and bandwidth of the wireless channel. In turn, the number of orthogonal pilot sequences and thereby the number of separable UEs is limited by the length of the available pilot sequences. Consequently, when the number of antennas grows large, the number of

spatially separable UEs is not limited by the number of antennas but rather by the number of available orthogonal pilot sequences. Therefore, the pilot sequences must be reused which unavoidably leads to interference between identical pilot sequences allocated to different UEs. This interference in massive MIMO systems is known as the pilot contamination problem.

Figure 1 illustrates that if a pilot is reused in adjacent or neighboring cells, there may be interference or pilot contamination. As the same pilot is transmitted by two UEs 10a and 10b to respective RBSs 110a and 110b in adjacent cells, the pilot transmitted by one of the UEs 10b may be heard by the RBS 110a serving the other UE 10a. The same holds for the other UE, i.e., the pilot transmitted by UE 10a is heard by RBS 110b. However, the RBSs 110a and 110b cannot differentiate the pilots transmitted by the two UEs 10a and 10b.

In massive MIMO systems, the pilot contamination or pilot interference problem is known to degrade the quality of CSI at the RBS, which in turn degrades the performance in terms of actually achieved spectral efficiency, beam forming gains, and cell edge UE throughput.

A well-known prior art technique is to avoid pilot sequence reuse-1 in neighboring cells and thereby maintain UE separation in the code, frequency, or time domain. Pilot sequence reuse-1, also called full reuse, implies that all pilot sequences are reused in every cell, which should be compared to pilot sequence reuse-2, where the effective pilot sequence cell-reuse equals two, i.e. each pilot sequence is reused in every second cell or pilot sequence reuse-3, where the effective pilot sequence cell-reuse equals three, i.e. each pilot is reused in every third cell. The basic idea is similar to higher frequency reuse schemes known in GSM (Global System for Mobile Communications).

Another prior art technique proposes a solution to the pilot contamination problem based on multi-cell cooperation to achieve spatial separation between UEs who use the same pilot sequence. According to the prior art, the cooperating cells exchange long term CSI and perform a coordinated pilot sequence assignment or allocation to UEs. A long term CSI is essentially the average of the UE channels over some time window. The long term CSI is exchanged in the form of so called covariance matrices of UE vector channels. The coordinated pilot assignment to UEs is performed such that spatially well

separated UEs in neighboring cells are assigned identical pilot sequences. By spatial separation, the impact of pilot contamination is mitigated.

The problem with the state of the art multi-cell coordination based scheme is three-fold:

- Cooperating network nodes such as RBSs or wireless access points need to measure, estimate and subsequently exchange channel covariance matrices. The exchange of such covariance matrices is problematic, because the size of such matrices grows quadratically with the number of antennas, whereas the actual number of the matrices grows linearly with the number of UEs and the number of interfering RBSs or access points;
- The estimation or measurement of the covariance matrices is problematic due to the issue of long term changes related to the UE channels. Such long term changes may e.g. comprise long term geometry changes of the system caused by e.g. mobility, and environmental changes in the propagation conditions.
- The processing of the covariance matrices to determine the spatially well separated UEs imposes a computational burden on the network nodes participating in the cooperation due to the frequent updates and to the computational burden of determining pilot assignment based on the received covariance matrix information.

Hence, although in theory multi-cell cooperation can help mitigate pilot contamination and its effects, the fundamental input, i.e., user channel covariance matrix acquisition, exchange, and processing, renders the cooperation problematic in practical systems, for example due to the above problems. There is thus a need for improved methods for mitigating pilot contamination.

SUMMARY

One prior art technique proposes a solution to some of the above mentioned pilot contamination problems by using location information rather than covariance matrices in determining the appropriate pilot sequence allocations or assignments to UEs. This idea is based on the observation that long term channel characteristics of UEs can be related to the UEs' locations. Therefore, UE separation, i.e., an establishment of a set of spatially separable UEs, can be found based on UE locations. This solution eliminates the

scalability problem that is inherently present in a channel covariance based solution both in terms of number of antennas and number of UEs and network nodes. The idea is to relate the mean and the standard deviation of the angle of arrival (AoA) to UE location rather than to channel measurements and estimation. Therefore, pilot sequence allocation can be arranged such that UEs with least overlapping AoA may reuse identical pilot sequences.

However, such a location-based solution where the spatial UE separation is based on AoA support, is accurate mainly for line-of-sight (LoS) channels for which the multipath signal propagation is confined to a limited angular range around the LoS between the UE and the network node. In non-LoS channels, the signal might propagate through different paths with AoAs that are very different from the LoS AoA. In addition, the multipath propagation for UEs with overlapping AoA support might still happen through different clusters in the propagation channel. A cluster in the wireless channel is a group of multipath components that have similar delay and angular properties. In such a scenario, the separation of UEs based on AoA support does not provide a sufficiently good separation of UEs to determine pilot sequence reuse.

An object of embodiments is to alleviate or at least reduce one or more of the above mentioned problems, and to provide an alternative solution for mitigating pilot contamination. This object and others are achieved by methods and apparatus according to the independent claims, and by the embodiments according to the dependent claims.

According to a first aspect, a method for determining reuse of pilot sequences for wireless devices of a wireless communication network is provided. The method is performed in a first network node of the wireless communication network. The first network node provides wireless coverage through a first grid of beams. The method comprises receiving a reference signal from a first wireless device and a second wireless device respectively over the first grid of beams, and selecting a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices respectively. The method further comprises determining whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

According to a second aspect, a method for coordinating pilot sequence allocation to a first and a second wireless device served by a respective first and second network node of a wireless communication network is provided. The method is performed in a coordinating unit configured to communicate with the first and the second network nodes. The method comprises receiving information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes respectively. The sets of beams have been selected by the first and the second network nodes based on a quality of reference signals received from the first and the second wireless devices over first and second grids of beams providing wireless coverage for the respective first and second network nodes. The method also comprises determining overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes respectively, determining whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps, and determining at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences. The method also comprises providing information defining the determined at least one pilot sequence to the first and the second network nodes.

According to a third aspect, a first network node for determining reuse of pilot sequences for wireless devices of a wireless communication network is provided. The first network node is configured to provide wireless coverage through a first grid of beams. The first network node is further configured to receive a reference signal from a first wireless device and a second wireless device respectively over the first grid of beams, and select a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices respectively. The first network node is also configured to determine whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

According to a fourth aspect, a coordinating unit for coordinating pilot sequence allocation to a first and a second wireless device served by a respective first and second network node of a wireless communication network is provided. The coordinating unit is configured to communicate with the first and the second network nodes. The coordinating

unit is further configured to receive information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes respectively. The sets of beams have been selected by the first and the second network nodes based on a quality of reference signals received from the first and the second wireless devices over first and second grids of beams providing wireless coverage for the respective first and second network nodes. The coordinating unit is also configured to determine overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes respectively, determine whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps, and determine at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences. The coordinating unit is also configured to provide information defining the determined at least one pilot sequence to the first and the second network nodes.

According to further aspects, computer programs and computer program products corresponding to the aspects above are provided.

One advantage of embodiments is that they provide an improved determination of pilot sequence reuse for non-LoS channels. UEs that are determined to reuse a same pilot sequence according to embodiments may still have overlapping AoA supports.

Another advantage of embodiments is that the determining of possible UE separation and pilot sequence reuse may happen more frequently compared to the channel covariance and location based solutions described previously that are based on long-term channel knowledge. This allows for a faster adaptation to the channel changes and hence improved mitigation of pilot contamination.

Still another advantage is that the impact of pilot contamination in terms of channel estimation quality is mitigated in situations in which pilot contamination cannot be avoided.

Other objects, advantages and features of embodiments will be explained in the following detailed description when considered in conjunction with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The various aspects of embodiments disclosed herein, including particular features and advantages thereof, will be readily understood from the following detailed description and the accompanying drawings.

Figure 1 schematically illustrates an example of pilot contamination.

Figure 2 schematically illustrates a multiple antenna eNodeB that provides wireless coverage through a grid-of-beams (GoB) according to embodiments of the invention.

Figures 3a-c are flow charts schematically illustrating embodiments of the method performed by a network node according to various embodiments.

Figure 4 is a flow chart schematically illustrating embodiments of the method performed by a coordinating unit according to various embodiments.

Figure 5 is a signaling diagram schematically illustrating signaling between network nodes and wireless devices according to embodiments.

Figures 6a-d are block diagrams schematically illustrating embodiments of the network nodes and the coordinating unit according to various embodiments.

DETAILED DESCRIPTION

In the following, different aspects will be described in more detail with references to certain embodiments and to accompanying drawings. For purposes of explanation and not limitation, specific details are set forth, such as particular scenarios and techniques, in order to provide a thorough understanding of the different embodiments. However, other embodiments that depart from these specific details may also exist.

Furthermore, in some instances detailed descriptions of well-known methods, nodes, interfaces, circuits, and devices are omitted so as not obscure the description with unnecessary detail. Those skilled in the art will appreciate that the functions described may be implemented in one or in several nodes. Some or all of the functions described may be implemented using hardware circuitry, such as analog and/or discrete logic gates interconnected to perform a specialized function, or ASICs. Likewise, some or all of the functions may be implemented using software programs and data in conjunction with one or more digital microprocessors or general purpose computers. Where nodes that communicate using the air interface are described, it will be appreciated that those nodes also have suitable radio communications circuitry. Moreover, the technology can

additionally be considered to be embodied entirely within any form of computer-readable memory, including non-transitory embodiments such as solid-state memory, magnetic disk, or optical disk containing an appropriate set of computer instructions that would cause a processor to carry out the techniques described herein.

Hardware implementations of the present invention may include or encompass, without limitation, digital signal processor (DSP) hardware, a reduced instruction set processor, hardware (e.g., digital or analog) circuitry including but not limited to application specific integrated circuit(s) (ASIC) and/or field programmable gate array(s) (FPGA(s)), and where appropriate state machines capable of performing such functions.

In terms of computer implementation, a computer is generally understood to comprise one or more processors or one or more controllers, and the terms computer, processor, and controller may be employed interchangeably. When provided by a computer, processor, or controller, the functions may be provided by a single dedicated computer or processor or controller, by a single shared computer or processor or controller, or by a plurality of individual computers or processors or controllers, some of which may be shared or distributed. Moreover, the term “processor” or “controller” also refers to other hardware capable of performing such functions and/or executing software, such as the example hardware recited above.

Wireless devices, which are referred to as UE in 3GPP terminology, may comprise, for example, cellular telephones, personal digital assistants, smart phones, laptop computers, handheld computers, machine-type communication/machine-to-machine (MTC/M2M) devices or other devices with wireless communication capabilities. Wireless devices may refer to terminals that are installed in fixed configurations, such as in certain machine-to-machine applications, as well as to portable devices, or devices installed in motor vehicles.

Embodiments are described in a non-limiting general context in relation to a full dimension MIMO 3GPP LTE system, where an eNodeB provides wireless coverage for UEs through a fixed grid-of-beams (GoB), spanning the angular coverage of a cell, where each beam in the GoB is a Discrete Fourier Transform (DFT) beam. That the GoB is fixed means that it cannot can be dynamically changed for an eNodeB. However, it may be changed from time to time on a longer term if needed e.g. due to changes related to the coverage area of the eNodeB resulting from changes in deployment or cell planning.

However, embodiments of the invention may be applied to any other wireless communication system and network nodes with multiple antennas that provide wireless coverage through a GoB, such as network nodes in spatially multiplexing wireless systems including future evolved 3GPP LTE systems and local area wireless systems standardized by the IEEE. Furthermore, embodiments of the invention may be generalized to other GoB solutions than a DFT GoB. The essential characteristics of the beams in the GoB are that they should have a well-defined main beam pointing in a specified direction and a sufficiently low sidelobe level. The beams may for example be synthesized using some tapering. The beam pointing directions do not need to be regularly spaced in $\sin(\phi)$ space, but could be regularly spaced in, e.g., ϕ-space, or irregularly spaced. The angular span of the GoB should cover the desired angular coverage of the cell. The angular span of the GoB means that the GoB may be formed in azimuth, elevation, or both azimuth and elevation dimension, depending on the shape of the coverage area as well as the antenna array configuration. For example, with one-dimensional linear arrays, the GoB can be formed in one dimension, i.e., either the azimuth or the elevation dimension. But for a two-dimensional planar array, it is possible to form the GoB in both dimensions. Furthermore, if the eNodeB is installed on top of a rooftop, like in rural areas, the GoB may only be formed in the azimuth dimension. On the other hand, if the eNodeB is deployed in high rise scenarios like in Manhattan, the GoB may be formed in both the azimuth and the elevation dimension.

In multiple antenna systems, the number of degrees of freedom available in the angular domain, i.e., the number of dominant clusters, is much smaller than the number of antennas. This is especially true as the number of antennas grows, such as in full dimension MIMO systems, and at higher frequencies. In fact, a fundamental challenge in such systems is that while the actual communication happens in a low-dimensional angular domain, the signal processing algorithms including channel training and estimation needs to be done in a high-dimensional spatial domain or antenna domain. Beamspace MIMO is a technique in which the spatial domain MIMO channel is transformed into an angular domain MIMO using orthogonal spatial beams that serve as approximate channel eigenfunctions. The spatial MIMO channel refers to the channel measured at the physical antennas, while the angular MIMO channel indicates the channel measured at the virtual antenna ports obtained using the orthogonal spatial

beams. This enables to leverage the channel knowledge in the low-dimensional angular domain to design signal processing algorithms, at least in part, in the low-dimensional angular domain instead of the high-dimensional antenna domain.

The problems related to pilot contamination and to the determination of a pilot sequence reuse that minimizes pilot contamination in e.g. a full dimension MIMO system, is addressed by a solution where identical pilot sequences are allocated to UEs (i.e. a same pilot sequence is reused by the UEs) that are well-separated in the angular domain, rather than being separated in location or in terms of long term channel statistics. This is achieved by determining in which angular bin the dominant clusters are residing in the channel between the eNodeB and each UE in a fixed-beam system. Identical pilot sequences are then assigned to UEs in a neighboring cell or even within a same cell that have no or the least number of clusters in common. The angular domain channel knowledge is thus exploited instead of the location information knowledge or the channel covariance matrix when determining an appropriate pilot sequence allocation to UEs. This is advantageous due to that the number of dominant clusters in a full dimension MIMO channel is much smaller than the number of antennas. Therefore, the UE separation can be performed at the cluster level in the angular domain based on the knowledge of only the dominant clusters for the channel between the UE and the eNodeB rather than of the full channel vectors observed or estimated at the antennas. Consequently, pilot sequence allocation can be arranged such that UEs that have the least number of common dominant clusters reuse identical pilot sequences.

According to embodiments of the invention, the eNodeB uses a fixed GoB and measures e.g. the received signal strength over the beams in the GoB using a reference signal transmitted by the UEs. Each beam in the GoB could, e.g., be a DFT beam, where the beams of the GoB provides wireless coverage over a whole cell with one beam in each angle of the angular domain as schematically illustrated in **Figure 2**. Since non-LoS channels typically consist of a few dominating clusters, only information related to a subset of the beams in a DFT GoB for each UE is enough to acquire accurate CSI for determining the spatially separated UEs.

Figure 3a is a flowchart illustrating one embodiment of a method for determining reuse of pilot sequences for wireless devices of a wireless communication network. The method is performed in a first network node of the wireless communication network. The

first network node provides wireless coverage through a first GoB. The method comprises:

- 310: Receiving a reference signal from a first wireless device and a second wireless device respectively over the first GoB.
- 320: Selecting a set of beams from the first GoB based on a quality of the received reference signal for the first and the second wireless devices respectively. The selected beams are thus the beams that correspond to the dominant clusters of multipath components. Selecting the set of beams from the first GoB may comprise measuring a quality value of the reference signal received over the first GoB, and selecting the set of beams with a highest measured quality value. The set of beams may comprise a pre-defined number of beams, or all beams with a measured quality value above a third threshold.
- 330: Determining whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

In an example embodiment, the first network node may be an eNodeB of an LTE network. The eNodeB may be configured to communicate over multiple antennas and to provide wireless coverage to wireless devices also referred to as UEs through a DFT GoB. In this example embodiment, the eNodeB may receive reference signals transmitted by UEs both in a served cell and in non-served cells. Therefore, at this stage, reuse of the reference signal which is used to select the beams for determining the dominant clusters of multipath components should be kept at a minimum level. The reference signals may in one non-limiting example embodiment be sounding reference signals (SRS) in LTE. The reference signals will not be used for precoding, coherent demodulation, or link adaptation, but only for selection of beams with highest received power or quality. Hence, the reference signal may be transmitted relatively sparsely in time and frequency. The reference signals do not have to sufficiently sample the whole bandwidth, as the eNodeB in this phase is only interested in detecting in what angular bins or beams the dominant clusters are residing. The eNodeB does not need to determine the exact behavior of the channel in these angular bins. Therefore, more time-frequency resources are available for reference signal transmission which thus facilitates a minimum reference signal reuse. The reference signals may in embodiments even be transmitted in an aperiodic manner,

e.g., when UE positions change. The transmission of reference signals would in this case be triggered by various trigger signals, such as changes in Global Positioning System (GPS) coordinates detected by an application program, changes in the coordinates of a 3GPP positioning system detected by a network node and/or UE, or an action by a human user e.g. starting an application program.

In the example embodiment performed by the eNodeB in the LTE network, the eNodeB may use quality measurements of the received reference signal, e.g., reference signal received power (RSRP) or reference signal received quality (RSRQ) received over all beams of the DFT GoB, to select the beams, in 320, and thereby determine the dominant clusters of multipath components for a UE in terms of beams in the GoB with the highest received power or quality. As an alternative to using quality measurements of a reference signal transmitted by the UE, the eNodeB may select beams from the GoB based on channel quality information (CQI) reports received from UEs for each beam in the GoB.

As mentioned above, the eNodeB may perform beam selection, in 320, based on reference signal quality measurements for each UE. The eNodeB may select only the best beam, i.e. the beam over which the eNodeB has measured the highest signal quality of the received reference signal. Alternatively, the eNodeB may select a few, i.e. more than one, of the best beams. Recent prior art discloses that in non-LoS channels choosing the seven best beams out of 64 beams is sufficient to capture a good channel characteristics in full dimension MIMO systems. How many beams that are selected as the selected subset of the GoB, could however be a design parameter determined a priori or adaptively. An a priori decision of how many beams to select may be based on, e.g., the amount of available radio and baseband resources, or on the angular spread in the particular propagation environment that the eNodeB has been deployed in. It is in this case pre-defined how many beams that should be selected. An adaptive selection of the number of beams may for example be based on signal quality reports. The eNodeB may select all beams that have an RSRP or CQI which is higher than a predefined or configured threshold of X dB below the best beam. X may be a design parameter. Another way to describe the adaptive embodiment is to say that all beams with a measured quality value above a third threshold are selected. Furthermore, the number of beams that are selected may differ for different UEs.

In embodiments of the invention, the determining of whether to allocate a same or different pilot sequences, in 330, may comprise determining the overlap between the selected sets of beams for the first and the second wireless devices in number of common beams. Common beams may be beams generated using a same beamforming vector. The determining 330 may also comprise determining to allocate a same pilot sequence to the first and the second wireless devices when the determined overlap in number of common beams is less than or equal to a first threshold, and determining to allocate different pilot sequences to the first and the second wireless devices otherwise.

In another embodiment, common beams are not just beams generated using a same beamforming vector, but also beams for which a difference in the quality of the reference signal received from the respective first and second wireless devices is below a second threshold. For example, if the signal strength of the received signal for a first UE is weak compared to the signal strength of a second UE over the same beam, such that the difference in quality of the reference signal received from the two UEs is large (above the second threshold), that same beam is not counted as a "common beam" for the two UEs. Even though the beam has been selected based on reference signal quality measurements for the two UEs, there may still be a large quality difference for the two UEs.

In the example embodiment of the method performed in the eNodeB of the LTE network, the eNodeB may for a first UE find a corresponding second UE in the same cell or in a neighboring cell that has the least number of selected beams in common. When the overlap in number of beams between the selected sets of beams for the two UEs is minimal, these two UEs may be assigned the same pilot sequence to be used for CSI measurements and for channel estimation. Ideally, the overlap in number of beams is zero, and the first threshold mentioned above is thus zero. However, a higher threshold for the overlap than zero is also possible.

Assuming each UE has a single antenna, the angular channel vector in beamspace for *N* beams is given by

$$\mathbf{h}_{kj}^{\mathrm{BS}} = \mathrm{h}_{kj}\mathbf{W} \tag{1}$$

where $\mathbf{h}_{kj}^{\mathrm{BS}}$ is the 1x*N* channel vector of UE *k* from eNodeB *j* in the beamspace, $\mathbf{W} = [\boldsymbol{w}_1\ \boldsymbol{w}_2\ \ldots\ \boldsymbol{w}_N]$ is an *M*x*N* beamforming matrix with $\boldsymbol{w}_n$ indicating

the *n*:th beamforming vector of size *Mx1* where *M* is the number of eNodeB antennas, and $\mathbf{h}_{kj}$ is the 1x*M* channel vector of UE *k* from eNodeB *j* in antenna space. The beamforming matrix can for example be a DFT matrix. The purpose of the transmission of the first reference signal by the UE *k* is to obtain an estimate of $\left|\left(\mathbf{h}_{kj}^{\mathrm{BS}}\right)_n\right|^2$ *or* $\left|\left(\mathbf{h}_{kj}^{\mathrm{BS}}\right)_n\right|, n = 1, \ldots, N, \forall j$, in order to select the beam(s) with the highest channel power, quality, or amplitude for UE *k*.

Let $\mathcal{N}_{\mathrm{kj}} \subset \{1,2, \ldots, \mathrm{N}\}$ denote the set of selected beams by eNodeB *j* for UE *k*. Then for each UE *k* the pilot sequence allocation problem for eNodeB *j* boils down to finding UE l such that $\mathcal{N}_{\mathrm{lj}}$ and $\mathcal{N}_{\mathrm{kj}}$ have a minimum - ideally zero - number of elements in common.

In the embodiments of the method for determining reuse of pilot sequences described above with reference to **Figure 3a**, the first and the second wireless devices may be served by the same first network node in a same cell or in different cells, or they may be served by different network nodes. In the latter case, the different serving network nodes need to coordinate the pilot sequence allocation. The pilot sequence allocation coordination may be performed centralized in a coordinating unit, node, or entity (see **Figure 3c**). In such an embodiment, all serving network nodes report their selected beams for wireless devices in the network to the coordinating unit, and the coordinating unit handles the determining of overlaps between the received sets of beams. Based on the determined overlaps, the coordinating unit may then determine what pilot sequences to allocate to the wireless devices, and will send information related to the determined allocation to the respective serving network nodes. Alternatively, the pilot sequence allocation coordination may be performed in a distributed manner (see **Figure 3b**). In the distributed case, serving network nodes may mutually exchange information about the selected beams for wireless devices in the network, such that the individual network nodes may allocate pilot sequences to the wireless devices that they serve in an accurate way.

Figure 3b is a flowchart illustrating an embodiment of the method performed in the first network node, according to the distributed coordination of pilot sequence allocation. The first wireless device is in this embodiment served by the first network node and the second wireless device is served by a second network node providing wireless coverage

through a second GoB. The second GoB may be the same as the first GoB, or it may be different. The method may comprise:

- 310: Receiving a reference signal from a first wireless device and a second wireless device respectively over the first GoB.
- 320: Selecting a set of beams from the first GoB based on a quality of the received reference signal for the first and the second wireless devices respectively. Selecting the set of beams from the first GoB may comprise measuring a quality value of the reference signal received over the first GoB, and selecting the set of beams with a highest measured quality value. The set of beams may comprise a pre-defined number of beams, or all beams with a measured quality value above a third threshold.
- 325: Receiving information defining sets of beams for the first and the second wireless devices as selected from the second GoB by the second network node, wherein the information is received from the second network node.
- 330: Determining whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices, and also on an overlap between the sets of beams defined by the received information, in 325.

Figure 5 is a signaling diagram illustrating an example embodiment for the distributed case. The signaling diagram illustrates the necessary information exchange between eNodeBs (referred to as BS1 and BS2) in a multi-cell system, in order to determine when to reuse a pilot sequence. A first eNodeB, BS1, serves two wireless devices UE1 and UE2, while a second eNodeB, BS2, serves a third wireless device UE3. In S10, S11, and S12, the three wireless devices UE1, UE2, and UE3 broadcast their reference signals. The quality of the reference signals are received (step 310 in **Figure 3b**) and measured by the two eNodeBs, BS1 and BS2, over their respective GoB. The measurements are used to select a set of beams (step 320 in **Figure 3b**) for each of the wireless devices, and to update a table with the selected sets of beams, in 510 and 511 respectively. In S20, the table information is exchanged between the eNodeBs (step 325 in **Figure 3b**). In this way, the eNodeBs BS1 and BS2 may – in a coordinated way – determine which wireless devices that can reuse a same pilot sequence (step 330 in **Figure 3b**). In this case, it is determined that the wireless devices UE1 and UE3 can be allocated a same pilot sequence (Pilot 1), while wireless device UE2 is allocated a

different one (Pilot 2) (step 340 in **Figure 3b**). The UEs are informed about the allocated pilot sequence in S30, S31, and S33 respectively (step 350 in **Figure 3b**).

Figure 3c is a flowchart illustrating an embodiment of the method performed in the first network node, according to the centralized coordination of pilot sequence allocation. The first wireless device is in this embodiment served by the first network node and the second wireless device is served by a second network node providing wireless coverage through a second GoB. The method may comprise:

- 310: Receiving a reference signal from a first wireless device and a second wireless device respectively over the first GoB.
- 320: Selecting a set of beams from the first GoB based on a quality of the received reference signal for the first and the second wireless devices respectively. Selecting the set of beams from the first GoB may comprise measuring a quality value of the reference signal received over the first GoB, and selecting the set of beams with a highest measured quality value. The set of beams may comprise a pre-defined number of beams, or all beams with a measured quality value above a third threshold.
- 330: Determining whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices. The determining comprises:
    - 331: Providing information defining the selected sets of beams to a coordinating unit for enabling coordination of pilot sequence allocation to wireless devices served by the first and the second network nodes based on the overlap between the selected sets of beams.
    - 332: Receiving information defining a pilot sequence to allocate to the first wireless device from the coordinating unit, and information indicating whether the same pilot sequence is allocated to the second wireless device, in response to the provided information.

In any of the embodiments described above with reference to **Figures 3a-c**, (although only illustrated in **Figure 3b**), the method may further comprise:

- 340: Allocating a pilot sequence to at least one of the first and the second wireless devices in accordance with the determining in 330 of whether to allocate the same or different pilot sequences to the first and the second wireless devices, and

- 350: Transmitting information defining the allocated pilot sequence to at least one of the first and the second wireless devices.

The method may optionally further comprise sending information defining the pilot sequence allocated to the first wireless device to the second network node serving the second wireless device. This embodiment is only relevant for the case when the first and the second wireless devices are served by different first and second network nodes respectively. In the distributed case described with reference to **Figure 3b**, the involved serving network nodes may run the same methods and may thus come to a same decision regarding whether to allocate the same pilot sequence to two wireless devices. However, one of the network nodes may be taking the decision on which one of the available pilot sequences that should be used, and it may thus be necessary to inform the other network node about what pilot sequence to use.

The method may optionally further comprise the following, when it is determined to allocate a same pilot sequence to the first and the second wireless devices:

- 360: Measuring the pilot sequence allocated to the first wireless device over the set of beams selected from the first GoB for the first wireless device excluding beams that correspond to the overlap.
- 370: Estimating a channel to the first wireless device using the measurement of the pilot sequence.

When it is determined to allocate different pilot sequences to the first and the second wireless devices, there is no need to exclude beams that correspond to the overlap, as there is no risk for pilot contamination.

As already briefly mentioned above, **Figure 2** is a schematic illustration of a multiple antenna eNodeB that provides wireless coverage through a GoB with DFT beams $\{w_1 - w_{14}\}$ according to embodiments of the invention. Three UEs, UE1, UE2, and UE3, are also illustrated. Based on RSRP measurements of reference signals transmitted by all three UEs over the beams of the GoB, the eNodeB selects a set of beams corresponding to the dominant clusters of multipath components for the channel to each UE. In the example embodiment illustrated in **Figure 2**, the selected set of beams comprises three beams. However, the set may comprise more or fewer beams as already mentioned above, and may in one example comprise only one beam.

In the example embodiment illustrated in **Figure 2,** it can be observed that $\{w_3, w_6, w_9\}$, $\{w_9, w_{11}, w_{13}\}$, and $\{w_5, w_{11}, w_{13}\}$ are the selected sets of beams corresponding to the dominant clusters for UE 1, UE 2, and UE 3, respectively. In order to determine whether any of the three UEs may reuse a same pilot sequence, the overlap between the selected sets of beams are determined for the different UEs. The result is that UE 1 and UE 2 have one beam in common $\{w_9\}$ in the corresponding selected sets, while UE 2 and UE 3 have two beams in common $\{w_{11}, w_{13}\}$. UE 1 and UE 3, however, have no beams in common, despite the significant overlap of their AoAs. It may be assumed that the other beams in the channel between the eNodeB and each of the UEs are much weaker than the respective selected three beams, and it is therefore reasonable to determine to allocate a same pilot sequence to UE 1 and UE 3.

However, if the eNodeB determines to allocate a same pilot sequence to UE1 and UE2 in **Figure 2** as they have just one beam in common, i.e. beam $\{w_9\}$, the eNodeB will subsequently measure the allocated pilot sequence to estimate a channel to the UE that the eNodeB is serving, e.g. UE1. When estimating the channel to UE1, the eNodeB may choose to not measure over the beams corresponding to the selected beams for UE2, i.e. beam $\{w_9\}$. This is due to that this beam contains significant contributions from the pilot sequence of UE2 which may e.g. be served by a neighboring cell. It may thus be beneficial to exclude this beam when estimating the channel to UE1 as it otherwise may contribute to a major part of the pilot contamination (caused by UE2 in Figure 2). This is also described in step 360 illustrated in **Figure 3b**. However, it may not always be optimal to exclude the common beam when estimating the channel. Excluding the common beam may introduce a CSI inaccuracy, while including the common beam introduces some level of pilot contamination. The decision on whether to exclude or include the common beam for channel estimation is thus a trade-off between CSI accuracy and reduced pilot contamination. The decision on whether to exclude the common beam may be based on the relative power of the common beam for UE1 and UE2. For example, if the power of channel of UE2 on the common beam is much weaker than that of UE1, the common beam may be included when doing the channel measurements for the channel to UE1. As described previously, a beam may not be regarded as a common beam if the difference in quality of the reference signal received from the two UEs is large, which is another way of implementing the trade-off between pilot contamination and CSI inaccuracy. Furthermore,

it may not be the best choice to reuse pilot sequences between UE1 and UE2 if the beam they have in common, i.e. beam $\{w_9\}$, is the strongest beam among the selected beams for UE1.

Assuming that the eNodeB determines to allocate a same pilot sequence to UE1 and UE3 in **Figure 2** instead, the eNodeB measures the actual channel using the pilot sequence sent by UE1 and UE3 in the channel estimation phase. One way to measure the channel $\mathbf{h}_{kj}$ to UE *k* from eNodeB *j* is to first measure the channels over the ports virtualized by the GoB, i.e., to measure $\mathbf{h}_{kj}^{\mathrm{BS}}$, and then calculate $\mathbf{h}_{kj}$ using (1) as:

$$\mathbf{h}_{kj} = \left(\mathbf{h}_{kj}^{\mathrm{BS}}\right)_1 \mathbf{w}_1{}^{\mathrm{H}} + \left(\mathbf{h}_{kj}^{\mathrm{BS}}\right)_2 \mathbf{w}_2{}^{\mathrm{H}} + \cdots + \left(\mathbf{h}_{kj}^{\mathrm{BS}}\right)_N \mathbf{w}_N{}^{\mathrm{H}} = \sum_{n=1}^{N} \left(\mathbf{h}_{kj}^{\mathrm{BS}}\right)_n \mathbf{w}_n{}^{\mathrm{H}} \quad (2)$$

Now, if there is no dominant cluster over beam *m*, then the channel gain observed over the corresponding virtualized port, i.e., $\left(\mathbf{h}_{kj}^{\mathrm{BS}}\right)_m$, will be very weak and can be ignored in (2) without causing significant channel estimation error. Under this condition, an accurate estimate of the channel of UE3 can be obtained by eliminating the beams that are in the selected beam set of UE1, i.e., $\{\mathbf{w}_3, \mathbf{w}_6, \mathbf{w}_9\}$, when using (2). In this way, the remaining pilot contamination may be significantly suppressed.

As described above with reference to **Figure 3c**, different serving network nodes may need to coordinate the pilot sequence allocation. The pilot sequence allocation coordination may be performed centralized in a coordinating unit. **Figure 4** is a flowchart illustrating an embodiment of the method for coordinating pilot sequence allocation to a first and a second wireless device served by a respective first and second network node of a wireless communication network, where the method is performed in the coordinating unit. The coordinating unit is configured to communicate with the first and the second network nodes. The method comprises:

- 410: Receiving information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes respectively. The sets of beams have been selected by the first and the second network nodes based on a quality of reference signals received from the first and the second wireless devices over first and second grids of beams providing wireless coverage for the respective first and second network nodes.

- 420: Determining overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes respectively.
- 430: Determining whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps.
- 440: Determining at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences.
- 450: Providing information defining the determined at least one pilot sequence to the first and the second network nodes.

In embodiments of the invention, the overlaps between the selected sets of beams are determined in number of common beams for the first and the second network nodes respectively. The determining, in 430, of whether to use a same or different pilot sequences for the first and the second wireless devices may comprise:

- Determining to allocate a same pilot sequence to the first and the second wireless devices when the determined overlaps in number of common beams for the first and the second network nodes respectively are both less than or equal to a first threshold.
- Determining to allocate different pilot sequences to the first and the second wireless devices otherwise.

Common beams may be beams generated using a same beamforming vector. In another embodiment, common beams are not just beams generated using a same beamforming vector, but also beams for which a difference in the quality of the reference signal received from the respective first and second wireless devices is below a second threshold.

Embodiments of apparatus described with reference to ***Figures 5a-d***

An embodiment of the first network node 500 for determining reuse of pilot sequences for wireless devices of a wireless communication network is schematically illustrated in the block diagram in **Figure 5a.** The first network node 500 is configured to provide wireless coverage through a first GoB. The first network node 500 is further configured to receive a reference signal from a first wireless device and a second wireless device respectively, over the first GoB, select a set of beams from the first GoB based on a quality of the received reference signal for the first and the second wireless devices

respectively, and determine whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

In embodiments, the first network node 500 is further configured to determine whether to allocate a same or different pilot sequences by being configured to determine the overlap between the selected sets of beams for the first and the second wireless devices in number of common beams. Common beams are beams generated using a same beamforming vector. Optionally, there may be another requirement of what is counted as common beams, and that is that common beams are beams for which a difference in the quality of the reference signal received from the respective first and second wireless devices is below a second threshold. The first network node 500 is also configured to determine whether to allocate a same or different pilot sequences by being configured to determine to allocate a same pilot sequence to the first and the second wireless devices when the determined overlap in number of common beams is less than or equal to a first threshold, and determine to allocate different pilot sequences to the first and the second wireless devices otherwise.

In an embodiment corresponding to the distributed coordination case, illustrated in **Figure 5c**, the first network node 500a is configured to serve the first wireless device. Furthermore, the second wireless device may be served by a second network node 500b providing wireless coverage through a second GoB. The first network node 500a may be further configured to receive information defining sets of beams for the first and the second wireless devices as selected from the second GoB by the second network node 500b. The information is received from the second network node 500b. The first network node 500a may be further configured to determine whether to allocate a same or different pilot sequences to the first and the second wireless devices based also on an overlap between the sets of beams defined by the received information.

In an embodiment corresponding to the centralized coordination case, illustrated in **Figure 5d**, the first network node 500a is configured to serve the first wireless device. Furthermore, the second wireless device may be served by a second network node 500b. The first network node 500a may be further configured to determine whether to allocate a same or different pilot sequences to the first and the second wireless devices by being configured to provide information defining the selected sets of beams to a coordinating

unit 550 for enabling coordination of pilot sequence allocation to wireless devices served by the first and the second network nodes, 500a and 500b, based on the overlap between the selected sets of beams. The first network node 500a may also be further configured to determine whether to allocate a same or different pilot sequences to the first and the second wireless devices by being configured to receive information defining a pilot sequence to allocate to the first wireless device from the coordinating unit 550, and information indicating whether the same pilot sequence is allocated to the second wireless device, in response to the provided information.

In any of the above described embodiment, the first network node 500a may be further configured to allocate a pilot sequence to at least one of the first and the second wireless devices in accordance with the determining of whether to allocate the same or different pilot sequences to the first and the second wireless devices, and transmit information defining the allocated pilot sequence to at least one of the first and the second wireless devices. The first network node 500 may in certain embodiments be further configured to send information defining the pilot sequence allocated to the first wireless device to a second network node serving the second wireless device. Furthermore, when it is determined to allocate a same pilot sequence to the first and the second wireless devices, the first network node 500 may be further configured to measure the pilot sequence allocated to the first wireless device over the set of beams selected from the first GoB for the first wireless device excluding beams that correspond to the overlap, and estimate a channel to the first wireless device using the measurement of the pilot sequence.

In any of the above described embodiments, the first network node 500 may be further configured to select a set of beams from the first GoB by being configured to measure a quality value of the reference signal received over the first GoB, and select the set of beams with a highest measured quality value. The set of beams may comprise a pre-defined number of beams, or all beams with a measured quality value above a third threshold.

As illustrated in **Figure 5a,** the first network node 500 may comprise at least one processor 510 and optionally also a memory 530. In embodiments, the memory 530 may be placed in some other node or unit or at least separately from the first network node 500. The first network node 500 may also comprise one or more input/output (I/O) units

520 configured to communicate with the second network node, with wireless devices in the network, and/or with the coordinating unit 550. The input/output (I/O) unit 520 may in embodiments comprise one or more of an X2 interface unit for communicating with other network nodes over X2, a transceiver connected to multiple antennas over antenna ports for wireless communication with wireless devices in the network, and an interface unit for communicating with the coordinating unit 550 using a suitable interface. The memory 530 may contain instructions executable by said at least one processor 510, whereby the first network node 500 may be operative to receive a reference signal from a first wireless device and a second wireless device respectively, over the first GoB, via the I/O unit. The first network node 500 may also be operative to select a set of beams from the first GoB based on a quality of the received reference signal for the first and the second wireless devices respectively, and determine whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices. The memory 530 may contain further instructions executable by said at least one processor 510, whereby the first network node 500 may be operative to perform any of the methods previously described herein.

In an another embodiment also illustrated in **Figure 5a**, the first network node 500 may comprise a receiving module 511 adapted to receive a reference signal from a first wireless device and a second wireless device respectively, over the first GoB, a selecting module 512 adapted to select a set of beams from the first GoB based on a quality of the received reference signal for the first and the second wireless devices respectively, and a determining module 513 adapted to determine whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

In embodiments, the first network node 500 may also comprise a allocating module adapted to allocate a pilot sequence to at least one of the first and the second wireless devices in accordance with the determining of whether to allocate the same or different pilot sequences to the first and the second wireless devices, a transmitting module adapted to transmit information defining the allocated pilot sequence to at least one of the first and the second wireless devices, a measuring module adapted to - when it is determined to allocate a same pilot sequence to the first and the second wireless

devices - measure the pilot sequence allocated to the first wireless device over the set of beams selected from the first GoB for the first wireless device excluding beams that correspond to the overlap, and an estimating module adapted to estimate a channel to the first wireless device using the measurement of the pilot sequence. The first network node 500 may contain further modules adapted to perform any of the methods previously described herein.

The modules described above are functional units which may be implemented in hardware, software, firmware or any combination thereof. In one embodiment, the modules are implemented as a computer program running on the at least one processor 510.

In still another alternative way to describe the embodiment in **Figure 5a**, the first network node 500 may comprise a Central Processing Unit (CPU) which may be a single unit or a plurality of units. Furthermore, the first network node 500 may comprise at least one computer program product (CPP) 541 with a computer readable medium 542 in the form of a non-volatile memory, e.g. an EEPROM (Electrically Erasable Programmable Read-Only Memory), a flash memory or a disk drive. The CPP 541 may comprise a computer program 540 stored on the computer readable medium 542, which comprises code means which when run on the CPU of the first network node 500 causes the first network node 500 to perform the methods described earlier in conjunction with **Figures 3a-c**. In other words, when said code means are run on the CPU, they correspond to the at least one processor 510 of the first network node 500 in **Figure 5a**.

An embodiment of the coordinating unit 550 for coordinating pilot sequence allocation to a first and a second wireless device served by a respective first and second network node of a wireless communication network is schematically illustrated in the block diagram in **Figure 5b.** The coordinating unit 550 is configured to communicate with the first and the second network nodes as illustrated in **Figure 5d**. The coordinating unit 550 is further configured to receive information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes respectively. The sets of beams have been selected by the first and the second network nodes based on a quality of reference signals received from the first and the second wireless devices over first and second grids of beams providing wireless coverage for the respective first and second network nodes. The coordinating unit 550 is also configured to

determine overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes respectively, and determine whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps. The coordinating unit 550 is further configured to determine at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences, and provide information defining the determined at least one pilot sequence to the first and the second network nodes.

In embodiments, the coordinating unit 550 is further configured to determine the overlaps between the selected sets of beams in number of common beams for the first and the second network nodes respectively. Common beams are beams generated using a same beamforming vector. Optionally, there may be another requirement of what is counted as common beams, and that is that common beams are beams for which a difference in the quality of the reference signal received from the respective first and second wireless devices is below a second threshold. The coordinating unit 550 may be further configured to determine whether to use a same or different pilot sequences for the first and the second wireless devices by being configured to determine to allocate a same pilot sequence to the first and the second wireless devices when the determined overlaps in number of common beams for the first and the second network nodes respectively are both less than or equal to a first threshold, and determine to allocate different pilot sequences to the first and the second wireless devices otherwise.

As illustrated in **Figure 5b,** the coordinating unit 550 may comprise at least one processor 560 and optionally also a memory 580. In embodiments, the memory 580 may be placed in some other node or unit, or at least separately from the coordinating unit 550. The coordinating unit 550 may also comprise one or more input/output (I/O) units 570 configured to communicate with the network nodes 500a, 500b. The input/output (I/O) unit 570 may in embodiments comprise an interface unit for communicating with the network nodes 500a, 500b, using a suitable interface. The memory 580 may contain instructions executable by said at least one processor 510, whereby the coordinating unit 550 may be operative to receive information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes respectively, via the I/O unit. The sets of beams have been selected by the first and the second network nodes

based on a quality of reference signals received from the first and the second wireless devices over first and second grids of beams providing wireless coverage for the respective first and second network nodes. The coordinating unit 550 is also operative to determine overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes respectively, and determine whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps. The coordinating unit 550 is further operative to determine at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences, and to provide information defining the determined at least one pilot sequence to the first and the second network nodes via the I/O unit. The memory 580 may contain further instructions executable by said at least one processor 560, whereby the coordinating unit 550 may be operative to perform any of the methods previously described herein.

In an another embodiment also illustrated in **Figure 5b**, the coordinating unit 550 may comprise a receiving module 561 adapted to receive information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes respectively. The sets of beams have been selected by the first and the second network nodes based on a quality of reference signals received from the first and the second wireless devices over first and second grids of beams providing wireless coverage for the respective first and second network nodes. The coordinating unit 550 may also comprise one or more determining modules 562 adapted to determine overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes respectively, determine whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps, and determine at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences. The coordinating unit 550 may further comprise a providing module 563 adapted to provide information defining the determined at least one pilot sequence to the first and the second network nodes.

In embodiments, the one or more determining modules 562 may be further adapted to determine the overlaps between the selected sets of beams in number of

common beams for the first and the second network nodes respectively, and to determine to allocate a same pilot sequence to the first and the second wireless devices when the determined overlaps in number of common beams for the first and the second network nodes respectively are both less than or equal to a first threshold, and to determine to allocate different pilot sequences to the first and the second wireless devices otherwise.

The modules described above are functional units which may be implemented in hardware, software, firmware or any combination thereof. In one embodiment, the modules are implemented as a computer program running on the at least one processor 560.

In still another alternative way to describe the embodiment in **Figure 5b**, the coordinating unit 550 may comprise a Central Processing Unit (CPU) which may be a single unit or a plurality of units. Furthermore, the coordinating unit 550 may comprise at least one computer program product (CPP) 591 with a computer readable medium 592 in the form of a non-volatile memory, e.g. an EEPROM (Electrically Erasable Programmable Read-Only Memory), a flash memory or a disk drive. The CPP 591 may comprise a computer program 590 stored on the computer readable medium 592, which comprises code means which when run on the CPU of the coordinating unit 550 causes the coordinating unit 550 to perform the methods described earlier in conjunction with **Figure 4**. In other words, when said code means are run on the CPU, they correspond to the at least one processor 560 of the coordinating unit 550 in **Figure 5b**.

The above mentioned and described embodiments are only given as examples and should not be limiting. Other solutions, uses, objectives, and functions within the scope of the accompanying patent claims may be possible.

CLAIMS

1. A method for determining reuse of pilot sequences for wireless devices of a wireless communication network, the method being performed in a first network node (500a) of the wireless communication network, the first network node (500a) providing wireless coverage through a first grid of beams, the method comprising:
   - receiving (310) a reference signal from a first wireless device and a second wireless device respectively over the first grid of beams,
   - selecting (320) a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices respectively, and
   - determining (330) whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

2. The method according to claim 1, wherein determining (330) whether to allocate a same or different pilot sequences comprises:
   - determining the overlap between the selected sets of beams for the first and the second wireless devices in number of common beams, wherein common beams are beams generated using a same beamforming vector,
   - determining to allocate a same pilot sequence to the first and the second wireless devices when the determined overlap in number of common beams is less than or equal to a first threshold, and
   - determining to allocate different pilot sequences to the first and the second wireless devices otherwise.

3. The method according to claim 2, wherein common beams are beams for which a difference in the quality of the reference signal received from the respective first and second wireless devices is below a second threshold.

4. The method according to claim 1, wherein the first wireless device is served by the first network node (500a) and the second wireless device is served by a second

network node (500b) providing wireless coverage through a second grid of beams, the method further comprising:

- receiving (325) information defining sets of beams for the first and the second wireless devices as selected from the second grid of beams by the second network node (500b), wherein the information is received from the second network node (500b),

and wherein determining (330) whether to allocate a same or different pilot sequences to the first and the second wireless devices is based also on an overlap between the sets of beams defined by the received information.

5. The method according to claim 1, wherein the first wireless device is served by the first network node (500a) and the second wireless device is served by a second network node (500b), and wherein determining (330) whether to allocate a same or different pilot sequences to the first and the second wireless devices comprises:

- providing (331) information defining the selected sets of beams to a coordinating unit (550) for enabling coordination of pilot sequence allocation to wireless devices served by the first and the second network nodes (500a, 500b) based on the overlap between the selected sets of beams, and
- receiving (332) information defining a pilot sequence to allocate to the first wireless device from the coordinating unit (550), and information indicating whether the same pilot sequence is allocated to the second wireless device, in response to the provided information.

6. The method according to any of the preceding claims, further comprising:

- allocating (340) a pilot sequence to at least one of the first and the second wireless devices in accordance with the determining (330) of whether to allocate the same or different pilot sequences to the first and the second wireless devices, and
- transmitting (350) information defining the allocated pilot sequence to at least one of the first and the second wireless devices.

7. The method according to claim 6, further comprising sending information defining the pilot sequence allocated to the first wireless device to a second network node (500b) serving the second wireless device.

8. The method according to claim 6 or 7, the method further comprising, when it is determined to allocate a same pilot sequence to the first and the second wireless devices:
   - measuring (360) the pilot sequence allocated to the first wireless device over the set of beams selected from the first grid of beams for the first wireless device excluding beams that correspond to the overlap, and
   - estimating (370) a channel to the first wireless device using the measurement of the pilot sequence.

9. The method according to any of the preceding claims, wherein selecting (320) a set of beams from the first grid of beams comprises:
   - measuring a quality value of the reference signal received over the first grid of beams, and
   - selecting the set of beams with a highest measured quality value, wherein the set of beams comprises: a pre-defined number of beams; or all beams with a measured quality value above a third threshold.

10. A method for coordinating pilot sequence allocation to a first and a second wireless device served by a respective first and second network node (500a, 500b) of a wireless communication network, the method being performed in a coordinating unit (550) configured to communicate with the first and the second network nodes (500a, 500b), the method comprising:
   - receiving (410) information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes (500a, 500b) respectively, wherein the sets of beams have been selected by the first and the second network nodes (500a, 500b) based on a quality of reference signals received from the first and the second wireless devices over first and second grids

of beams providing wireless coverage for the respective first and second network nodes (500a, 500b),

- determining (420) overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes (500a, 500b) respectively,
- determining (430) whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps,
- determining (440) at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences, and
- providing (450) information defining the determined at least one pilot sequence to the first and the second network nodes (500a, 500b).

11. The method according to claim 10, wherein the overlaps between the selected sets of beams are determined in number of common beams for the first and the second network nodes (500a, 500b) respectively, wherein common beams are beams generated using a same beamforming vector, and wherein determining (430) whether to use a same or different pilot sequences for the first and the second wireless devices comprises:
    - determining to allocate a same pilot sequence to the first and the second wireless devices when the determined overlaps in number of common beams for the first and the second network nodes (500a, 500b) respectively are both less than or equal to a first threshold, and
    - determining to allocate different pilot sequences to the first and the second wireless devices otherwise.

12. The method according to claim 11, wherein common beams are beams for which a difference in the quality of reference signals received from the respective first and second wireless devices is below a second threshold.

13. A first network node (500a) for determining reuse of pilot sequences for wireless devices of a wireless communication network, the first network node (500a) being configured to provide wireless coverage through a first grid of beams, the first network node (500a) being further configured to:
    - receive a reference signal from a first wireless device and a second wireless device respectively over the first grid of beams,
    - select a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices respectively, and
    - determine whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices.

14. The first network node (500a) according to claim 13, further configured to determine whether to allocate a same or different pilot sequences by being configured to:
    - determine the overlap between the selected sets of beams for the first and the second wireless devices in number of common beams, wherein common beams are beams generated using a same beamforming vector,
    - determine to allocate a same pilot sequence to the first and the second wireless devices when the determined overlap in number of common beams is less than or equal to a first threshold, and
    - determine to allocate different pilot sequences to the first and the second wireless devices otherwise.

15. The first network node (500a) according to claim 14, wherein common beams are beams for which a difference in the quality of the reference signal received from the respective first and second wireless devices is below a second threshold.

16. The first network node (500a) according to claim 13, configured to serve the first wireless device, and wherein the second wireless device is served by a second

network node (500b) providing wireless coverage through a second grid of beams, the first network node (500a) being further configured to:

- receive information defining sets of beams for the first and the second wireless devices as selected from the second grid of beams by the second network node (500b), wherein the information is received from the second network node (500b), and
- determine whether to allocate a same or different pilot sequences to the first and the second wireless devices based also on an overlap between the sets of beams defined by the received information.

17. The first network node (500a) according to claim 13, configured to serve the first wireless device, and wherein the second wireless device is served by a second network node (500b), and further configured to determine whether to allocate a same or different pilot sequences to the first and the second wireless devices by being configured to:

- provide information defining the selected sets of beams to a coordinating unit (550) for enabling coordination of pilot sequence allocation to wireless devices served by the first and the second network nodes (500a, 500b) based on the overlap between the selected sets of beams, and
- receive information defining a pilot sequence to allocate to the first wireless device from the coordinating unit (550), and information indicating whether the same pilot sequence is allocated to the second wireless device, in response to the provided information.

18. The first network node (500a) according to any of claims 13-17, further configured to:

- allocate a pilot sequence to at least one of the first and the second wireless devices in accordance with the determining of whether to allocate the same or different pilot sequences to the first and the second wireless devices, and
- transmit information defining the allocated pilot sequence to at least one of the first and the second wireless devices.

19. The first network node (500a) according to claim 18, further configured to send information defining the pilot sequence allocated to the first wireless device to a second network node (500b) serving the second wireless device.

20. The first network node (500a) according to claim 18 or 19, further configured to, when it is determined to allocate a same pilot sequence to the first and the second wireless devices:
- measure the pilot sequence allocated to the first wireless device over the set of beams selected from the first grid of beams for the first wireless device excluding beams that correspond to the overlap, and
- estimate a channel to the first wireless device using the measurement of the pilot sequence.

21. The first network node (500a) according to any of claims 13-20, further configured to select a set of beams from the first grid of beams by being configured to:
- measure a quality value of the reference signal received over the first grid of beams, and
- select the set of beams with a highest measured quality value, wherein the set of beams comprises: a pre-defined number of beams; or all beams with a measured quality value above a third threshold.

22. A coordinating unit (550) for coordinating pilot sequence allocation to a first and a second wireless device served by a respective first and second network nodes (500b) of a wireless communication network, the coordinating unit (550) being configured to communicate with the first and the second network nodes (500a, 500b), the coordinating unit (550) being further configured to:
- receive information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes (500a, 500b) respectively, wherein the sets of beams have been selected by the first and the second network nodes (500a, 500b) based on a quality of reference signals received from the first and the second wireless devices over first and second grids

of beams providing wireless coverage for the respective first and second network nodes (500a, 500b),

- determine overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes (500a, 500b) respectively,
- determine whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps,
- determine at least one pilot sequence to allocate to the first and the second wireless devices, in accordance with whether it is determined to use a same or different pilot sequences, and
- provide information defining the determined at least one pilot sequence to the first and the second network nodes (500a, 500b).

23. The coordinating unit (550) according to claim 22, further configured to determine the overlaps between the selected sets of beams in number of common beams for the first and the second network nodes (500a, 500b) respectively, wherein common beams are beams generated using a same beamforming vector, the coordinating unit (550) being further configured to determine whether to use a same or different pilot sequences for the first and the second wireless devices by being configured to:
    - determine to allocate a same pilot sequence to the first and the second wireless devices when the determined overlaps in number of common beams for the first and the second network nodes (500a, 500b) respectively are both less than or equal to a first threshold, and
    - determine to allocate different pilot sequences to the first and the second wireless devices otherwise.

24. The coordinating unit (550) according to claim 23, wherein common beams are beams for which a difference in the quality of reference signals received from the respective first and second wireless devices is below a second threshold.

25. A computer program (540) comprising computer readable code which when run on a first network node (500a) causes the first network node to perform a method as claimed in any of claims 1-9.

26. A computer program (590) comprising computer readable code which when run on a coordinating unit (550) causes the coordinating unit to perform a method as claimed in any of claims 10-12.

27. A computer program product (541, 591) comprising a computer readable medium (542, 592) and a computer program (540, 590) according to any of claims 25-26, wherein the computer program is stored on the computer readable medium.

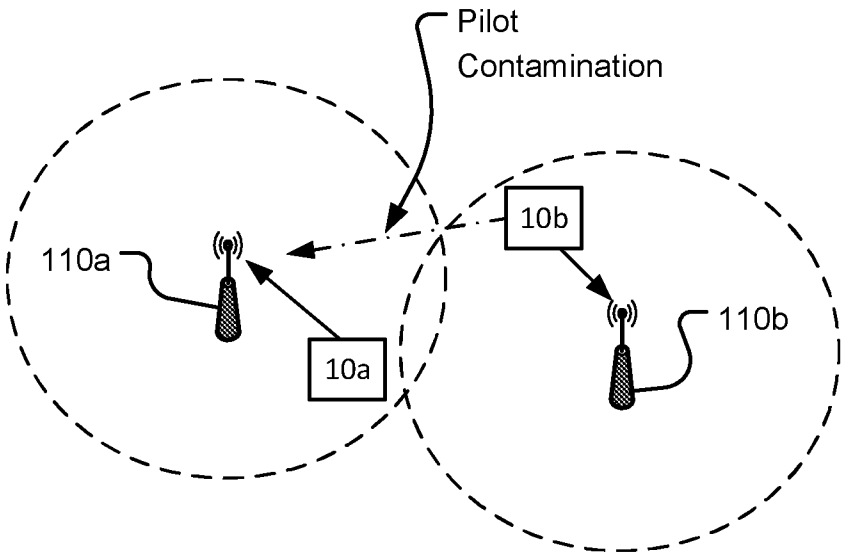

Pilot
Contamination
110a
10a
10b
110b

FIG. 1

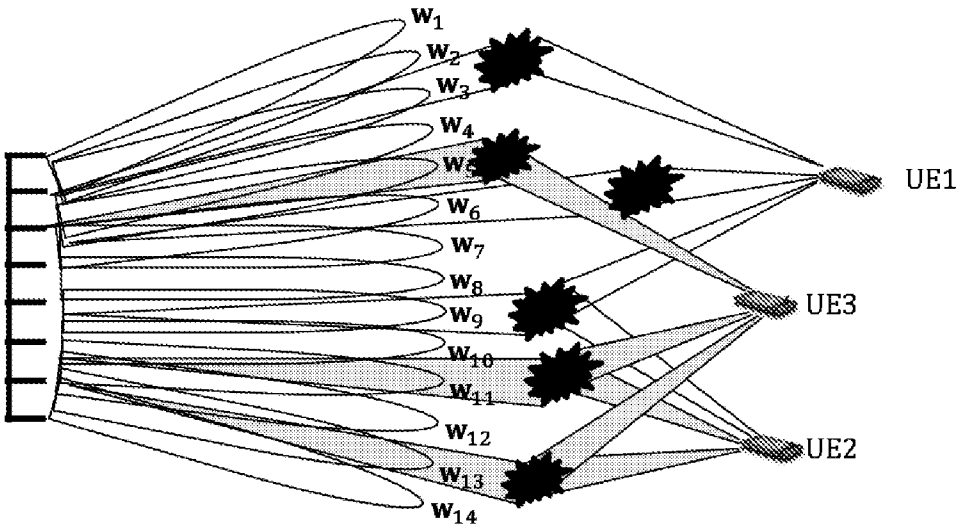

W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
W13
W14
UE1
UE3
UE2

FIG. 2

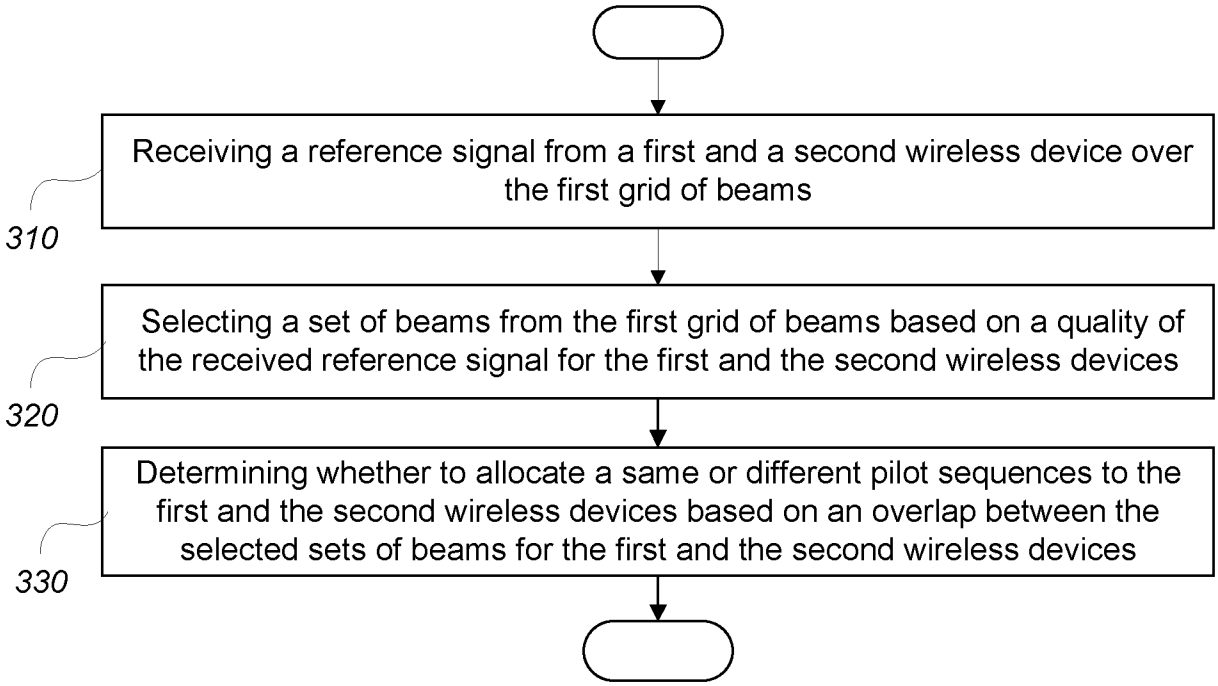

Receiving a reference signal from a first and a second wireless device over the first grid of beams
310
Selecting a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices
320
Determining whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices
330

FIG. 3A

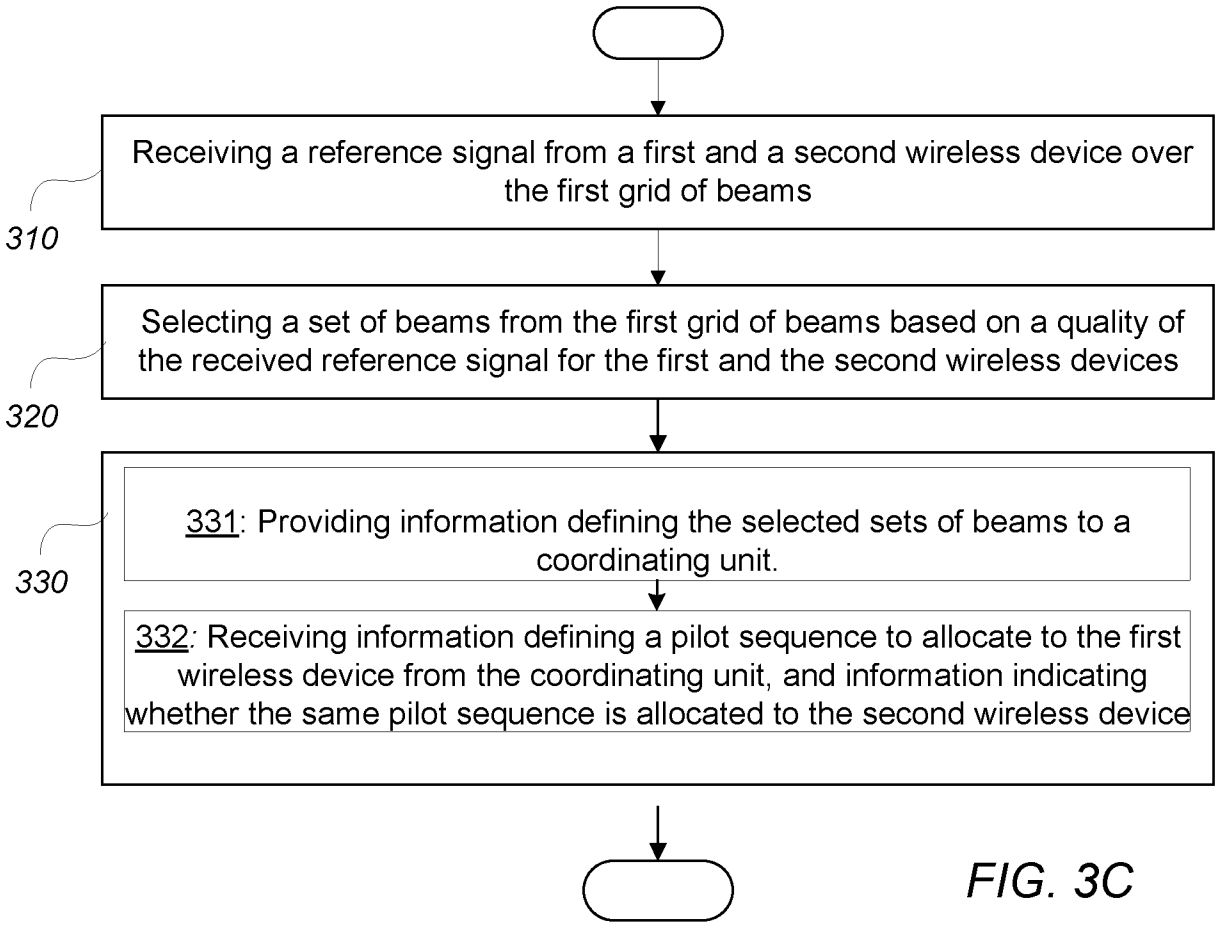

Receiving a reference signal from a first and a second wireless device over the first grid of beams
310
Selecting a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices
320
331: Providing information defining the selected sets of beams to a coordinating unit.
330
332: Receiving information defining a pilot sequence to allocate to the first wireless device from the coordinating unit, and information indicating whether the same pilot sequence is allocated to the second wireless device

FIG. 3C

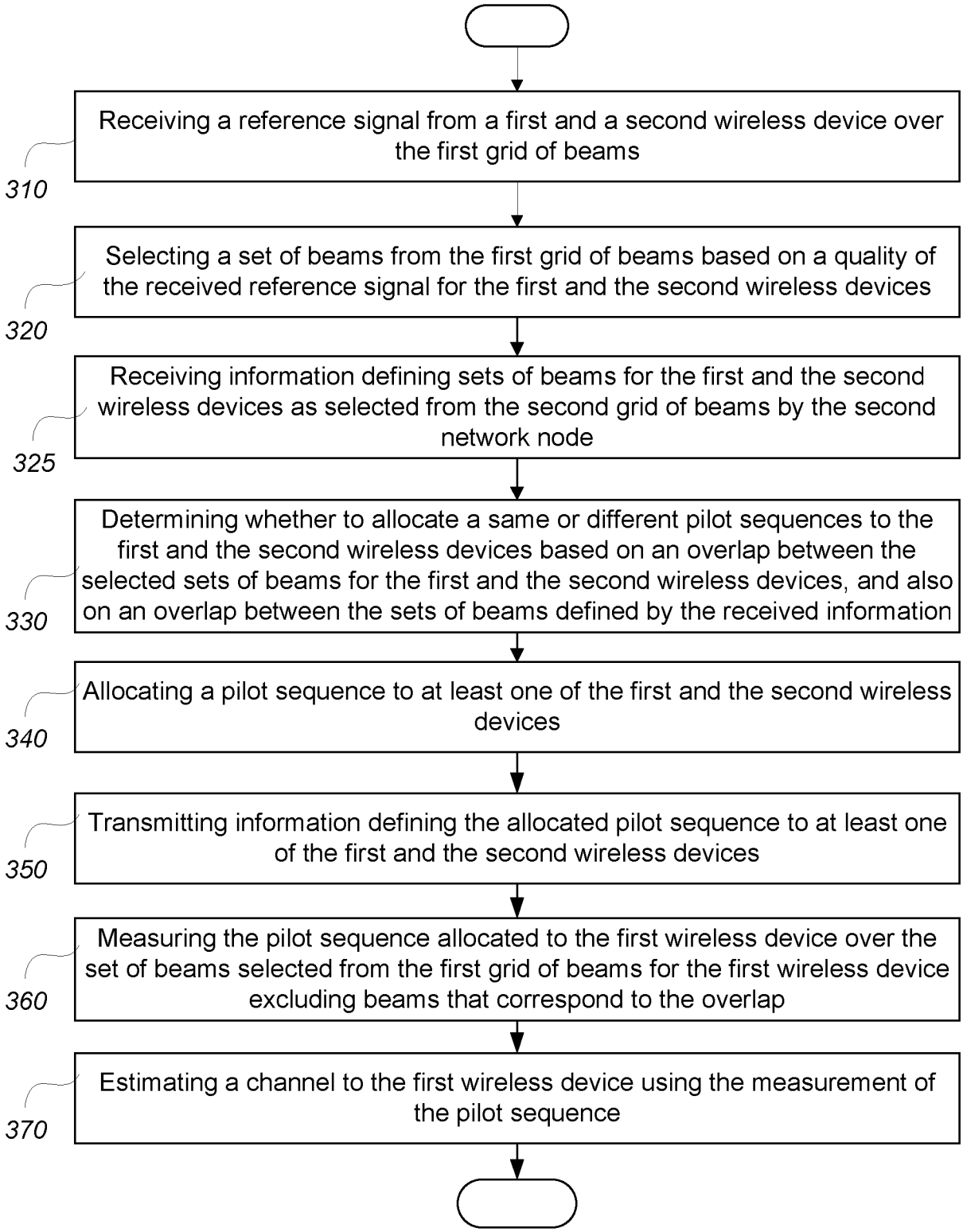

Receiving a reference signal from a first and a second wireless device over the first grid of beams
310
Selecting a set of beams from the first grid of beams based on a quality of the received reference signal for the first and the second wireless devices
320
Receiving information defining sets of beams for the first and the second wireless devices as selected from the second grid of beams by the second network node
325
Determining whether to allocate a same or different pilot sequences to the first and the second wireless devices based on an overlap between the selected sets of beams for the first and the second wireless devices, and also on an overlap between the sets of beams defined by the received information
330
Allocating a pilot sequence to at least one of the first and the second wireless devices
340
Transmitting information defining the allocated pilot sequence to at least one of the first and the second wireless devices
350
Measuring the pilot sequence allocated to the first wireless device over the set of beams selected from the first grid of beams for the first wireless device excluding beams that correspond to the overlap
360
Estimating a channel to the first wireless device using the measurement of the pilot sequence
370

FIG. 3B

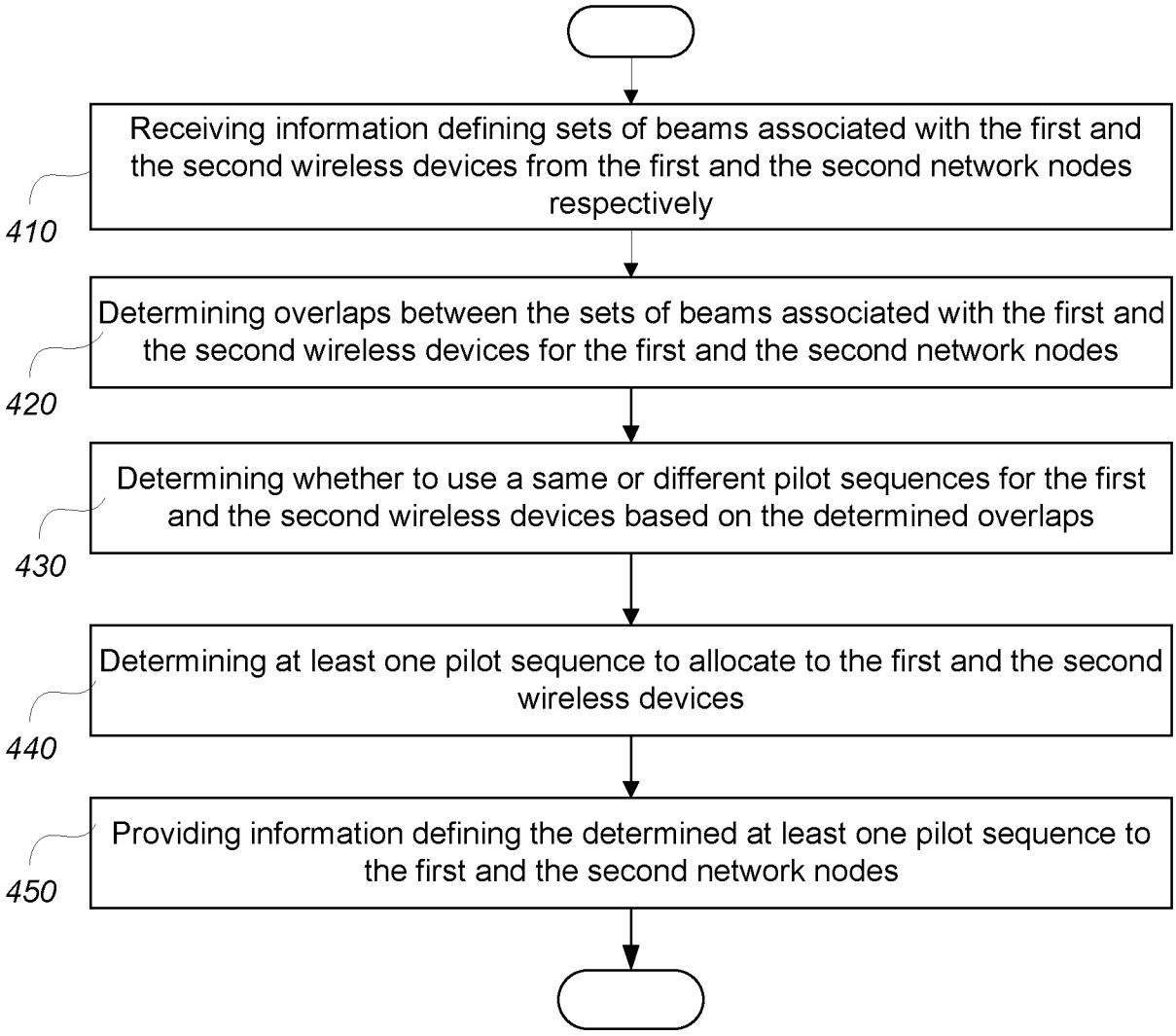

Receiving information defining sets of beams associated with the first and the second wireless devices from the first and the second network nodes respectively
410
Determining overlaps between the sets of beams associated with the first and the second wireless devices for the first and the second network nodes
420
Determining whether to use a same or different pilot sequences for the first and the second wireless devices based on the determined overlaps
430
Determining at least one pilot sequence to allocate to the first and the second wireless devices
440
Providing information defining the determined at least one pilot sequence to the first and the second network nodes
450

FIG. 4

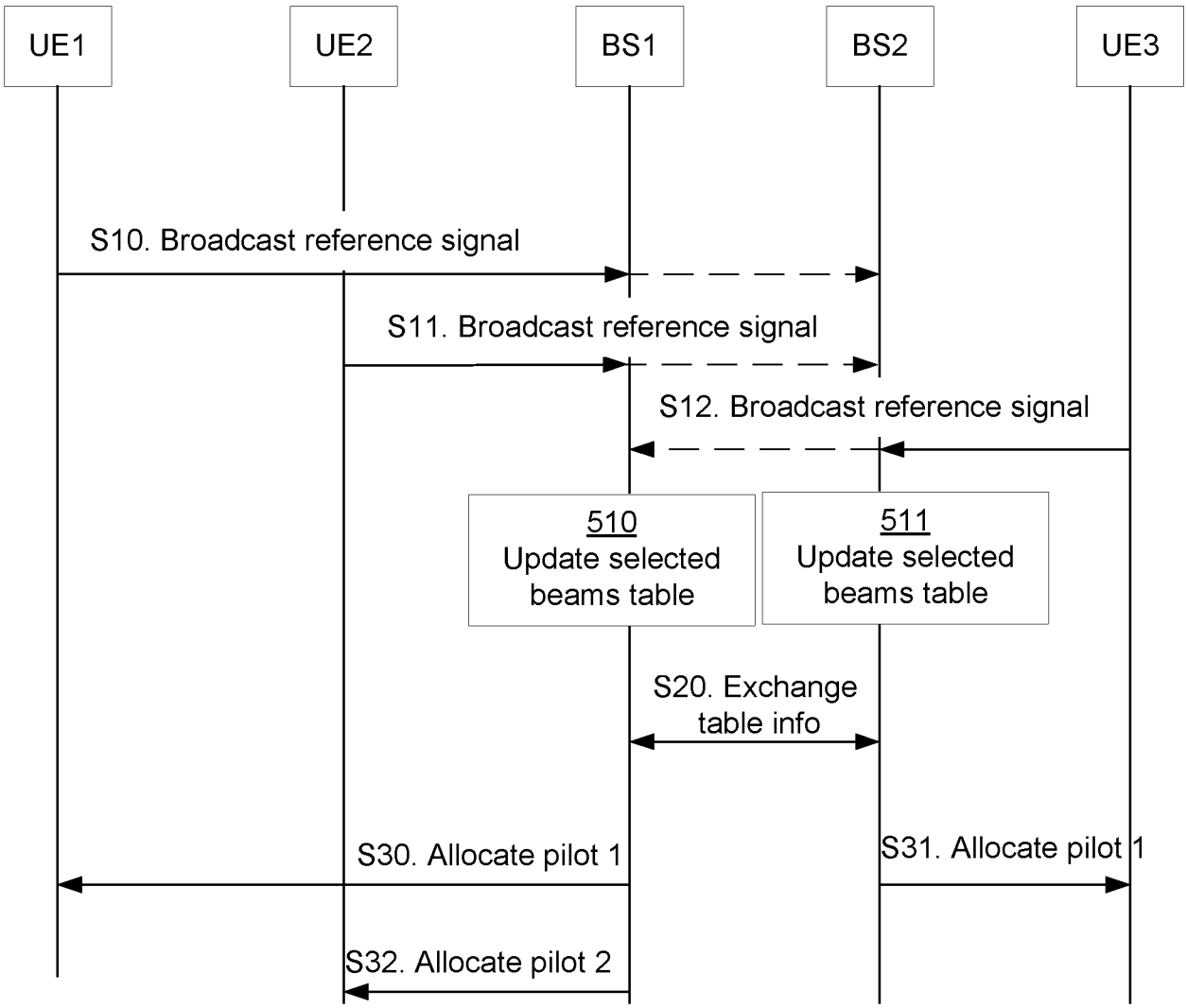

UE1
UE2
BS1
BS2
UE3
S10. Broadcast reference signal
S11. Broadcast reference signal
S12. Broadcast reference signal
510
Update selected beams table
511
Update selected beams table
S20. Exchange table info
S30. Allocate pilot 1
S31. Allocate pilot 1
S32. Allocate pilot 2

FIG. 5

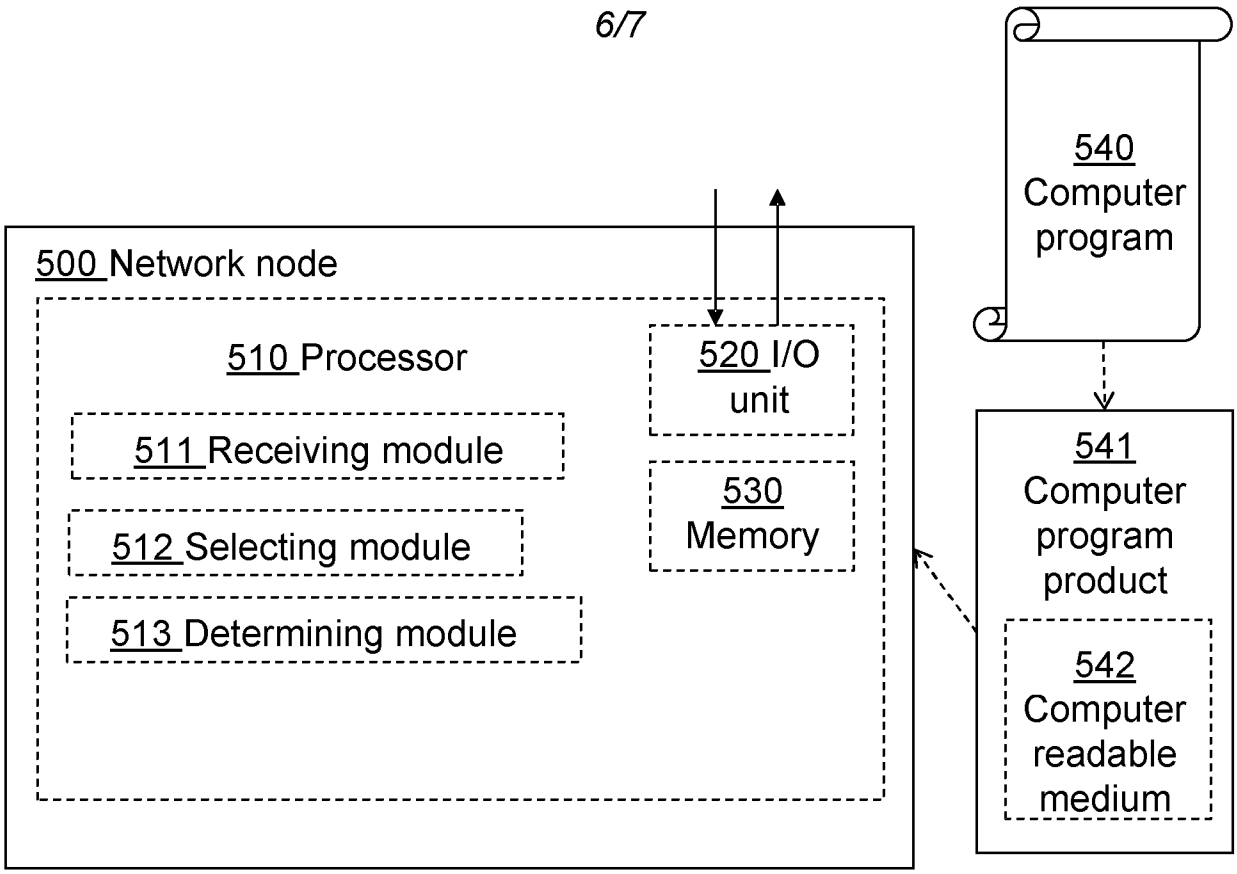

500 Network node
510 Processor
511 Receiving module
512 Selecting module
513 Determining module
520 I/O unit
530 Memory
540 Computer program
541 Computer program product
542 Computer readable medium

FIG. 6A

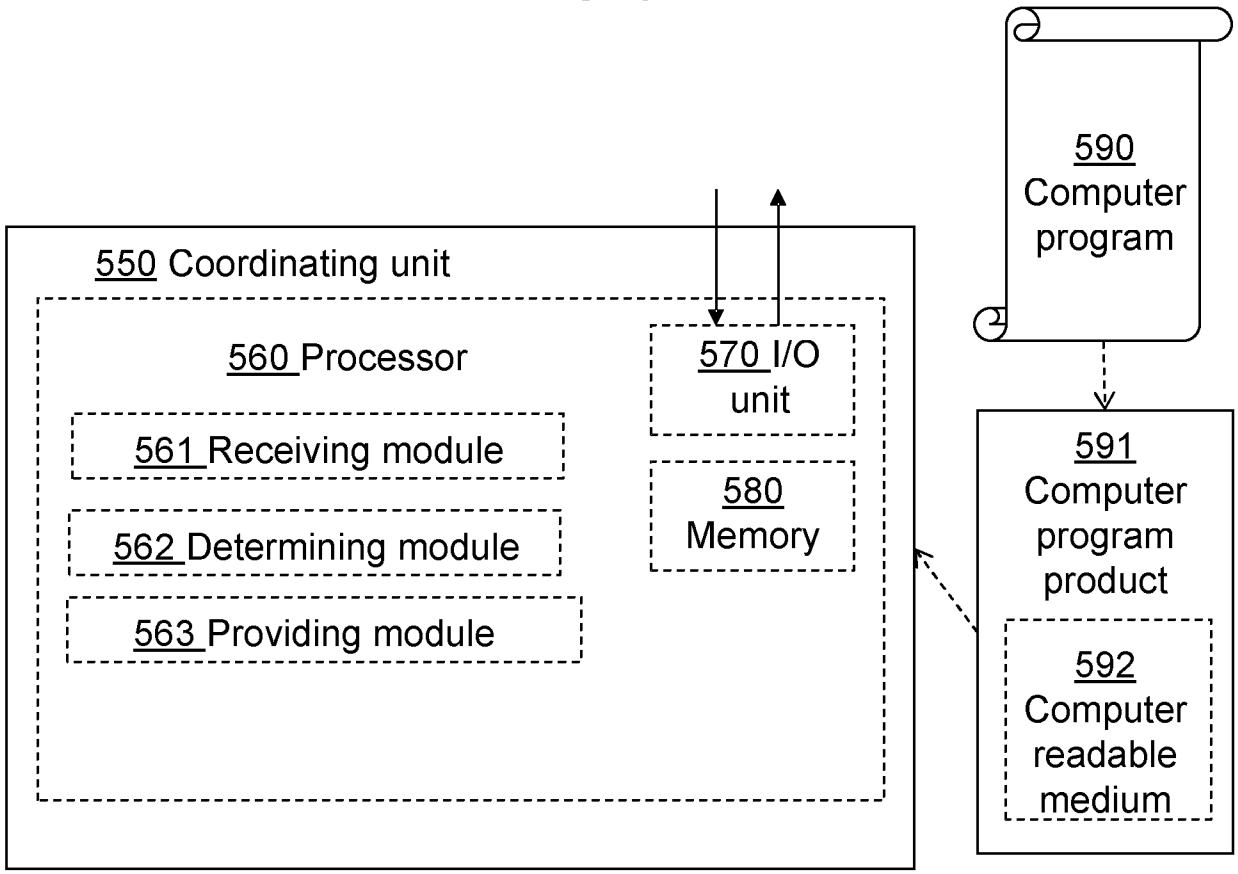

550 Coordinating unit
560 Processor
561 Receiving module
562 Determining module
563 Providing module
570 I/O unit
580 Memory
590 Computer program
591 Computer program product
592 Computer readable medium

FIG. 6B

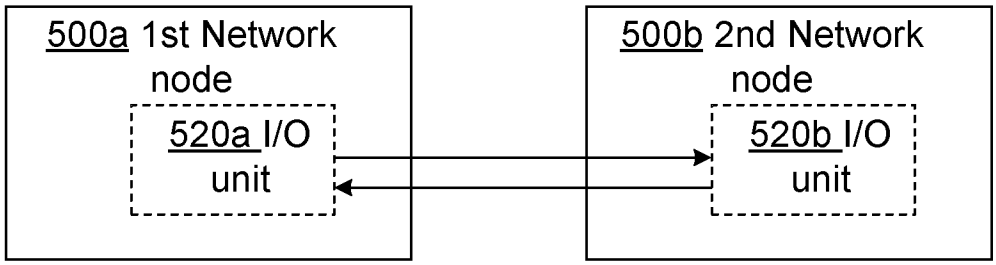

500a 1st Network node
520a I/O unit
500b 2nd Network node
520b I/O unit

FIG. 6C

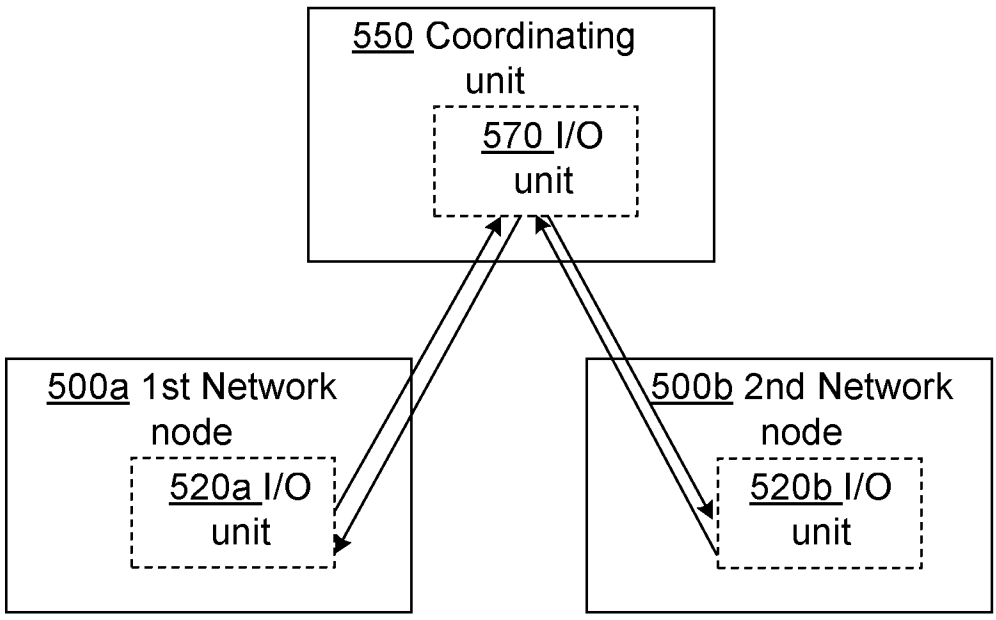

550 Coordinating unit
570 I/O unit
500a 1st Network node
520a I/O unit
500b 2nd Network node
520b I/O unit

FIG. 6D

INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2015/051337

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/08 H04L5/00 H04B7/04
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B H04L

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2005/153657 A1 (MARUTA YASUSHI [JP]) 14 July 2005 (2005-07-14) paragraphs [0008], [0014] - [0016]; figure 1	1-27
Y	US 2014/362805 A1 (NYSTRÖM JOHAN [SE] ET AL) 11 December 2014 (2014-12-11) paragraphs [0037], [0011]	1-27

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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

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

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 August 2016	06/09/2016

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Akbudak, Tarik

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INTERNATIONAL SEARCH REPORT

International application No
PCT/SE2015/051337

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	WO 2015/022577 A1 (ALCATEL LUCENT [FR]) 19 February 2015 (2015-02-19) page 9, line 24 - line 27; figures 1,2 page 10, line 16 - line 28	1-27
A	CN 103 875 190 A (SAMSUNG ELECTRONICS CO LTD) 18 June 2014 (2014-06-18) the whole document -& US 2013/040684 A1 (HYUN K Y; JEONG H P; KIM T; PARK J; TAE Y K; YU H) 14 February 2013 (2013-02-14)	1-27
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Information on patent family members

International application No
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