(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 3 659 286 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
06.10.2021 Bulletin 2021/40

(21) Application number: **17754141.4**

(22) Date of filing: **11.08.2017**

(51) Int Cl.:
H04L 5/00 *(2006.01)* ***H04W 28/02*** *(2009.01)*
H04L 12/801 *(2013.01)*

(86) International application number:
PCT/EP2017/070436

(87) International publication number:
WO 2019/029822 (14.02.2019 Gazette 2019/07)

(54) ADAPTIVE CSI RESOURCE ALLOCATION AND ADJUSTMENT BASED ON DIFFERENTIATED CHANNEL CONDITIONS

ADAPTIVE ZUWEISUNG UND ANPASSUNG VON CSI-RESSOURCEN AUF BASIS VON DIFFERENZIERTEN KANALBEDINGUNGEN

ATTRIBUTION ET AJUSTEMENT ADAPTATIFS DE RESSOURCES DE CSI SUR LA BASE DE CONDITIONS DE CANAL DIFFÉRENCIÉES

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(43) Date of publication of application:
03.06.2020 Bulletin 2020/23

(73) Proprietor: **Huawei Technologies Co., Ltd.**
Longgang District
Shenzhen, Guangdong 518129 (CN)

(72) Inventors:
- **ZU, Keke**
  164 40 Kista (SE)
- **KAHN, Marcus**
  164 40 Kista (SE)
- **FU, Hongliang**
  164 40 Kista (SE)
- **DENG, Zhongmin**
  164 40 Kista (SE)

(74) Representative: **Körber, Martin Hans et al**
Mitscherlich PartmbB
Patent- und Rechtsanwälte
Sonnenstrasse 33
80331 München (DE)

(56) References cited:
EP-A1- 2 418 782 **WO-A1-2016/048089**

- **HUAWEI ET AL: "Discussion on CSI Framework Design", 3GPP DRAFT; R1-1706926, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Hangzhou, China; 20170515 - 20170519 14 May 2017 (2017-05-14), XP051272156, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/RAN1/Docs/ [retrieved on 2017-05-14]**
- **HUAWEI ET AL: "DL CSI-RS design for NR CSI acquisition", 3GPP DRAFT; R1-1611241, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Reno, USA; 20161114 - 20161118 5 November 2016 (2016-11-05), XP051189813, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/tsg_ran/WG1_RL1/TSGR1_87/Docs/ [retrieved on 2016-11-05]**

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

EP 3 659 286 B1

Description

TECHNICAL FIELD

[0001] The aspects of the present disclosure relate generally to mobile communications systems and more particularly to radio resource usage.

BACKGROUND

[0002] Scheduling strategies used in modern wireless communication systems rely on information about channel conditions to efficiently schedule radio resources. An access node, such as a base station, may obtain channel state information (CSI) from CSI reports and/or sounding reference signals (SRS) transmitted by user equipment (UE). CSI allows access nodes to adapt transmission strategies based on current conditions of each radio channel. Adaptation is crucial for achieving reliable communication with high data rates in multi-antenna wireless communication systems.

[0003] In frequency division duplex (FDD) systems, such as long term evolution (LTE) cellular systems, CSI is often provided by CSI reports transmitted by a UE and received by the access node. In time division duplex (TDD) systems, CSI is often estimated from SRS transmitted by a UE. Transmission of CSI, CSI reports and/or SRS, may be periodic or aperiodic.

[0004] Fast changing channels require more frequent CSI transmissions, while slow changing channels can achieve reliable communication with less frequent CSI transmissions. Because radio resources used for CSI are not available for data transmission, there is a tradeoff

[0005] between having accurate up to date CSI and data transmission rates. Conventional wireless systems often fix or limit the amount of radio resources used for CSI and do not effectively adapt the CSI resource configurations based on current channel conditions resulting in unnecessarily limiting the number of UE that may be served by an access node, lower data rates, or both. Thus there is a need for improved apparatus and methods for effectively adapting CSI resource configurations based on conditions of the radio channel.

The document Huawei et al: "Discussion on CSI Framework design", 3GPP Draft/RI-1706926 is a standardization document regarding CSI Framework design. Especially, this document shows a flexible CSI approach dependent upon channel conditions.

[0006] The document Huawei et al: "DL CSI-RAS Design for an NR CSI acquisition" 3GPP Draft/RI-1611241 is also a standardization document regarding CSI Framework design. Especially, also here a dynamic CSI Framework depended upon channel conditions is shown.

[0007] The Document WO 2016-048089 A1 moreover shows a method and a system for performing channel estimation. Especially, also here a dynamic CSI Framework dependent upon channel conditions is shown.

SUMMARY

[0008] It is an object of the disclosed embodiments to provide improved apparatus and methods for efficiently allocating channel state information (CSI) resources in a wireless communication system. Fixed and non-adaptive approaches to CSI resource allocation result in inefficient and wasteful CSI resource usage that can limit data rates and reduce the number of devices an access node can service. This problem is solved by the approaches to adaptive CSI resource allocation and system parameter adjustment disclosed herein.

[0009] The present invention is defined by the independent claims. Embodiments labeled as inventive embodiments in the following, which are not covered by the scope of protection afforded by the independent claims, are to be understood as examples helpful for understanding the invention, but not as embodiments of the invention.

[0010] According to a first aspect of the disclosed embodiments the above and further objects and advantages are obtained by a processing node coupled to a wireless communications network. The processing node is configured to receive one or more channel features, wherein the one or more channel features are associated with a radio channel corresponding to a radio link connecting an access node and a user equipment. The processing node is configured to determine one or more distinguishing channel conditions based on the received one or more channel features, determine a desired channel state information (CSI) resource configuration based on the one or more distinguishing channel conditions, allocate the desired CSI resource configuration based on the desired CSI resource configuration, and adjust a current CSI resource configuration associated with the radio channel based on the determined desired CSI resource configuration. Adaptive allocation of CSI resources allows for improved efficiency of resource usage, improved communication, and larger numbers of UE to be served.

[0011] In a possible implementation form of the processing node according to the first aspect the processing node is further configured to actively adjust a system setting based on one or more of the one or more channel features; the one or more distinguishing channel conditions; the desired CSI resource configuration; a desired channel condition; and

an available CSI resource pool. Active adjustment of system settings allows an access node to predictably modify the channel conditions of the served UE so CSI resources can be re-allocated in a desired way.

[0012] In a further possible implementation form of the processing node according to the first aspect as such, or according to any one of the previous possible implementation forms, the processing node is configured to determine a differentiated channel condition approximation based on the one or more channel features and the one or more differentiating channel conditions, and to determine the desired CSI resource configuration based on a mapping of the one or more differentiating channel condition approximations to the desired CSI resource configuration. Use of a mapping to determine the desired CSI resource configuration allows numerical approaches, including heuristics and learning algorithms, to be implemented, which can improve selection of the desired CSI resource configuration.

[0013] According to the invention, the processing node is configured to determine a desired CSI resource configuration by selecting a differentiated coherence time model from a plurality of differentiated coherence time models, wherein the plurality of differentiated coherence time models comprise one or more of a Clarke's model, an LOS model, a NLOS small pointing error model, and a NLOS large pointing error model. The processing node is configured to compute a differentiated coherence time approximation based on the selected differentiated coherence time model, and determine the desired CSI resource configuration based on the determined differentiated coherence time approximation. This provides a more accurate approximation of coherence time leading to better channel differentiation and CSI resource allocation.

[0014] In a further possible implementation form of processing node according to first aspect as such or the previous possible implementation form the processing node is configured to select, when the radio channel is determined to be in a LOS condition, the LOS model as the differentiated coherence time model. This provides improved coherence time approximation for LOS channels.

[0015] In a further possible implementation form of processing node according to first aspect as such or a previous possible implementation form the processing node is configured to select, when the radio channel is determined to be in a dominant NLOS condition with small pointing error, the NLOS small pointing error model as the differentiated coherence time model. This provides improved coherence time approximation for NLOS channels having small pointing error.

[0016] In a further possible implementation form of processing node according to first aspect as such or a previous possible implementation form the processing node is configured to select, when the radio channel is determined to be in a dominant NLOS condition with large pointing error, the NLOS large pointing error model (eq. 4) as the differentiated coherence time model. This provides improved coherence time approximation for NLOS channels having large pointing error.

[0017] In a further possible implementation form of processing node according to first aspect as such or a previous possible implementation form the processing node is configured to select the differentiated coherence time model as a statistical data based model, and to compute the differentiated coherence time approximation based on the statistical data based model. Statistical data based models provide improved flexibility broader applicability of coherence time approximations.

[0018] In a further possible implementation form of the processing node according to the first aspect as such or the previous possible implementation form the processing node is configured to update the statistical data based model based on historical data. Updating the statistical model allows the algorithms to compensate for and/or to track changes in the wireless communication system.

[0019] In a further possible implementation form of the processing node according to the first aspect as such or according to any one of the previous possible implementation forms, the desired CSI resource configuration comprises one or more of a desired CSI period, a desired number of resource blocks, a desired position of resource blocks, a desired type of combs, and a desired phase rotation, and the current CSI resource configuration comprises a corresponding one or more of a current CSI period, a current number of resource blocks, a current position of resource blocks, a current type of combs, and a current phase rotation. The processing node is configured to adjust the current CSI resource configuration when a difference between the desired CSI resource configuration and the current CSI resource configuration exceeds a threshold value. Use of multiple CSI resource types improves allocation efficiency and use of a threshold provides a simple and effective way to trigger adjustment of the CSI resource configurations.

[0020] In a further possible implementation form of the processing node according to the first aspect as such or according to any one of the previous possible implementation forms, the one or more distinguishing channel conditions comprise a plurality of distinguishing channel conditions, the plurality of distinguishing channel conditions being associated with a plurality of radio channels, and wherein each radio channel in the plurality of radio channels corresponds to a radio link connecting the access node to one user equipment in a plurality of user equipment. The processing node is configured to select for each radio channel in the plurality of radio channels a differentiated coherence time model from the plurality of coherence time models based on the distinguishing channel conditions associated with the each radio channel to determine a differentiated coherence time approximation for each radio channel in the plurality of radio channels based on the corresponding selected coherence time model and the associated distinguishing channel con-

ditions, to determine for each radio channel in the plurality of radio channels a desired CSI configuration based on the determined differentiated coherence time approximations and/or a current CSI allocation, and to adjust one or more current CSI resource configurations based on the corresponding determined desired CSI resource allocation. Each radio channel in the plurality of radio channels is associated with one of the one or more current CSI resource configurations. Taking all served UE into consideration when allocating resources and/or adjusting system settings leads to better efficiencies and improves overall performance of the wireless communication system.

[0021] In an further possible implementation form of the processing node according to the first aspect as such or the previous possible implementation form of the first aspect the wireless communications network comprises a set of available CSI resource configurations. When the wireless communications network comprises sufficient CSI resources to satisfy all the desired CSI resource configurations, the processing node is configured to assign, for each radio channel in the plurality of radio channels, a new CSI resource configuration from the set of available CSI resource configurations. When the wireless communications network comprises insufficient CSI resources to satisfy all the desired CSI resource configurations, the processing node is configured to recover extra CSI resources by reducing an amount of CSI resources being used by radio channels having more CSI resources than required by the corresponding desired CSI resource configuration, and assign the recovered extra CSI resources to radio channels having fewer CSI resources than required by the corresponding desired CSI resource configuration. Shifting resources between UE in a resource starved network allows more UE to be served with improved throughput.

[0022] In a further possible implementation form of the processing node according to the first aspect as such or according to any one of the previous possible implementation form of the first aspect the system settings include one or more of a carrier frequency, a beam width, a beam phase, a beam pointing direction, and a transmit power. These system settings provide improved differentiation among UE to be achieved when adjusting the system settings.

[0023] In a further possible implementation form of the processing node according to the first aspect as such or according to any one of the previous possible implementation forms of the first aspect the processing node is configured to select the threshold value from a set of one or more predetermined threshold values based on an overall system throughput. Use of a predetermined set of threshold values allows system performance to be adjusted in various ways depending on changing criteria.

[0024] In a further possible implementation form of the processing node according to the first aspect as such or according to any one of the previous possible implementation forms of the first aspect the processing node is configured to adjust the threshold value based on the available CSI resources, and/or historical values of a computed differentiated coherence time approximation. Adjusting the threshold based current and past system information allows the network to adapt to changing conditions.

[0025] In a further possible implementation form of the processing node according to the first aspect as such or according to any one of the previous possible implementation forms of the first aspect the current CSI resource configuration includes one or more of a CSI reporting period, a sounding reference signal period, a number and positions of resource block allocation, type of comb, phase rotation, cyclic shifts, and code multiplexing, and wherein the processing node is configured to adjust the current CSI resource configuration based on the desired CSI resource configuration. Use of various CSI resource configuration values provides greater efficiencies during allocation of the available CSI resources.

[0026] In a further possible implementation form of the processing node according to the first aspect as such or according to any one of the previous possible implementation forms of the first aspect the one or more channel features include one or more of carrier frequency, beam width, beam phase, AOA/DOA, CDI, angular rotation, linear mobility, pointing error, path loss, user equipment position, and the processing node is configured to determine the desired CSI resource configuration based on the one or more channel features. This group of channel features supports a wide variety of effective adaptation algorithms.

[0027] According to a second aspect of the disclosed embodiments the above and further objects and advantages are obtained by a method that includes receiving one or more channel features, wherein the one or more channel features are associated with a radio channel corresponding to a radio link connecting an access node and a user equipment, determining one or more distinguishing channel conditions based on the received one or more channel features, determining a desired CSI resource configuration based on the distinguishing channel conditions, and adjusting a current CSI resource configuration associated with the radio channel, based on the determined desired CSI resource configuration. Adaptive allocation of CSI resources allows for improved efficiency of resource usage, improved communication, and larger numbers of UE to be served.

[0028] In a possible implementation form of the method according to the second aspect, the method includes adjusting system settings based on the desired CSI resource configuration and/or a desired channel conditions, wherein the system settings comprise one or more of a carrier frequency, a beam width, a beam phase, a beam pointing direction, and a transmit power. Active adjustment of system settings allows an access node to predictably modify the channel conditions of the served UE so CSI resources can be re-allocated in a desired way.

[0029] According to a third aspect of the disclosed embodiments the above and further objects and advantages are

obtained by a computer program product that includes non-transitory computer program instructions that when executed by a processor are configured to cause the processor to perform the method according to the second aspect as such or according to the first possible implementation form of the second aspect. Adaptive allocation of CSI resources allows for improved efficiency of resource usage, improved communication, and larger numbers of UE to be served.

BRIEF DESCRIPTION OF THE DRAWINGS

[0030] In the following detailed portion of the present disclosure, the aspects of the disclosed embodiments will be explained in more detail with reference to the example embodiments shown in the drawings, in which:

Figure 1 illustrates a flow diagram of an exemplary process for updating channel state information resource configurations incorporating aspects of the disclosed embodiments;
Figure 2 illustrates a graph of line-of-sight probability in an urban macro environment incorporating aspects of the disclosed embodiments;
Figure 3 illustrates a graphs of line-of-sight probability in an urban micro environment incorporating aspects of the disclosed embodiments;
Figure 4 illustrates a flow diagram of an exemplary method for adjusting CSI resource configurations based on coherence time approximations incorporating aspects of the disclosed embodiments;
Figure 5 illustrates a message flow diagram of an exemplary method for updating CSI configurations incorporating aspects of the disclosed embodiments;
Figure 6 illustrates a message flow diagram of an exemplary method for updating system settings incorporating aspects of the disclosed embodiments;
Figure 7 illustrates a graph of coherence times in a wireless communications network incorporating aspects of the disclosed embodiments;
Figure 8 illustrates a graph of differentiated coherence time patterns in a wireless communications network incorporating aspects of the disclosed embodiments;
Figure 9 illustrates a pictorial diagram of a wireless communication system incorporating aspects of the present disclosure;
Figure 10 illustrates a block diagram of an exemplary processing node incorporating aspects of the disclosed embodiments.

DETAILED DESCRIPTION OF THE DISCLOSED EMBODIMENTS

[0031] Figure 1 illustrates a flow diagram showing an exemplary embodiment for updating channel state information (CSI) resource configurations based on differentiated channel condition approximations (DCCA). An initial set of system settings 102 are used to establish a radio link between an access node and one or more user equipment (UE) being served by the access node (AN). The term "radio link" as used herein generally refers to a two way radio frequency communication link between two transceivers or transmitter-receivers over which information may be exchanged. For example a radio link is formed between an access node and a user equipment when the user equipment connects to the access node and begins exchanging information. The terms "channel" and "radio channel" are used herein to refer to the path or paths traveled by radio signals sent and/or received over a radio link. "System settings" or "setting" refers to values that may be configured in a transmitter or receiver that are associated with the physical layer of a radio link. System settings may include various physical layer values such as carrier frequency, beam width, beam phase, beam pointing direction, transmit power, etc.

[0032] In one embodiment, referring also to Figures 9 and 10, channel features are received 104 by a processing node 900 for some or all of the radio channels corresponding to a radio link or channel 1032 connecting an access node 1018 and the one or more UE 1020 being served by the access node 1018. Channel features provide information useful for adapting CSI resource configurations and system settings and may be used to improve overall radio resource usage. Additional channel features may be derived from the received channel features as desired.

[0033] Channel features may be detected and/or otherwise recognized and include information useful for describing the radio channels within a radio link. Certain channel features may be obtained directly from the system configuration such as the system settings described above. Other channel features may be detected from measurements. For example beam pointing direction can be directly obtained from the measured channel direction indicator (CDI). Mobility can be obtained from the time difference of arrival (TDOA) or fingerprint positioning, for example. Additional channel features can be inferred or derived from other features or measurements. For example, the pointing error can be inferred from mobility features where a UE with high mobility may have a high pointing error, while a UE with low mobility may have a small pointing error. Other channel features may be determined based on historical values through the use of various modeling techniques such as statistical modeling or heuristic modeling. For example the velocity of a UE can be estimated

through analysis of past UE position or location measurements.

[0034] Channel features are used to determine 114 distinguishing channel conditions (DCC) that may be used to identify differences among the various radio channels being used to service UE. Differences among the radio channels can be exploited by an access node, such as access node 1018 to improve how CSI resources are allocated and scheduled to each UE 1020 being served. Channel conditions used to distinguish the radio channels may include conditions such as line of sight (LOS), non-line of sight (NLOS) with strong reflections or dominant paths, pointing error, NLOS without dominant paths (or can be termed as Rayleigh condition).

[0035] In certain embodiments, it may be advantageous to determine differentiated channel condition approximations (DCCA) 108, 110, 112 for each radio channel based on the associated DCC and received channel features. When DCCA determination is used a DCCA 108, 110, 112 may be determined for each radio channel between a UE and the serving access node, where the DCCA 108, 110, 112 provides information useful for allocation and scheduling of CSI resources. The DCCA 108, 110, 112 may be any appropriate value or modeling technique suitable for determining an amount of CSI resources to be allocated to each radio channel. As will be discussed further below, one example of an appropriate DCCA is a differentiated coherence time approximation (DCTA). The DCCA 108, 110, 112 associated with each UE may be determined based on different modeling or approximation techniques using any of the channel features, DCA, or other information known about the radio channels or UE. This differentiation between the radio channels allows different CSI resource configurations to be allocated to different radio channels. For example a slowly varying radio channel with a long coherence time requires fewer CSI reports than a rapidly varying radio channel with a relatively short coherence time.

[0036] Based on the system scheduling criteria, the DCCA, which in certain embodiments may be a DCTA, are mapped to differentiated scheduling periods or more generally to a desired CSI resource configuration for each radio channel. Available radio resources are mapped and scheduled 116 base on system scheduling criteria, the determined DCCA 108, 110, 112, the received channel features, and/or the DCC. Mapping and scheduling 116 is guided by both system scheduling criteria as well as the DCCA 108, 110, 112 to determine or allocate 126 a desired CSI resource configuration 118, 120, 122 for each radio channel. The differentiation among radio channels indicated by the DCCA 108, 110, 112 determination 114 allows algorithms for mapping and scheduling to more efficiently and intelligently adjust 126 CSI resource configurations 118, 120, 122 to maximize radio resource usage. For example, CSI resources used by a stable or slowly varying radio channel may be reduced, and the recovered CSI resources may then be allocated to a less stable or faster varying radio channel.

[0037] Alternatively, in certain embodiments, desired CSI resource configurations may be determined 126 based on historical values of DCC and channel features. Statistical and/or heuristic modeling techniques may be applied to the DCC and/or channel features and configured for selection of, or determination 126 of a desired CSI resource configuration. The statistical/heuristic model can also be updated as new information is obtained about the radio channels.

[0038] In certain embodiments, system settings may be adjusted 124 to further differentiate the radio channels and improve effectiveness of CSI resource configuration determination 126. Determination 126 of DCCA 108, 110, 112 along with information obtained during mapping and scheduling 116, such as the desired CSI resource configurations, may be used to adjust 124 the system settings in a way that allows reduction of CSI resources allocated to some radio channels thereby freeing up CSI resources that may then be used by other radio channels.

[0039] Modern wireless communication systems are beginning to implement techniques such as beamforming that provide for significant differentiation of channel conditions among the radio channels being served by an access node. Further it is possible in these new systems to predictably influence channel conditions through modification of the system settings allowing active control of differentiation among the radio channels.

[0040] Any appropriate metric may be used as the DCCA such as for example, differentiated coherence time approximation (DCTA) and differentiated angular spread (DCAS). Coherence time is an interval of time over which the impulse response of a radio channel remains substantially unchanged or unvarying. The angular spread (AS) is an angular range within which about 95 percent of the channel energy is concentrated. For a LOS channel the AS is usually below about 2 degrees. For a NLOS channel with a dominate path, the AS is usually no more than about 20 degrees and about 95 percent of the channel energy is concentrated on half of the direction of arrival (DoA) for that channel. For a NLOS channel that does not have a dominant path, the AS is larger than 20 degrees and there is substantially no sparsity in terms of the DoA. This variation of AS among different radio channels allows the AS to be used to differentiate the radio channels making it an appropriate value for use as a DCCA.

[0041] As an aide to understanding it is instructive to illustrate portions of the above embodiments with examples based on coherence times. Coherence time provides a measure of channel stability and can be used when allocating CSI resources to the radio channels servicing the UE. Radio channels with relatively short coherence times require more frequent CSI updates than radio channels with longer coherence times.

[0042] Conventional wireless systems approximate coherence times using Clarke's model as shown by equation 1:

$$T_c = \sqrt{\frac{9}{16\pi}} \frac{1}{f_d} \cong \frac{0.423}{f_d} \qquad \text{eq. 1}$$

[0043] where f_d is the maximum Doppler frequency shift associated with the radio channel. Coherence time approximations derived using Clarke's model, eq. 1, hereinafter referred to as Clarke's coherence time, provide an approximation of coherence time related only to UE speed. The faster a UE moves, the faster the radio channel changes and the smaller the coherence time becomes. Thus coherence time approximations in conventional wireless systems, such as Long Term Evolution (LTE) based wireless communication systems, are related only to UE speed.

[0044] Coherence time approximations may also be determined using channel quality indicator (CQI) values which in certain embodiments may be a simple index value. CQI values may be based on channel measurements such as signal to noise ratio (SNR) information and are also sometimes used to select transmission schemes such as modulation and coding schemes (MCS).

[0045] Clarke's coherence time may be used as a trigger for scheduling data packets, or it may be used for calculating the delay associated with a data packet. To accomplish this, the UE being served by an access node are categorized into different speed levels. All UE belonging to the same speed level are assigned one scheduling update period and the UE belonging to a different speed level are assigned a different scheduling update period. With this approach, Clarke's coherence time is calculated for each UE. When the Clarke's coherence time value is greater than the scheduling update period, the corresponding UE are allocated a higher scheduling priority.

[0046] Clarke's coherence time model, eq. 1, assumes that incoming signals arrive uniformly over the full 360 degree angular range. This assumption usually holds under rich scattering environments with omnidirectional reception and low frequency carriers, such as below 2.6 GHz as used in some older 2G/3G/4G type wireless systems. However, it is expected that next generation wireless systems will be configured with a large number of antennas and/or higher frequencies, such as for example 3.5 GHz, 5 GHz, 10 GHz, 15GHz. It is also likely that beamforming will be implemented to take advantage of benefits provided by large antennas and/or for overcoming drawbacks of higher frequencies such as path loss. Therefore, beam-centric wireless systems, such as massive multi-input multi-output (MaMIMO) systems, will have much more variation or differentiation among the radio channels than conventional wireless systems.

[0047] Figure 2 illustrates a graph 200 showing the line of sight (LOS) probability 206 (i.e. the probability that a radio link connecting a UE to an access node will be a LOS radio link) for an Urban Macro use case with inter site distance (ISD) of 500 meters. Figure 3 illustrates a graph 300 showing the LOS probability 306 for an Urban Micro use case with an inter-site distance of 200 meters. In graphs 200 and 300 the inter-site distance is shown in meters along the horizontal axis 204, 304 and the probability is shown along the vertical axis 202, 302. Table 1 shows the system parameters used for the Urban Macro (UMa) and the Urban Micro (UMi) use cases illustrated in the graphs 200 and 300.

Table 1 System Parameter Configuration

	BS height	Carrier frequency	ISD	UE height	UE distribution	UE mobility	Min UE-eNB distance
UMa	25 m	2 GHz	500 m	1 m	Uniform	3 km/h	35 m
UMi	10 m	2 GHz	200 m	1 m	Uniform	3 km/h	10

[0048] As illustrated in Figures 2 and 3 there is a fairly good probability of having a LOS radio channel when the UE is close to the access node. Unfortunately, Clarke's model does not yield as accurate an approximation of coherence time in LOS radio channels as may be available through other coherence time modeling techniques, and therefore may not be appropriate for approximating coherence time in next generation beam-centric wireless communication systems.

[0049] Using CQI measurements for approximating coherence time can be effective for highly scattered Rayleigh fading channels, where the LOS probability is rare. The CQI index is a one dimensional reflection of signal power in the form of SNR and neglects the phase information. Therefore it is fundamentally difficult to estimate the actual coherence time for beam channels using CQI.

[0050] Various alternatives to the Clarke's model, eq. 1, are available for approximating coherence times for radio channels with differing characteristics. For example, coherence time for radio channels with a LOS condition can be modeled using an LOS coherence time model, also referred to herein as an LOS model, as shown in equation 2:

$$T_c = \frac{D_\lambda}{f_d \sin(\alpha_{los})} cos^{-1}(2\theta^2 logR + 1) \quad \text{eq. 2}$$

where the quantity $D_\lambda = \frac{D}{\lambda}$, and D is the transmit-receive distance, λ is the carrier wavelength, α_{los} is the direction toward the transmitter, θ is the beam width, and R is the channel correlation.

[0051] For radio channels experiencing a non-line of sight condition (NLOS), the coherence time associated with the dominant NLOS path, which is usually caused by strong reflections, can, when the pointing error is small, be modeled with a NLOS small pointing error model as shown in equation 3:

$$T_c = \frac{1}{f_d} \sqrt{\frac{1/_{R^{4-1}}}{(2\pi)^2\theta^4 + \frac{1}{2\theta^4 R^4}(\frac{sin\mu_r}{D_{r,\lambda}})^2}} \quad \text{eq. 3}$$

where the quantity $D_{r,\lambda} = \frac{D_r}{\lambda}$ is the scatter-receive distance D_r normalized by the carrier wavelength λ, and μ_r is the pointing direction.

[0052] When an NLOS radio channel with a dominant path has large pointing error, the coherence time can be approximated using a NLOS large pointing error model as shown in equation 4:

$$T_c = \sqrt{\frac{1 - (1 + \theta^4 \log R)^2}{\frac{1}{4}(1 + \theta^2 logR)(\frac{f_d sin\mu_r}{D_{r\lambda}})^2 (2\pi f_d)^2 \theta^4}} \quad \text{eq. 4}$$

[0053] Referring now to Figure 4 there can be seen an exemplary embodiment of a method 400 for actively adjusting CSI resource configurations and actively adjusting system settings in a wireless communication system. Conventional wireless systems typically fix the CSI resource configurations and system settings when a UE connects. In contrast, the exemplary method 400 continually and repeatedly adjusts the CSI resource allocations and system settings to enhance communications between an access node and the UE it is serving. The illustrated embodiment advantageously adjusts CSI resource configurations to enhance communication with UE being served and/or to increase the number of UEs being served. The illustrated embodiment is further configured to actively adjust system settings such that further differentiation among the radio channels is achieved thereby enhancing benefits provided through active allocation of the CSI resources. The exemplary embodiment illustrates the use of DCTA as the DCCA, however those skilled in the art will readily recognize that any suitable metric or measure may be advantageously employed as a DCCA.

[0054] The method 400 begins with an initial set of system settings 402 which are used to establish a radio link between an access node and one or more user equipment being served by the access node. Next channel features are recognized 404 and/or detected based on information gathered about each radio link being maintained by an access node. In certain embodiments recognition/detection 404 of the channel features may be performed by other processes or methods and be received by the method 400.

[0055] Channel features may be any useful value associated with a radio link including known values such as system parameters or settings etc., measured values such as SNR, etc., or derived or determined values such as UE speed, direction, or distance, etc.

[0056] The linear mobility of a UE and/or its position may be estimated from measurements such as round trip time (RTT), time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (AoA), received signal strength indication (RSSI), and/or global position system (GPS). Angular mobility may be estimated based on the AoA/DOA, CDI, the change of beam phase, as well as other measured or detected values.

[0057] The accuracy of any mobility estimations is not important to the operation of the method 400. A UE may be categorized into different mobility levels where the range between each mobility level is large enough to tolerate the presence of positioning error. For example, a UE may be categorized into two linear mobility levels, a high level (such as above 15 kilometers per hour) and low level (such as below 15 kilometers per hour). Angular mobility may be similarly categorized as high level (such as above 10 degrees) and a low level (such as below 10 degrees).

[0058] Pointing direction may be directly obtained from the CDI and/or AoA and direction of arrival (DoA) measurements.

The CDI is used in LTE wireless communication systems, and especially in LTE-A systems, for providing quantized information about the favored beamforming direction. The AoA/DoA is one of the defined measurements required by wireless communication system standards such as the 3GPP LTE standards.

[0059] In a NLOS beam channels, there is pointing error between the UE and the reflected beams due to mobility of the UE. When the UE moves in a linear and/or an angular direction, the set of scatters seen at the UE will be different if the beam is not adaptive. This effect is referred to as pointing error. The UE can be correspondingly inferred as large pointing error if at least one of the linear or angular levels is high. Otherwise a small pointing error may be assigned.

[0060] When there are no dominant LOS or NLOS paths, the channel condition can be recognized as having a Rayleigh condition.

[0061] The above discussed channel features may be detected from system settings, measurements, and/or obtained from other channel features as summarized in Table 2.

Table 2 The Relation between Channel Condition and feature

Conditions	*LOS*	*Linear mobility*	*Angular rotation*	*Pointing direction*	*Pointing error*	*Rayleigh*
Measurements or features	Angle spread, delay spread, RSRP, RSSI, CQI, etc.	RTT, TOA, TDOA, AOA, RSSI, GPS, etc.	AOA, DOA, beam phase, *linear mobility*, etc.	CDI, AOA, DOA, *linear mobility*, etc.	AOA, DOA, beam phase, *linear mobility, angular rotation,* etc.	Angle spread, delay spread, RSRP, RSSI, CQI, etc.

[0062] The channel features 404 are used to determine 416 a DCTA based on the coherence time models described above. LOS/NLOS, dominant path, and pointing error are determined 436 to distinguish the radio channel, then a series of decisions 406, 408, 410, 418 are used to select an appropriate coherence time model such as for example from the above described coherence time approximations shown in eq. 1, eq. 2, eq. 3, and eq. 4.

[0063] When the radio channel is LOS 406, then an LOS coherence time model, eq. 2, is used to determine 414 a DCTA. When the radio channel is NLOS with a dominant path 408 and the pointing error is small 418y, a small pointing error coherence time model, eq. 3, is used to determine 422 the DCTA. When the radio channel is NLOS with a dominant path 408 and the pointing error is not small 418n, then a large pointing error coherence time model, eq. 4, is used to determine 424 the DCTA. When the radio channel is NLOS and has no dominant path, the

[0064] radio channel is treated as Rayleigh fading 410 and Clarke's coherence time model, eq. 1, may be used to determine 420 a DCTA for the radio channel.

[0065] Any or all of the determined coherence times 414, 422, 424, may then be used in a mapping and scheduling procedure 428 to determine a desired CSI resource configuration 434. Determination of a desired CSI resource configuration 434 may be done with any suitable mapping and scheduling 428 procedure or algorithms. The scheduling criterions can be pre-developed according to specific system design requirements and may include for example CSI event reduction, maximizing system throughput, maximizing the number of UE being served by an access node, maximizing reliability, balancing system load, etc. A scheduler may have several scheduling criterions that can be applied according to different system requirements and these scheduling criterions may be selected or modified as system requirements or conditions change.

[0066] An exemplary embodiment of suitable mapping and scheduling 428 appropriate for use with a DCTA is illustrated below. In the illustrated embodiment the system is configured to use periodic CSI, such as periodic CSI reports and/or periodic SRS, and the mapping and scheduling 428 selects an appropriate CSI period based on the coherence time approximations for each channel. As used herein the term CSI period refers to a period used for any periodic CSI resources, such as for example, the CSI reporting period associated with periodic CSI reports and the SRS transmission period associated with periodic SRS transmission.

[0067] When the system budget includes sufficient CSI resources to support all UE being served by an access node, a first scheduling approach may be used as illustrated in eq. 5 below. A desired CSI period may be determined by selecting the largest CSI period supported by the system that is smaller than the coherence time of the radio channel. This CSI period selection can be expressed for the k^{th} UE in a set of UE being serviced by an access node as shown in equation 5:

$$T_{csi,k} = \min_j arg\left(\frac{\lfloor T_{c,k} \rfloor}{T_{p,j}} - 1\right) \text{ with } \frac{\lfloor T_{c,k} \rfloor}{T_{p,j}} - 1 > 0 \qquad \text{Eq. 5}$$

where $T_{csi,k}$ is the desired CSI period to be allocated for the k[th] UE, $T_{c,k}$ is the approximated coherence time determined 416 for the k[th] UE, $T_{p,j}$ is the j[th] supported CSI period in the set of CSI periods supported by the system, and $\lfloor \bullet \rfloor$ is the floor operator. In certain wireless communication systems the CSI period for transmission of periodic SRS can be as small as 2 milliseconds or as large as once every 160 milliseconds.

[0068] When the system does not have enough CSI resources available to meet the requirements of all UE being serviced by an access node, an alternative approach for scheduling CSI resource configurations may be used. A scheduling offset ΔT_k may be calculated for each UE as:

$$\Delta T_k = \lfloor T_{c,k} \rfloor - T'_{csi,k} \text{ for } k = 1, \ldots, K \qquad \text{Eq. 6}$$

where K is the total number of UE being serviced by the access node, and the scheduling offset ΔT_k represents the difference between the coherence time approximation for the k[th] UE $T_{c,k}$ and the currently allocated CSI period $T'_{csi,k}$ for the k[th] UE. A UE having a positive scheduling offset ΔT_k has an approximated coherence time $T_{c,k}$ that is greater than the current CSI reporting period $T'_{csi,k}$. A positive scheduling offset ΔT_k provides an opportunity to recover CSI resources by increasing the CSI period. Conversely, a UE having a negative scheduling offset ΔT_k has an approximated coherence time $T_{c,k}$ that is smaller than the current CSI reporting period $T'_{csi,k}$. A UE with negative scheduling offset ΔT_k will require additional CSI resources to maintain efficient radio communications.

[0069] In one embodiment the mapping and scheduling 428 can begin by recovering CSI resources from UE that are currently allocated more CSI resources than needed as may be indicated by a positive scheduling offset ΔT_k. UE having a positive scheduling offset ΔT_k can be sorted in descending order:

$$SP_{increase} = sort\,(\Delta T_k, descending) \text{ for } k = 1, \ldots, M, \qquad \text{Eq. 7}$$

where M is the number of UE with positive scheduling offset ΔT_k, $M \leq K$, and K is the number of UEs being served by the access node. The scheduling priority $SP_{increase}$ for increasing the CSI period is based on the sorting order obtained from eq. 7.

[0070] Next the mapping and scheduling 428 may be configured to allocate additional CSI resources to UE that have a negative scheduling offset ΔT_k. UE with negative scheduling offset ΔT_k are given a scheduling priority as shown by the following equation:

$$SP_{decrease} = sort\,(-\Delta T_k, descending) \text{ for } k = 1, \ldots, N, \qquad \text{Eq. 8}$$

where N is the number of UE having a negative scheduling offset ΔT_k, and $N \leq K$. Then a scheduling priority for decreasing the CSI period $SP_{decrease}$ is performed in the descending order as shown in eq. 8.

[0071] The desired CSI period, or desired CSI resource configuration, is used to adaptively allocate and adjust the CSI resources 432 for each UE. The scheduling offset ΔT_k can be used for triggering the CSI reconfiguration 432 as desired. For example, the scheduling offset ΔT_k may be compared to a pre-determined time difference and configured to trigger CSI adjustment 432 when the pre-determined time difference or threshold value is exceeded. Alternatively a pre-determined ratio or percentage may be used as a threshold value to trigger CSI adjustment 432. When CSI adjustment 432 is triggered, the obtained scheduling priorities $SP_{increase}$, $SP_{decrease}$ and/or the scheduling offsets ΔT_k may be used to adaptively update the CSI resource configurations 432. In certain embodiments it may be desirable to adapt the threshold value based on current and/or past conditions of the wireless system.

[0072] In certain embodiments it may be desirable to actively adjust the system settings 412 such that a desired DCTA is obtained for some or all of the UE being served. Information 436 determined to differentiate the radio channels as well as information derived during mapping and scheduling 428 can be used to determine 430 when adjustment of the system settings may be advantageous. The system settings may then be adjusted 412 as desired. For example, information 436 obtained while determining coherence time 416 may be used to guide adjustment 412 of the system settings such that CSI resources may be shifted from one UE to another.

[0073] At times and under the right conditions adjustment of the system settings may be employed as an alternative to adjusting the CSI resource configurations. Based on the obtained scheduling priorities $SP_{increase}$, $SP_{decrease}$ and/or the scheduling offsets ΔT_k, equivalent actions can be effectively implemented by adjusting 412 the system settings to

allocate or adjust resources such as resource blocks (RBs), or by implementing UE pairing.

[0074] Figure 5 and Figure 6 illustrate signaling flow diagrams showing exemplary signaling between processing node 516, AN 518, and UE 520. In Figure 5 and Figure 6 the processing node 516 is depicted as a vertical line, the AN 518 is depicted as a vertical line, and the UE 520 is depicted as a vertical line. Messages passed between the processing node 516, the AN 518, and the UE 520 are depicted by horizontal arrows such as the horizontal arrow 502 which illustrates a message being sent from the processing node 516 to the UE 520. Time increases downward such that messages shown toward the top occur before messages shown toward the bottom. Figure 5 and Figure 6 depict the processing node 516 and the AN 518 as separate entities, however the disclosed embodiments are not so constrained and may have the functionality of both the processing node 516 and AN 518 performed by a single processing node or distributed among several processing nodes as desired.

[0075] Referring now to the message flow 500 illustrated in Figure 5, the first three messages 502, 504, and 506 illustrate messages used in conventional wireless communication systems. A processing node 516 or access node 518 sends a default CSI resource configuration message 502 to the UE 520. For example this default CSI resource configuration may indicate a periodic CSI report with a fixed CSI period of 40 milliseconds. The UE 520 then begins sending periodic CSI messages or reports 504, 506 back to the AN 518 and/or a processing node 516, such as a scheduling node. These periodic CSI reports 504, 506 may include measurements or derived values such as a rank indication (RI), a channel quality index (CQI), a pre-coding matrix indicator (PMI), beam index (BI), channel direction indicator (CDI), etc. This fixed approach to configuring CSI resources can result in UE 520, that have relatively stable or unvarying radio channels, sending more CSI reports than is necessary thereby wasting CSI resources, leaving other UE 520 that may have rapidly varying radio channels starving for CSI resources.

[0076] The problem of over-allocating CSI resources to some UE while under allocating or starving other UE may be alleviated by switching to an adaptive CSI configuration mode 508. Once the adaptive mode 508 is enabled, information about the radio channel is obtained by the AN 518 or other network node and sent 510 to the processing node 516. Channel information may include values such as carrier frequency, beam width, pointing direction, etc. In certain embodiments the channel information may also include estimated or derived information such as LOS condition, UE mobility, path loss, etc., or alternatively the processing node 516 may derive this information. The processing node 516 may use the channel information to determine a DCCA, such as for example a DCTA based on various coherence time models such as the coherence time models shown in eq. 1 through eq. 4 above.

[0077] The processing node 516 may then direct 512 the UE 520 to adjust the CSI resource configuration or the CSI period. For example the default CSI reporting period of 40 milliseconds may be lengthened to about 80 milliseconds. The UE 520 then begins sending CSI reports 514 at the adjusted CSI period. Adaptively adjusting CSI resource configurations based on DCCA provides flexible CSI resource usage allowing for improved servicing of UE 520 by an AN 518.

[0078] Figure 6 illustrates a continuation signaling flow 600 that may follow the exemplary signaling flow 500 illustrated in Figure 5 and described above. The UE 520 continues to send 602 periodic CSI reports at the adjusted CSI period which was changed when the AN 518 sent a message 512 to the UE 520.

[0079] Alternatively, or in addition to adjusting 512 the CSI resource configuration, the processing node 516 may actively adjust system settings 604 in a way that aids or improves CSI resource usage. Active adjustment of the system settings 604 is illustrated in the signal flow 600. The AN 518 provides 606 channel information such as carrier frequency, beam width, pointing direction, etc. and estimations of distinguishing channel conditions such as LOS condition, mobility, path loss etc. Alternatively, certain channel information may be derived within the processing node 516 coupled to the wireless communication network.

[0080] In one embodiment, a threshold value may be introduced to trigger 608 reconfiguration 610 of the CSI resources or adjustment of the CSI period. The threshold value may be pre-determined or adaptively adjusted based on channel information, and may be a specific time value, a ratio, or other type of threshold value used to trigger CSI resource configuration. For example, the threshold value may be a ratio such as the absolute value of the scheduling offset divided by the current CSI period $\frac{|\Delta T_k|}{T_{csi}^t}$. When triggered, an updated CSI resource reconfiguration is sent 610 to the UE 520 whereupon the UE 520 will adjust its CSI resource configuration, such as a CSI period, to a new value. For example the CSI period may be increased 610 to about 120ms.

[0081] Figure 7 illustrates a graph 700 showing coherence time approximations for changing radio channel conditions. Coherence time is depicted in seconds, increasing upwards, along a vertical axis 702. UE speed in kilometers per hour is depicted increasing to the right along a horizontal axis 704. Coherence time versus UE speed for a strong Rayleigh channel as approximated using Clarke's model, eq. 1, is shown in the bottom graph 710. Coherence time versus UE speed for a NLOS beam channel as approximated using the coherence time models shown in eq. 3 and eq. 4 is shown in the middle graph 708. Coherence time versus UE speed for a LOS channel as approximated using the coherence time model of eq. 2 is shown in the top graph 706. The graphs 700 illustrate how selecting an appropriate coherence time model can provide significantly differentiated coherence time approximations. For example the coherence time of

a Rayleigh channel 710 can be nearly 200 times shorter than the coherence time of a LOS channel 706.

[0082] Figure 8 illustrates a graph 800 showing how coherence time of a radio channel changes as a function of beam width. Coherence time is depicted in seconds increasing upwards along a vertical axis 802 and beam width is depicted in degrees along a horizontal axis 804 with beam width increasing toward the right. Coherence time for a LOS beam channel is illustrated by graph 806, and a coherence time for a NLOS beam channel is illustrate by graph 808.

[0083] A LOS beam channel 806 and a NLOS beam channel 808 have nearly the same coherence time (about 2 seconds) when the beam width is about 6 degrees. Reducing the beam width to about 2 degrees for the NLOS beam channel 808 can double the coherence to about 12 seconds. In contrast, reducing the beam width of a LOS beam channel 806 causes a reduction in the associated coherence time. Graph 800 illustrates how changing system settings, such as beam width, can change conditions of a radio channel in predictable ways, such as changing the coherence time of the radio channel. For example reducing the beam width of a NLOS channel can lengthen the coherence time of that channel thereby freeing up CSI resources for use by a channel having a short coherence time. Thus actively changing systems settings can be employed to create differentiation among UE and to improve use of available CSI resources.

[0084] Figure 9 illustrates a block diagram of an exemplary processing node 900 appropriate for implementing embodiments of the present disclosure. The illustrated processing node 900 includes a processor 902 coupled to a computer memory 904, a network interface 906, and optionally a user interface (UI) 908. The processing node 900 may be incorporated in or coupled to a wireless communication system and is appropriate for implementing any of the methods and processes described herein. The processing node 900 may be implemented as a separate processing entity, or may when desired be incorporated into an access node, UE or other entity in a wireless communication system.

[0085] The processor 902 may be a single processing device or may comprise a plurality of processing devices including special purpose devices, such as for example, digital signal processing (DSP) devices, microprocessors, and general purpose computer processors. The processor 902 may be configured to implement embodiments of the methods and apparatus for adjusting CSI resource configurations and/or system settings described herein. In certain embodiments the processor may include a CPU working in tandem with a graphics processing unit (GPU) and may include specialized DSP hardware firmware and software to handle signal processing tasks. The processor 902 may also include one or more processing cores configured for parallel processing.

[0086] The processor 902 is coupled or connected to a memory 904 which may be a combination of various types of volatile and non-volatile computer memory such as for example read only memory (ROM), random access memory (RAM), magnetic or optical disk, or other types of computer accessible memory. The memory 904 stores computer program instructions that may be accessed and executed by the processor 902 to cause the processor to perform a variety of desirable computer implemented processes or methods such as embodiments of methods for detection of channel features, adjustment of CSI resource configurations, and/or active adjustment of system settings.

[0087] The program instructions stored in memory 904 may be organized as sets or groups of program instructions often referred to in the software industry with various terms such as programs, software components, software modules, units, etc. Each module may include a set of functionality designed to support a certain purpose. For example a software module may be of a recognized type such as an operating system, an application, a device driver, or other conventionally recognized type of software component. Also included in the memory 904 are program data and data files which may be stored and processed by the processor 902 while executing a set of computer program instructions. Various portions of the program instructions may be distributed among a plurality of processing devices or processors that work together to carry out the desired methods or processes.

[0088] In certain embodiments, the processing node 900 includes a network interface 906 coupled to the processor 902 and configured to communicate with other entities in a wireless communications network 800. The network interface 906 may be of a standardized type, such as Ethernet and/or WiFi, or may be specific to a particular network implementation. In certain embodiments the network interface may include a radio frequency unit capable of communicating over a wireless communication network. Alternatively, the network interface 906 may be coupled to a wired to other physical computer communication network.

[0089] The UI 908 may include one or more user interface elements such as a touch screen, keypad, buttons, voice command processor, as well as other elements adapted for exchanging information with a user. The UI 908 may also include a display unit configured to display a variety of information appropriate for a computing device or mobile user equipment and may be implemented using any appropriate display type such as for example organic light emitting diodes (OLED), liquid crystal display (LCD), as well as less complex elements such as LEDs or indicator lamps. Alternatively, the computing apparatus may not include a UI 908 such as when the processing node 900 is configured to be controlled and administered remotely via the network interface 906.

[0090] In certain embodiments, the processing node may be coupled to an antenna array 914 or other device capable of transmitting and receiving radio signals, such as when the processing node 900 is incorporated into an access node.

[0091] Figure 10 illustrates a block diagram of an exemplary wireless communication network 1000 that may advantageously employ the methods and apparatus disclosed herein. The wireless communication network 1000 includes

three cells 1010, 1016, 1022 with each cell having an access node 1012, 1018, 1024 configured to service one or more UE 1014, 1020, 1026, 1028, 1030. The wireless communication network 1000 may include more or less than three cells, and each cell may include more than one access node, and service any number of zero or more UE. An access node 1018 is configured to communicate with one or more UE 1020, 1028, 1030 over respective radio links 1032, 1034, 1036.

[0092] A processing node 1050 is coupled to the access node 1018 and may be configured to adjust CSI resource configurations and/or system settings associated with each radio link 1032, 1034, 1036 in accordance with any of the methods disclosed herein. The processing node 1050 may be configured as a separate processing node 1050 coupled to one or

[0093] more access nodes 1012, 1018, 1024. Alternatively the processing node 1050 may be incorporated within an access node 1018, or distributed among other processing devices within the wireless communications network 1000.

[0094] In certain embodiments, the processing node 1050, may be incorporated within a UE 1014, 1020, 1026, 1028, 1030. When incorporated into a UE 1020, 1028, 1030, the processing node 1050 may be configured adjust the CSI resource configuration by sending a desired CSI resource configuration to the serving access node 1018 whereupon receiving the desired CSI resource configuration, the serving access node 1018 will coordinate the desired adjustment.

Claims

1. A processing node (900) coupled to a wireless communications network (1000), the processing node (900) being configured to:

receive one or more channel features, wherein the one or more channel features are associated with a radio channel corresponding to a radio link (1032) connecting an access node (1018) and a user equipment (1020);
determine one or more distinguishing channel conditions based on the received one or more channel features;
determine a desired channel state information, CSI, resource configuration based on the one or more distinguishing channel conditions;
allocate the desired CSI resource configuration based on the desired CSI resource configuration; and
adjust a current CSI resource configuration associated with the radio channel, based on the determined desired CSI resource configuration,

wherein the processing node (900) is configured to determine a desired CSI resource configuration by:

selecting a differentiated coherence time model from a plurality of differentiated coherence time models, wherein the plurality of differentiated coherence time models comprise one or more of a Clarke's model, an LOS model, a NLOS small pointing error model, and a NLOS large pointing error model; compute a differentiated coherence time approximation based on the selected differentiated coherence time model; and determine the desired CSI resource configuration based on the determined differentiated coherence time approximation,

wherein the Clarke's model is defined as:

$$T_c = \sqrt{\frac{9}{16\pi}}\frac{1}{f_d} \cong \frac{0.423}{f_d} ,$$

wherein T_C is a coherence time,
wherein f_d is a maximum Doppler frequency shift associated with the radio channel,

wherein the LOS model is defined as:

$$T_c = \frac{D_\lambda}{f_d \sin(\alpha_{los})} cos^{-1}(2\theta^2 logR + 1) ,$$

wherein $D_\lambda = \frac{D}{\lambda}$, and D and *D* is the transmit-receive distance, λ is the carrier wavelength,
α_{los} is a direction towards a transmitter
θ is the beam width,
R is the channel correlation,

Wherein the NLOS small pointing error model is defined as:

$$T_c = \frac{1}{f_d}\sqrt{\frac{{}^{1}/_{R^{4-1}}}{(2\pi)^2\theta^4+\frac{1}{2\theta^4R^4}(\frac{sin\mu_r}{D_{r,\lambda}})^2}},$$

wherein $D_{r,\lambda} = \frac{D_r}{\lambda}$ is a scatter-receive distance D_r normalized by the carrier wavelength λ, and μ_r is a pointing direction, and
wherein the NLOS large pointing error model is defined as:

$$T_c = \sqrt{\frac{1-(1+\theta^4\log R)^2}{\frac{1}{4}(1+\theta^2 logR)(\frac{f_d sin\mu_r}{D_{r\lambda}})^2(2\pi f_d)^2\theta^4}}$$

2. The processing node (900) of claim 1, wherein the processing node (900) is further configured to actively adjust (124) a system setting based on one or more of: the one or more channel features; the one or more distinguishing channel conditions; the desired CSI resource configuration; a desired channel condition; and an available CSI resource pool.

3. The processing node (900) of claims 1 or 2, wherein the processing node (900) is configured to:

determine a differentiated channel condition approximation based on the one or more channel features and the one or more differentiating channel conditions; and
determine the desired CSI resource configuration based on a mapping of the one or more differentiating channel condition approximations to the desired CSI resource configuration.

4. The processing node (900) according to any of the claims 1 to 3, wherein the processing node (900) is configured to select, when the radio channel is determined to be in a LOS condition, the LOS model as the differentiated coherence time model.

5. The processing node (900) according to any of the claims 1 to 4, wherein the processing node (900) is configured to select, when the radio channel is determined to be in a dominant NLOS condition with small pointing error, the NLOS small pointing error model as the differentiated coherence time model.

6. The processing node (900) according to any of the claims 1 to 4, wherein the processing node (900) is configured to select, when the radio channel is determined to be in a dominant NLOS condition with large pointing error, the NLOS large pointing error model as the differentiated coherence time model.

7. The processing node (900) according to any of the claims 1 to 4, wherein the processing node (900) is configured to select the differentiated coherence time model as a statistical data based model, and to compute the differentiated coherence time approximation based on the statistical data based model.

8. The processing node (900) according to claim 7, wherein the processing node (900) is configured to update the statistical data based model based on historical data.

9. The processing node (900) according to any one of the preceding claims, wherein the desired CSI resource configuration comprises one or more of a desired CSI period, a desired number of resource blocks, a desired position of resource blocks, a desired type of combs, and a desired phase rotation, and the current CSI resource configuration comprises a corresponding one or more of a current CSI period, a current number of resource blocks, a current position of resource blocks, a current type of combs, and a current phase rotation, and wherein the processing node (900) is configured to adjust the current CSI resource configuration when a difference between the desired CSI resource configuration and the current CSI resource configuration exceeds a threshold value.

10. The processing node (900) according to any one of the preceding claims wherein the one or more distinguishing channel conditions comprise a plurality of distinguishing channel conditions, the plurality of distinguishing channel conditions being associated with a plurality of radio channels, wherein each radio channel in the plurality of radio channels corresponds to a radio link (1032) connecting the access node (1018) to one user equipment (1020) in a plurality of user equipment (1020, 1028, 1030), the processing node (900) being configured to:

select for each radio channel in the plurality of radio channels a differentiated coherence time model from the plurality of coherence time models based on the distinguishing channel conditions associated with the each radio channel;
determine a differentiated coherence time approximation for each radio channel in the plurality of radio channels based on the corresponding selected coherence time model and the associated distinguishing channel conditions;
determine for each radio channel in the plurality of radio channels a desired CSI configuration based on the determined differentiated coherence time approximations and/or a current CSI allocation; and,
adjust one or more current CSI resource configurations based on the corresponding determined desired CSI resource allocation, wherein each radio channel in the plurality of radio channels is associated with one of the one or more current CSI resource configurations.

11. The processing node (900) according to claim 12 wherein the wireless communications network (1000) comprises a set of available CSI resource configurations, and

when the wireless communications network (1000) comprises sufficient CSI resources to satisfy all the desired CSI resource configurations, the processing node (900) is configured to assign, for each radio channel in the plurality of radio channels, a new CSI resource configuration from the set of available CSI resource configurations; and
when the wireless communications network (1000) comprises insufficient CSI resources to satisfy all the desired CSI resource configurations, the processing node (900) is configured to recover extra CSI resources by reducing an amount of CSI resources being used by radio channels having more CSI resources than required by the corresponding desired CSI resource configuration, and allocate the recovered extra CSI resources to radio channels having fewer CSI resources than required by the corresponding desired CSI resource configuration.

12. A method (100) comprising:

receive (104) one or more channel features, wherein the one or more channel features are associated with a radio channel corresponding to a radio link connecting an access node and a user equipment;
determine (114) one or more distinguishing channel conditions based on the received one or more channel features;
determine (116) a desired channel state information, CSI, resource configuration based on the distinguishing channel conditions; and,
adjust (126) a current CSI resource configuration associated with the radio channel, based on the determined desired CSI resource configuration, wherein the desired CSI resource configuration is determined by:
selecting a differentiated coherence time model from a plurality of differentiated coherence time models, wherein the plurality of differentiated coherence time models comprise one or more of a Clarke's model, an LOS model, a NLOS small pointing error model, and a NLOS large pointing error model; computeing a differentiated coherence time approximation based on the selected differentiated coherence time model; and determine the desired CSI resource configuration based on the determined differentiated coherence time approximation,

wherein the Clarke's model is defined as:

$$T_c = \sqrt{\frac{9}{16\pi}} \frac{1}{f_d} \cong \frac{0.423}{f_d} ,$$

wherein T_C is a coherence time,
wherein f_d is a maximum Doppler frequency shift associated with the radio channel,

wherein the LOS model is defined as:

$$T_c = \frac{D_\lambda}{f_d \sin(\alpha_{los})} \cos^{-1}(2\theta^2 logR + 1)\ ,$$

wherein $D_\lambda = \frac{D}{\lambda}$, and D and *D* is the transmit-receive distance,λ is the carrier wavelength,
α_{los} is a direction towards a transmitter
θ is the beam width,
R is the channel correlation,

wherein the NLOS small pointing error model is defined as:

$$T_c = \frac{1}{f_d} \sqrt{\frac{1/_{R^{4-1}}}{(2\pi)^2\theta^4 + \frac{1}{2\theta^4 R^4}(\frac{sin\mu_r}{D_{r,\lambda}})^2}},$$

wherein $D_{r,\lambda} = \frac{D_r}{\lambda}$ is a scatter-receive distance D_r normalized by the carrier wavelength λ, and μ_r is a pointing direction, and wherein the NLOS large pointing error model is defined as:

$$T_c = \sqrt{\frac{1 - (1 + \theta^4 \log R)^2}{\frac{1}{4}(1 + \theta^2 logR)(\frac{f_d sin\mu_r}{D_{r\lambda}})^2 (2\pi f_d)^2 \theta^4}}$$

13. The method (100) according to claim 12 further comprising adjusting (124) a system settings based on the desired CSI resource configuration and/or a desired channel conditions, wherein the system settings comprise one or more of a carrier frequency, beam width, beam phase, beam pointing direction, and transmit power.

14. A computer program product comprising non-transitory computer program instructions that when executed by a processor (902) are configured to cause the processor (902) to perform the method according to claim 12 or 13.

Patentansprüche

1. Verarbeitungsknoten (900), der mit einem drahtlosen Kommunikationsnetzwerk (1000) gekoppelt ist, wobei der Verarbeitungsknoten (900) zu Folgendem konfiguriert ist:

Empfangen eines oder mehrerer Kanalmerkmale, wobei das eine oder die mehreren Kanalmerkmale mit einem Funkkanal assoziiert sind, der einer Funkverbindung (1032) entspricht, die einen Zugangsknoten (1018) und ein Benutzergerät (1020) verbindet;
Bestimmen einer oder mehrerer Kanalunterscheidungsbedingungen auf Grundlage des einen oder der mehreren empfangenen Kanalmerkmale;
Bestimmen einer gewünschten Kanalstatusinformation-Ressourcenkonfiguration (CSI-Ressourcenkonfiguration),auf Grundlageder einen oder mehreren Kanalunterscheidungsbedingungen;
Zuweisen der gewünschten CSI-Ressourcenkonfiguration auf Grundlage der gewünschten CSI-Ressourcenkonfiguration; und
Anpassen einer aktuellen CSI-Ressourcenkonfiguration, die mit dem Funkkanal assoziiert ist, auf Grundlage der bestimmten gewünschten CSI-Ressourcenkonfiguration, wobei der Verarbeitungsknoten (900) dazu konfiguriert ist, eine gewünschte CSI-Ressourcenkonfiguration durch Folgendes zu bestimmen:
Auswählen eines differenzierten Kohärenzzeitmodells aus einer Vielzahl von differenzierten Kohärenzzeitmodellen, wobei die Vielzahl von differenzierten Kohärenzzeitmodellen eines oder mehrere eines Clarke-Modells, eines LOS-Modells, eines NLOS-Modells für kleine Ausrichtungsfehler und eines NLOS-Modells für große Ausrichtungsfehler umfasst;
Berechnen einer differenzierten Kohärenzzeitnäherung auf Grundlagedes ausgewählten differenzierten Kohärenzzeitmodells; und Bestimmen der gewünschten CSI-Ressourcenkonfiguration auf Grundlage der bestimmten

differenzierten Kohärenzzeitnäherung;
wobei das Clarke-Modell wie folgt definiert ist:

$$T_c = \sqrt{\frac{9}{16\pi}} \frac{1}{f_d} \cong \frac{0.423}{f_d} ,$$

wobei T_C eine Kohärenzzeit ist,
wobei f_d eine maximale Doppler-Frequenzverschiebung ist, die mit dem Funkkanal assoziiert ist,
wobei das LOS-Modell wie folgt definiert ist:

$$T_c = \frac{D_\lambda}{f_d \sin(\alpha_{los})} cos^{-1}(2\theta^2 logR + 1) ,$$

wobei $D_\lambda = \frac{D}{\lambda}$ und D und D die Sende-Empfangs-Entfernung ist, λ dieTrägerwellenlänge ist,
α_{los} eine Richtung hin zu einem Sender ist
θ die Strahlbreite ist,
R die Kanalkorrelation ist,
Wobei das NLOS-Modell für kleine Ausrichtungsfehler wie folgt definiert ist:

$$T_c = \frac{1}{f_d} \sqrt{\frac{{}^1/_{R^4-1}}{(2\pi)^2\theta^4 + \frac{1}{2\theta^4 R^4}(\frac{sin\mu_r}{D_{r,\lambda}})^2}},$$

wobei $D_{r,\lambda} = \frac{D_r}{\lambda}$ eine Streuungs-Empfangs-Entfernung D_r ist, die durch dieTrägerwellenlänge A normalisiert ist und μ_r eine Ausrichtungsrichtung ist, und
wobei das NLOS-Modell für große Ausrichtungsfehler wie folgt definiert ist:

$$T_c = \sqrt{\frac{1 - (1 + \theta^4 \log R)^2}{\frac{1}{4}(1 + \theta^2 logR)(\frac{f_d sin\mu_r}{D_{r\lambda}})^2 (2\pi f_d)^2 \theta^4}}$$

2. Verarbeitungsknoten (900) nach Anspruch 1, wobei der Verarbeitungsknoten (900) ferner dazu konfiguriert ist, eine Systemeinstellung auf Grundlage von einem oder mehreren des Folgenden aktiv anzupassen (124): dem einen oder den mehreren Kanalmerkmalen; der einen oder den mehreren Kanalunterscheidungsbedingungen; der gewünschten CSI-Ressourcenkonfiguration; einer gewünschten Kanalbedingung; und einem verfügbaren CSI-Ressourcenpool.

3. Verarbeitungsknoten (900) nach Anspruch 1 oder 2, wobei der Verarbeitungsknoten (900) zu Folgendem konfiguriert ist:

Bestimmen einer differenzierten Kanalbedingungsnäherung auf Grundlage des einen oder der mehreren Kanalmerkmale und der einen oder den mehreren differenzierenden Kanalbedingungen; und
Bestimmen der gewünschten CSI-Ressourcenkonfiguration auf Grundlage einer Zuordnung der einen oder mehreren differenzierenden Kanalbedingungsnäherungen zu der gewünschten CSI-Ressourcenkonfiguration.

4. Verarbeitungsknoten (900) nach einem der Ansprüche 1 bis 3, wobei der Verarbeitungsknoten (900) dazu konfiguriert ist, das LOS-Modell als das differenzierte Kohärenzzeitmodell auszuwählen, wenn bestimmt wird, dass sich der Funkkanal in einer LOS-Bedingung befindet.

5. Verarbeitungsknoten (900) nach einem der Ansprüche 1 bis 4, wobei der Verarbeitungsknoten (900) dazu konfiguriert

ist, das NLOS-Modell für kleine Ausrichtungsfehler als das differenzierte Kohärenzzeitmodell auszuwählen, wenn bestimmt wird, dass sich der Funkkanal in einer dominanten NLOS-Bedingung mit kleinem Ausrichtungsfehler befindet.

6. Verarbeitungsknoten (900) nach einem der Ansprüche 1 bis 4, wobei der Verarbeitungsknoten (900) dazu konfiguriert ist, das NLOS-Modell für große Ausrichtungsfehler als das differenzierte Kohärenzzeitmodell auszuwählen, wenn bestimmt wird, dass sich der Funkkanal in einer dominanten NLOS-Bedingung mit großem Ausrichtungsfehler befindet.

7. Verarbeitungsknoten (900) nach einem der Ansprüche 1 bis 4, wobei der Verarbeitungsknoten (900) dazu konfiguriert ist, das differenzierte Kohärenzzeitmodell als ein auf statistischen Daten basierendes Modell auszuwählen und die differenzierte Kohärenzzeitnäherung auf Grundlage des auf statistischen Daten basierenden Modells zu berechnen.

8. Verarbeitungsknoten (900) nach Anspruch 7, wobei der Verarbeitungsknoten (900) dazu konfiguriert ist, das auf statistischen Daten basierende Modell auf Grundlage von historischen Daten zu aktualisieren.

9. Verarbeitungsknoten (900) nach einem der vorstehenden Ansprüche, wobei die gewünschte CSI-Ressourcenkonfiguration eines oder mehrere einer gewünschten CSI-Periode, einer gewünschten Anzahl an Ressourcenblöcken, einer gewünschten Position von Ressourcenblöcken, eines gewünschten Kammtyps und einer gewünschten Phasenrotation umfasst, und die aktuelle CSI-Ressourcenkonfiguration dementsprechend eine oder mehrere einer aktuellen CSI-Periode, einer aktuellen Anzahl an Ressourcenblöcken, einer aktuellen Position von Ressourcenblöcken, eines aktuellen Kammtyps und einer aktuellen Phasenrotation umfasst, und wobei der Verarbeitungsknoten (900) dazu konfiguriert ist, die aktuelle CSI-Ressourcenkonfiguration anzupassen, wenn eine Differenz zwischen der gewünschten CSI-Ressourcenkonfiguration und der aktuellen CSI-Ressourcenkonfiguration einen Schwellenwert überschreitet.

10. Verarbeitungsknoten (900) nach einem der vorstehenden Ansprüche, wobei die eine oder mehreren Kanalunterscheidungsbedingungen eine Vielzahl von Kanalunterscheidungsbedingungen umfassen, wobei die Vielzahl von Kanalunterscheidungsbedingungen mit einer Vielzahl von Funkkanälen assoziiert ist, wobei jeder Funkkanal in der Vielzahl von Funkkanälen einer Funkverbindung (1032) entspricht, die den Zugangsknoten (1018) mit einem Benutzergerät (1020) in einer Vielzahl von Benutzergeräten (1020, 1028, 1030) verbindet, wobei der Verarbeitungsknoten (900) zu Folgendem konfiguriert ist:

Auswählen, für jeden Funkkanal in der Vielzahl von Funkkanälen, eines differenzierten Kohärenzzeitmodells aus der Vielzahl von Kohärenzzeitmodellen auf Grundlage der Kanalunterscheidungsbedingungen, die mit jedem Funkkanal assoziiert sind;
Bestimmen einer differenzierten Kohärenzzeitnäherung für jeden Funkkanal in der Vielzahl von Funkkanälen auf Grundlage des entsprechenden ausgewählten Kohärenzzeitmodells und denassoziierten Kanalunterscheidungsbedingungen;
Bestimmen, für jeden Funkkanal in der Vielzahl von Funkkanälen, einer gewünschten CSI-Konfiguration auf Grundlage der bestimmten differenzierten Kohärenzzeitnäherungen und/oder einer aktuellen CSI-Zuweisung; und,
Anpassen einer oder mehrerer aktueller CSI-Ressourcenkonfigurationen auf Grundlage der entsprechendenbestimmten gewünschten CSI-Ressourcenzuweisung, wobei jeder Funkkanal in der Vielzahl von Funkkanälen mit einer der einen oder mehreren aktuellen CSI-Ressourcenkonfigurationen assoziiert ist.

11. Verarbeitungsknoten (900) nach Anspruch 12, wobei das drahtlose Kommunikationsnetzwerk (1000) einen Satz verfügbarer CSI-Ressourcenkonfigurationen umfasst, und

wenn das drahtlose Kommunikationsnetzwerk (1000) ausreichend CSI-Ressourcen umfasst, um alle gewünschten CSI-Ressourcenkonfigurationen zu erfüllen, der Verarbeitungsknoten (900) dazu konfiguriert ist, für jeden Funkkanal in der Vielzahl von Funkkanälen eine neue CSI-Ressourcenkonfiguration aus dem Satz verfügbarer CSI-Ressourcenkonfigurationen zuzuteilen; und
wenn das drahtlose Kommunikationsnetzwerk (1000) unzureichend CSI-Ressourcen umfasst, um alle gewünschten CSI-Ressourcenkonfigurationen zu erfüllen, der Verarbeitungsknoten (900) dazu konfiguriert ist, zusätzliche CSI-Ressourcen zurückzugewinnen, indem eine Menge an CSI-Ressourcen reduziert wird, die durch Funkkanäle verwendet wird, die mehr CSI-Ressourcen aufweisen als durch die entsprechende gewünschte CSI-Ressourcenkonfiguration erforderlich ist, und die zurückgewonnenen zusätzlichen CSI-Ressourcen

Funkkanälen zuzuweisen, die weniger CSI-Ressourcen aufweisen als durch die entsprechende gewünschte CSI-Ressourcenkonfiguration erforderlich ist.

12. Verfahren (100), das Folgendes umfasst:

Empfangen (104) eines oder mehrerer Kanalmerkmale, wobei das eine oder die mehreren Kanalmerkmale mit einem Funkkanal assoziiert sind, der einer Funkverbindung entspricht, die einen Zugangsknoten und ein Benutzergerät verbindet;
Bestimmen (114) einer oder mehrerer Kanalunterscheidungsbedingungen auf Grundlagedes einen oder der mehreren Kanalmerkmale;
Bestimmen (116) einer gewünschten Kanalstatusinformation-Ressourcenkonfiguration (CSI-Ressourcenkonfiguration), auf Grundlage derKanalunterscheidungsbedingungen; und
Anpassen (126) einer aktuellen CSI-Ressourcenkonfiguration, die mit dem Funkkanal assoziiert ist, auf Grundlage der bestimmten gewünschten CSI-Ressourcenkonfiguration,
wobei die gewünschte CSI-Ressourcenkonfiguration wie folgt bestimmt wird:

Auswählen eines differenzierten Kohärenzzeitmodells aus einer Vielzahl von differenzierten Kohärenzzeitmodellen, wobei die Vielzahl von differenzierten Kohärenzzeitmodellen eines oder mehrere eines Clarke-Modells, eines LOS-Modells, eines NLOS-Modells für kleine Ausrichtungsfehler und eines NLOS-Modells für große Ausrichtungsfehler umfasst;
Berechnen einer differenzierten Kohärenzzeitnäherung auf Grundlage des ausgewählten differenzierten Kohärenzzeitmodells; und Bestimmen der gewünschten CSI-Ressourcenkonfiguration auf Grundlage der bestimmten differenzierten Kohärenzzeitnäherung;
wobei das Clarke-Modell wie folgt definiert ist:

$$T_c = \sqrt{\frac{9}{16\pi}}\frac{1}{f_d} \cong \frac{0.423}{f_d} ,$$

wobei T_C eine Kohärenzzeit ist,
wobei f_d eine maximale Doppler-Frequenzverschiebung ist, die mit dem Funkkanal assoziiert ist, wobei das LOS-Modell wie folgt definiert ist:

$$T_c = \frac{D_\lambda}{f_d \sin(\alpha_{los})} cos^{-1}(2\theta^2 logR + 1) ,$$

wobei $D_\lambda = \frac{D}{\lambda}$ und D und D die Sende-Empfangs-Entfernung ist, λ die Trägerwellenlänge ist
α_{los} eine Richtung hin zu einem Sender ist
θ die Strahlbreite ist,
R die Kanalkorrelation ist,
wobei das NLOS-Modell für kleine Ausrichtungsfehler wie folgt definiert ist:

$$T_c = \frac{1}{f_d}\sqrt{\frac{1/R^{4-1}}{(2\pi)^2\theta^4 + \frac{1}{2\theta^4 R^4}(\frac{\sin\mu_r}{D_{r,\lambda}})^2}},$$

wobei $D_{r,\lambda} = \frac{D_r}{\lambda}$ eine Streuungs-Empfangs-Entfernung D_r ist, die durch dieTrägerwellenlänge λ normalisiert ist und μ_r eine Ausrichtungsrichtung ist, und
wobei das NLOS-Modell für große Ausrichtungsfehler wie folgt definiert ist:

$$T_c = \sqrt{\frac{1-(1+\theta^4 \log R)^2}{\frac{1}{4}(1+\theta^2 logR)(\frac{f_d sin\mu_r}{D_{r\lambda}})^2(2\pi f_d)^2\theta^4}}$$

13. Verfahren (100) nach Anspruch 12, das ferner Anpassen (124) einer Systemeinstellungen auf Grundlage der gewünschten CSI-Ressourcenkonfiguration und/oder einer gewünschter Kanalbedingungen umfasst, wobei die Systemeinstellungen eine oder mehrere einer Trägerfrequenz, einer Strahlbreite, einer Strahlphase, einer Strahlausrichtungsrichtung und einer Sendeleistung umfassen.

14. Computerprogrammprodukt, das nicht transitorische Computerprogrammanweisungen umfasst, die bei Ausführung durch einen Prozessor (902) dazu konfiguriert sind, den Prozessor (902) zu veranlassen, das Verfahren nach Anspruch 12 oder 13 auszuführen.

Revendications

1. Nœud de traitement (900) couplé à un réseau de communication sans fil (1000), le nœud de traitement (900) étant configuré pour :

recevoir une ou plusieurs caractéristiques de canal, dans lequel les une ou plusieurs caractéristiques de canal sont associées à un canal radio correspondant à une liaison radio (1032) connectant un nœud d'accès (1018) et un équipement utilisateur (1020) ;
déterminer une ou plusieurs conditions de canal distinctives sur la base des une ou plusieurs caractéristiques de canal reçues ;
déterminer une configuration de ressources d'informations d'état de canal, CSI, souhaitée sur la base des une ou plusieurs conditions de canal distinctives ;
attribuer la configuration de ressources CSI souhaitée sur la base de la configuration de ressources CSI souhaitée ; et
ajuster une configuration de ressources CSI actuelle associée au canal radio, sur la base de la configuration de ressources CSI souhaitée déterminée, dans lequel le nœud de traitement (900) est configuré pour déterminer une configuration de ressources CSI souhaitée en :

sélectionnant un modèle de temps de cohérence différencié parmi une pluralité de modèles de temps de cohérence différenciés, dans lequel la pluralité de modèles de temps de cohérence différenciés comprennent un ou plusieurs d'un modèle de Clarke, d'un modèle LOS, d'un modèle de petite erreur de pointage NLOS et d'un modèle de grande erreur de pointage NLOS ;
calculer une approximation de temps de cohérence différenciée sur la base du modèle de temps de cohérence ; et déterminer la configuration de ressources CSI souhaitée sur la base de l'approximation de temps de cohérence différenciée déterminée,
dans lequel le modèle de Clarke est défini comme :

$$T_c = \sqrt{\frac{9}{16\pi}}\frac{1}{f_d} \cong \frac{0.423}{f_d},$$

où T_c est un temps de cohérence,
où f_d est un déplacement de fréquence Doppler maximal associé au canal radio,
dans lequel le modèle LOS est défini comme :

$$T_c = \frac{D_\lambda}{f_d \sin(\alpha_{los})} cos^{-1}(2\theta^2 logR + 1),$$

où $D_\lambda = \frac{D}{\lambda}$, et D et D est la distance d'émission-réception, λ est la longueur d'onde porteuse, α_{los} est une direction vers un émetteur

θ est la largeur de faisceau,
R est la corrélation de canal,
dans lequel le modèle de petite erreur de pointage NLOS est défini comme :

$$T_c = \frac{1}{f_d}\sqrt{\frac{{}^{1}/_{R^4-1}}{(2\pi)^2\theta^4+\frac{1}{2\theta^4R^4}(\frac{sin\mu_r}{D_{r,\lambda}})^2}},$$

où $D_{r,\lambda} = \frac{D_r}{\lambda}$ est une distance de diffusion-réception D_r normalisée par la longueur d'onde porteuse A, et μ_r est une direction de pointage, et
dans lequel le modèle de grande erreur de pointage NLOS est défini comme :

$$T_c = \sqrt{\frac{1-(1+\theta^4\log R)^2}{\frac{1}{4}(1+\theta^2 logR)(\frac{f_d sin\mu_r}{D_{r\lambda}})^2(2\pi f_d)^2\theta^4}}$$

2. Nœud de traitement (900) selon la revendication 1, dans lequel le nœud de traitement (900) est en outre configuré pour ajuster activement (124) un paramètre système sur la base d'une ou plusieurs parmi : les une ou plusieurs caractéristiques de canal ; les une ou plusieurs conditions de canal distinctives ; la configuration de ressource CSI souhaitée ; une condition de canal souhaitée ; et un groupe de ressources CSI disponible.

3. Nœud de traitement (900) selon les revendications 1 ou 2, dans lequel le nœud de traitement (900) est configuré pour :

déterminer une approximation de condition de canal différenciée sur la base des une ou plusieurs caractéristiques de canal et des une ou plusieurs conditions de canal de différenciation ; et
déterminer la configuration de ressources CSI souhaitée sur la base d'un mappage des une ou plusieurs approximations de condition de canal de différenciation avec la configuration de ressources CSI souhaitée.

4. Nœud de traitement (900) selon l'une quelconque des revendications 1 à 3, dans lequel le nœud de traitement (900) est configuré pour sélectionner, lorsque le canal radio est déterminé comme étant dans une condition LOS, le modèle LOS en tant que modèle de temps de cohérence différencié.

5. Nœud de traitement (900) selon l'une quelconque des revendications 1 à 4, dans lequel le nœud de traitement (900) est configuré pour sélectionner, lorsque le canal radio est déterminé comme étant dans une condition NLOS dominante avec une petite erreur de pointage, le modèle de petite erreur de pointage NLOS en tant que modèle de temps de cohérence différencié.

6. Nœud de traitement (900) selon l'une quelconque des revendications 1 à 4, dans lequel le nœud de traitement (900) est configuré pour sélectionner, lorsque le canal radio est déterminé comme étant dans une condition NLOS dominante avec une grande erreur de pointage, le modèle de grande erreur de pointage NLOS en tant que modèle temporel de cohérence différencié.

7. Noeud de traitement (900) selon l'une quelconque des revendications 1 à 4, dans lequel le nœud de traitement (900) est configuré pour sélectionner le modèle de temps de cohérence différencié en tant que modèle basé sur des données statistiques, et pour calculer l'approximation de temps de cohérence différenciée sur la base du modèle basé sur des données statistiques.

8. Noeud de traitement (900) selon la revendication 7, dans lequel le nœud de traitement (900) est configuré pour mettre à jour le modèle basé sur des données statistiques sur la base de données historiques.

9. Nœud de traitement (900) selon l'une quelconque des revendications précédentes, dans lequel la configuration de ressources CSI souhaitée comprend un ou plusieurs d'une période CSI souhaitée, d'un nombre souhaité de blocs de ressources, d'une position souhaitée de blocs de ressources, d'un type souhaité de peignes et d'une rotation de phase souhaitée, et la configuration de ressources CSI actuelle comprend un ou plusieurs éléments correspon-

dants parmi une période CSI actuelle, un nombre actuel de blocs de ressources, une position actuelle de blocs de ressources, un type actuel de peignes et une rotation de phase actuelle, et dans lequel le nœud de traitement (900) est configuré pour régler la configuration de ressources CSI actuelle lorsqu'une différence entre la configuration de ressource CSI souhaitée et la configuration de ressource CSI actuelle dépasse une valeur seuil.

10. Nœud de traitement (900) selon l'une quelconque des revendications précédentes, dans lequel les une ou plusieurs conditions de canal distinctives comprennent une pluralité de conditions de canal distinctives, la pluralité de conditions de canal distinctives étant associée à une pluralité de canaux radio, dans lequel chaque canal radio dans la pluralité de canaux radio correspond à une liaison radio (1032) connectant le nœud d'accès (1018) à un équipement utilisateur (1020) dans une pluralité d'équipements utilisateur (1020, 1028, 1030), le nœud de traitement (900) étant configuré pour :

sélectionner pour chaque canal radio dans la pluralité de canaux radio un modèle de temps de cohérence différencié parmi la pluralité de modèles de temps de cohérence sur la base des conditions de canal distinctives associées à chaque canal radio ;
déterminer une approximation de temps de cohérence différenciée pour chaque canal radio dans la pluralité de canaux radio sur la base du modèle de temps de cohérence sélectionné correspondant et des conditions de canal distinctives associées ;
déterminer pour chaque canal radio dans la pluralité de canaux radio une configuration CSI souhaitée sur la base des approximations de temps de cohérence différenciées déterminées et/ou d'une attribution CSI actuelle ; et,
ajuster une ou plusieurs configurations de ressources CSI actuelles sur la base de l'attribution de ressources CSI souhaitée déterminée correspondante, dans lequel chaque canal radio dans la pluralité de canaux radio est associé à une des une ou plusieurs configurations de ressources CSI actuelles.

11. Nœud de traitement (900) selon la revendication 12, dans lequel le réseau de communication sans fil (1000) comprend un ensemble de configurations de ressources CSI disponibles, et

lorsque le réseau de communication sans fil (1000) comprend des ressources CSI suffisantes pour satisfaire à toutes les configurations de ressources CSI souhaitées, le nœud de traitement (900) est configuré pour attribuer, pour chaque canal radio dans la pluralité de canaux radio, une nouvelle configuration de ressources CSI parmi l'ensemble de configurations de ressources CSI disponibles ; et
lorsque le réseau de communication sans fil (1000) comprend des ressources CSI insuffisantes pour satisfaire à toutes les configurations de ressources CSI souhaitées, le nœud de traitement (900) est configuré pour récupérer des ressources CSI supplémentaires en réduisant une quantité de ressources CSI utilisées par des canaux radio ayant plus de ressources CSI que ce qui est requis par la configuration de ressources CSI souhaitée correspondante, et attribuer les ressources CSI supplémentaires récupérées à des canaux radio ayant moins de ressources CSI que ce qui est requis par la configuration de ressources CSI souhaitée correspondante.

12. Procédé (100) comprenant :

recevoir (104) une ou plusieurs caractéristiques de canal, dans lequel les une ou plusieurs caractéristiques de canal sont associées à un canal radio correspondant à une liaison radio connectant un nœud d'accès et un équipement utilisateur ;
déterminer (114) une ou plusieurs conditions de canal distinctives sur la base des une ou plusieurs caractéristiques de canal reçues ;
déterminer (116) une configuration de ressources d'informations d'état de canal, CSI, sur la base des conditions de canal distinctives ; et,
ajuster (126) une configuration de ressources CSI actuelle associée au canal radio, sur la base de la configuration de ressources CSI souhaitée déterminée,
dans lequel la configuration de ressources CSI souhaitée est déterminée par :

la sélection d'un modèle de temps de cohérence différencié parmi une pluralité de modèles de temps de cohérence différenciés, dans lequel la pluralité de modèles de temps de cohérence différenciés comprennent un ou plusieurs d'un modèle de Clarke, d'un modèle LOS, d'un modèle de petite erreur de pointage NLOS et d'un modèle de grande erreur de pointage NLOS ;
le calcul d'une approximation de temps de cohérence différenciée sur la base du modèle de temps de cohérence différencié sélectionné ; et déterminer la configuration de ressources CSI souhaitée sur la base

de l'approximation de temps de cohérence différenciée déterminée,
dans lequel le modèle de Clarke est défini comme :

$$T_c = \sqrt{\frac{9}{16\pi}} \frac{1}{f_d} \cong \frac{0.423}{f_d} ,$$

où T_c est un temps de cohérence,
où f_d est un déplacement de fréquence Doppler maximal associé au canal radio, dans lequel le modèle LOS est défini comme :

$$T_c = \frac{D_\lambda}{f_d \sin(\alpha_{los})} cos^{-1}(2\theta^2 logR + 1) ,$$

où $D_\lambda = \frac{D}{\lambda}$, et D et D est la distance d'émission-réception, A est la longueur d'onde porteuse
α_{los} est une direction vers un émetteur
θ est la largeur de faisceau,
R est la corrélation de canal,
dans lequel le modèle de petite erreur de pointage NLOS est défini comme :

$$T_c = \frac{1}{f_d} \sqrt{\frac{1/R^{4-1}}{(2\pi)^2\theta^4 + \frac{1}{2\theta^4 R^4}(\frac{sin\mu_r}{D_{r,\lambda}})^2}},$$

où $D_{r,\lambda} = \frac{D_r}{\lambda}$ est une distance de diffusion-réception D_r normalisée par la longueur d'onde porteuse λ et μ_r est une direction de pointage, et
dans lequel le modèle de grande erreur de pointage NLOS est défini comme :

$$T_c = \sqrt{\frac{1-(1+\theta^4 \log R)^2}{\frac{1}{4}(1+\theta^2 logR)(\frac{f_d sin\mu_r}{D_{r\lambda}})^2 (2\pi f_d)^2 \theta^4}}$$

13. Procédé (100) selon la revendication 12 comprenant en outre l'ajustement (124) de paramètres système sur la base de la configuration de ressources CSI souhaitée et/ou de conditions de canal souhaitées, dans lequel les paramètres système comprennent un ou plusieurs éléments parmi une fréquence porteuse, une largeur de faisceau, une phase de faisceau, une direction de pointage du faisceau et une puissance d'émission.

14. Produit de programme informatique comprenant des instructions de programme informatique non transitoires qui, lorsqu'elles sont exécutées par un processeur (902), sont configurées pour amener le processeur (902) à mettre en œuvre le procédé selon la revendication 12 ou 13.

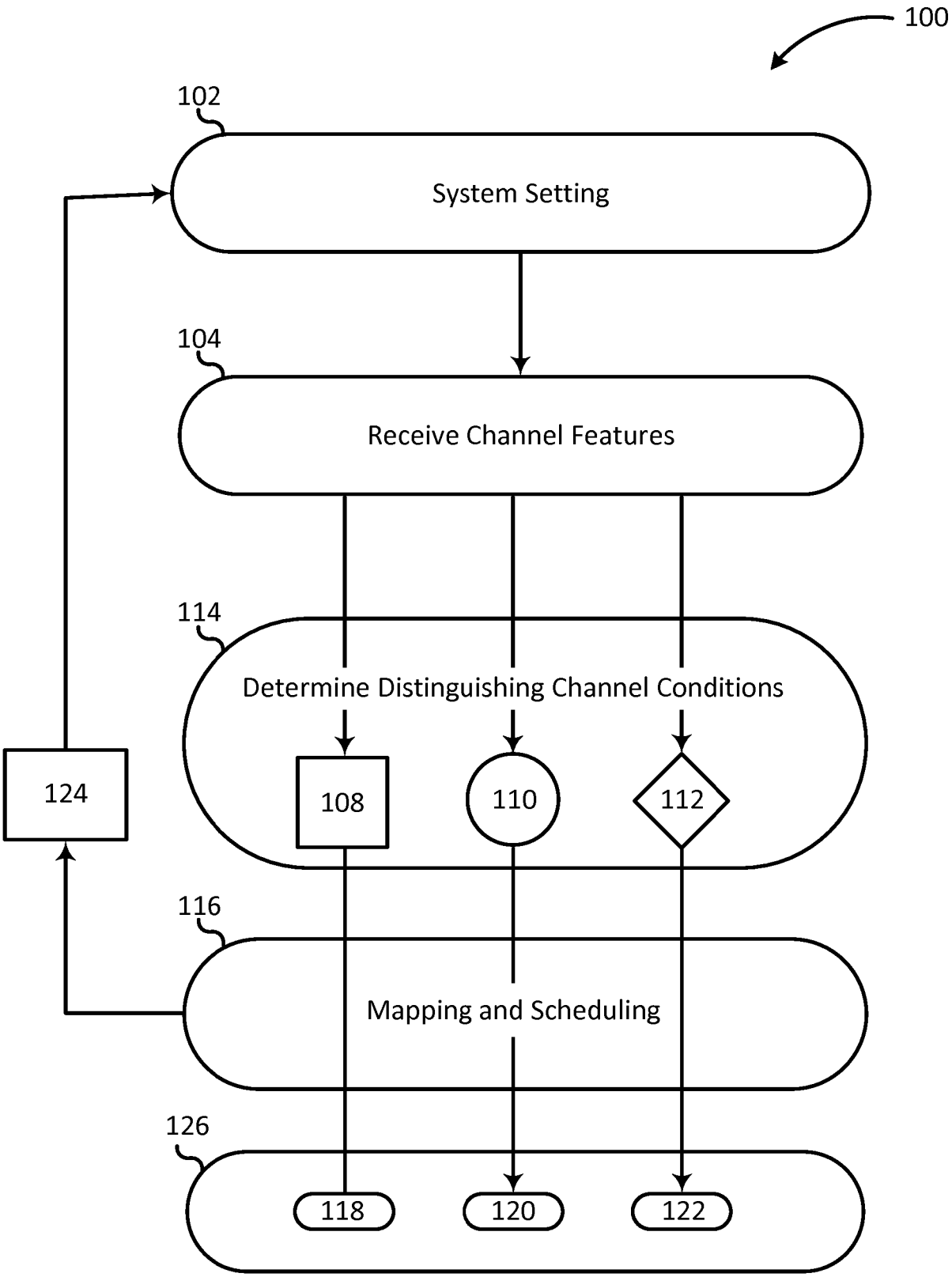
100
102
System Setting
104
Receive Channel Features
114
Determine Distinguishing Channel Conditions
108
110
112
124
116
Mapping and Scheduling
126
118
120
122

Figure 1

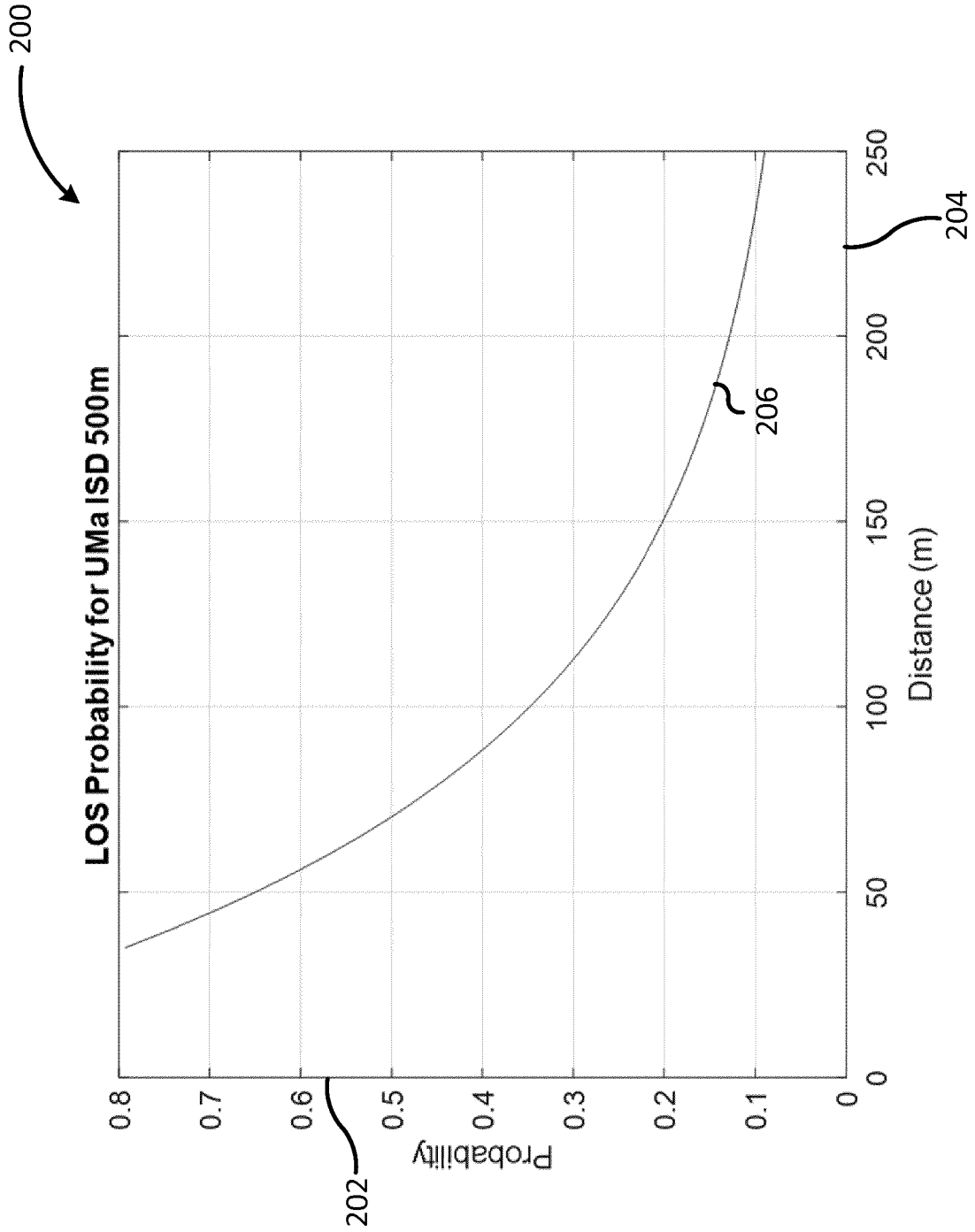
200
LOS Probability for UMa ISD 500m
Probability
Distance (m)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
50
100
150
200
250
202
204
206

Figure 2

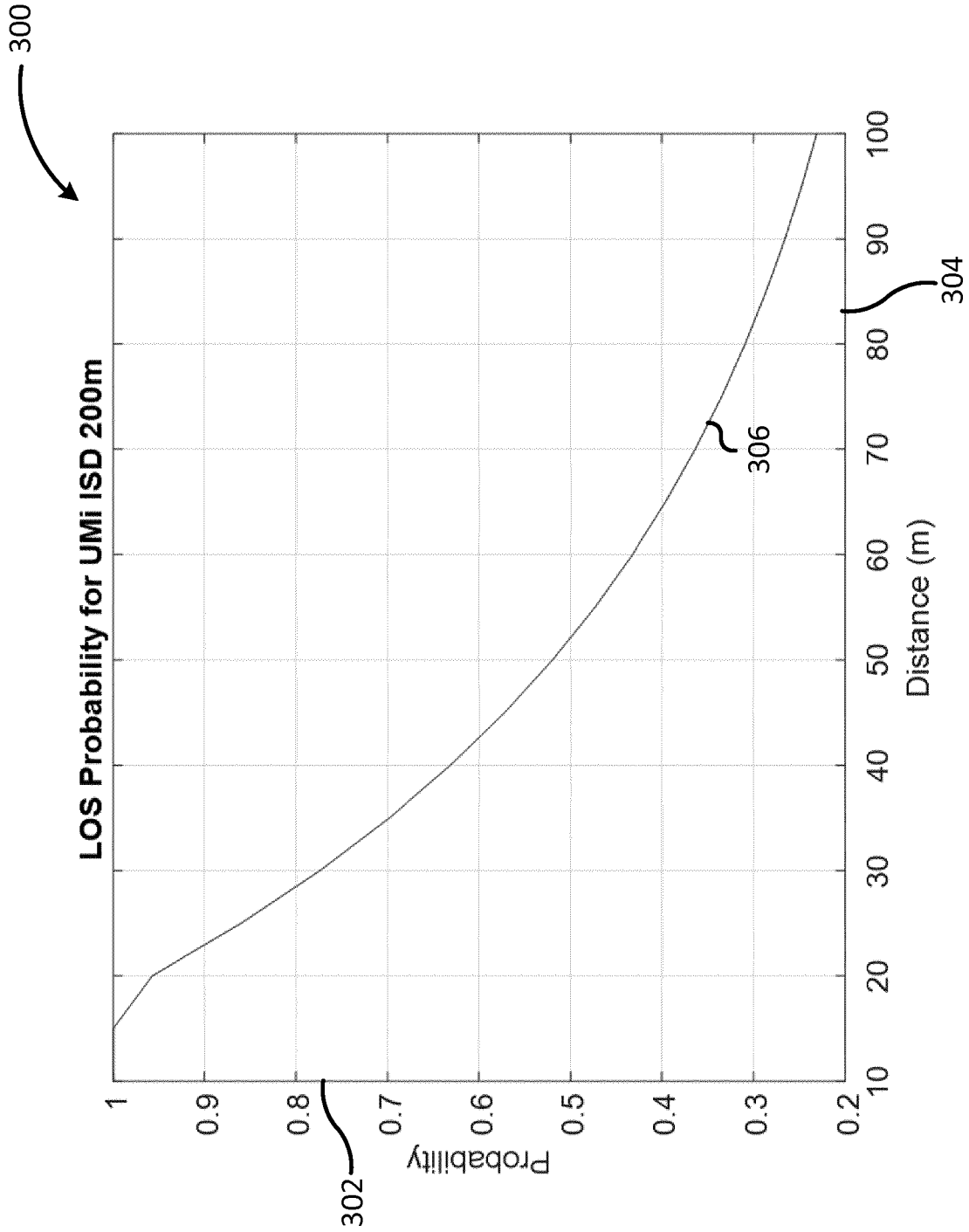
300
LOS Probability for UMi ISD 200m
Probability
Distance (m)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
10
20
30
40
50
60
70
80
90
100
302
304
306

Figure 3

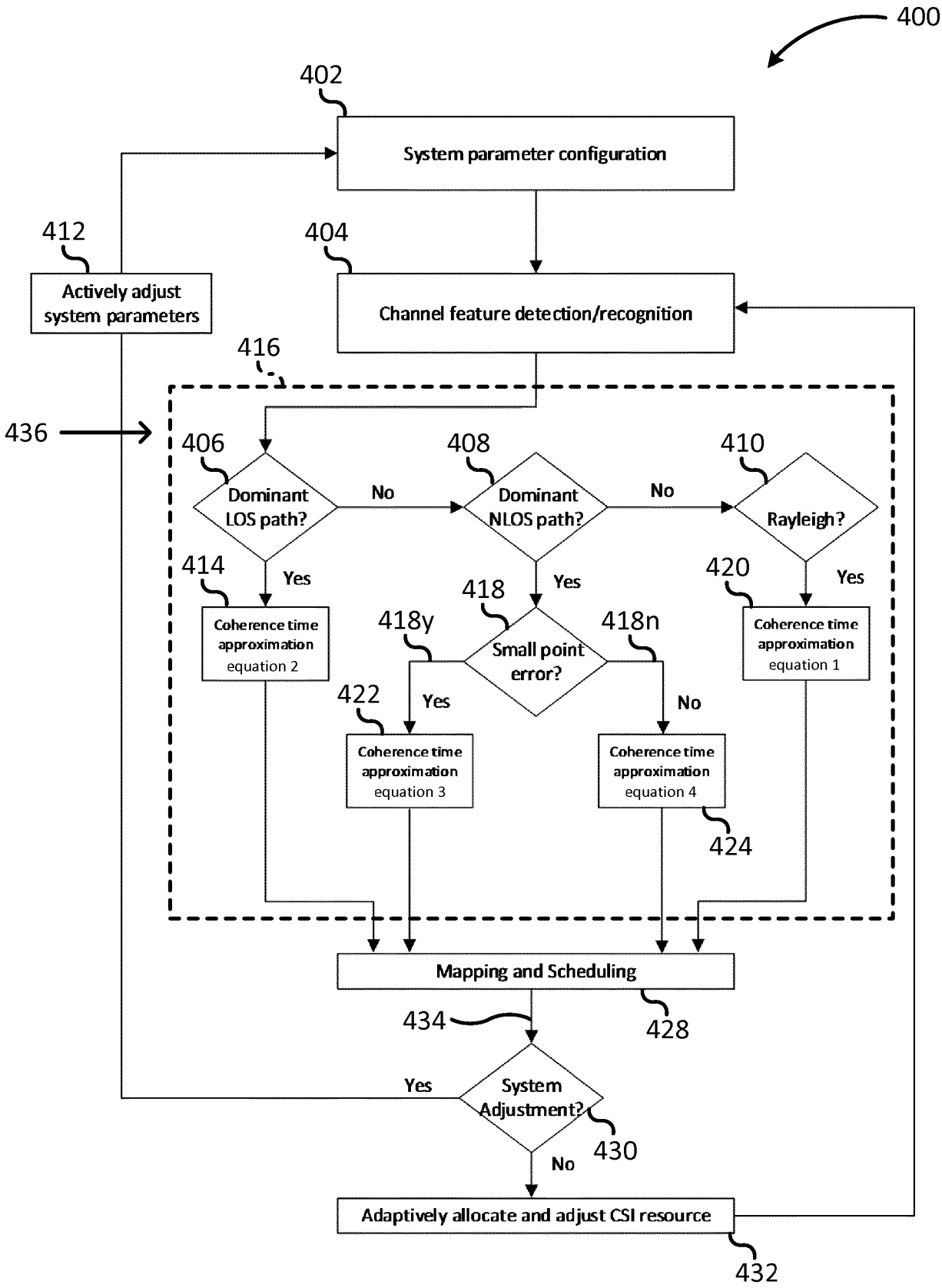
400
402
System parameter configuration
412
Actively adjust system parameters
404
Channel feature detection/recognition
416
436
406
Dominant LOS path?
No
408
Dominant NLOS path?
No
410
Rayleigh?
414
Yes
Coherence time approximation equation 2
418
Yes
Small point error?
418y
418n
420
Yes
Coherence time approximation equation 1
422
Yes
Coherence time approximation equation 3
No
Coherence time approximation equation 4
424
Mapping and Scheduling
428
434
Yes
System Adjustment?
430
No
Adaptively allocate and adjust CSI resource
432

Figure 4

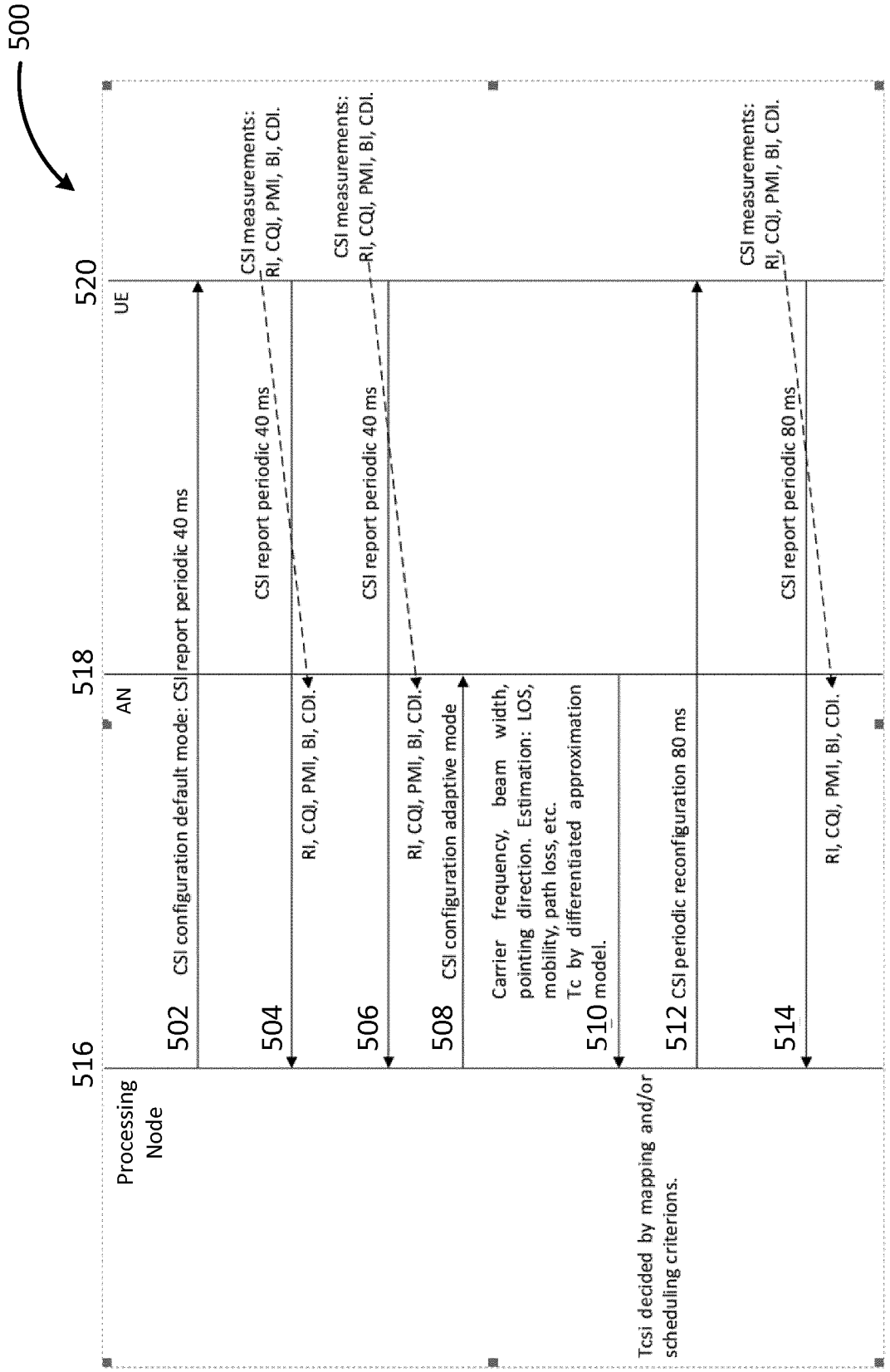
500
516
Processing Node
518
AN
520
UE
502 CSI configuration default mode: CSI report periodic 40 ms
504
CSI report periodic 40 ms
CSI measurements: RI, CQI, PMI, BI, CDI.
RI, CQI, PMI, BI, CDI.
506
CSI report periodic 40 ms
CSI measurements: RI, CQI, PMI, BI, CDI.
RI, CQI, PMI, BI, CDI.
508 CSI configuration adaptive mode
Carrier frequency, beam width, pointing direction. Estimation: LOS, mobility, path loss, etc.
Tc by differentiated approximation
510 model.
Tcsi decided by mapping and/or scheduling criterions.
512 CSI periodic reconfiguration 80 ms
514
CSI report periodic 80 ms
CSI measurements: RI, CQI, PMI, BI, CDI.
RI, CQI, PMI, BI, CDI.

Figure 5

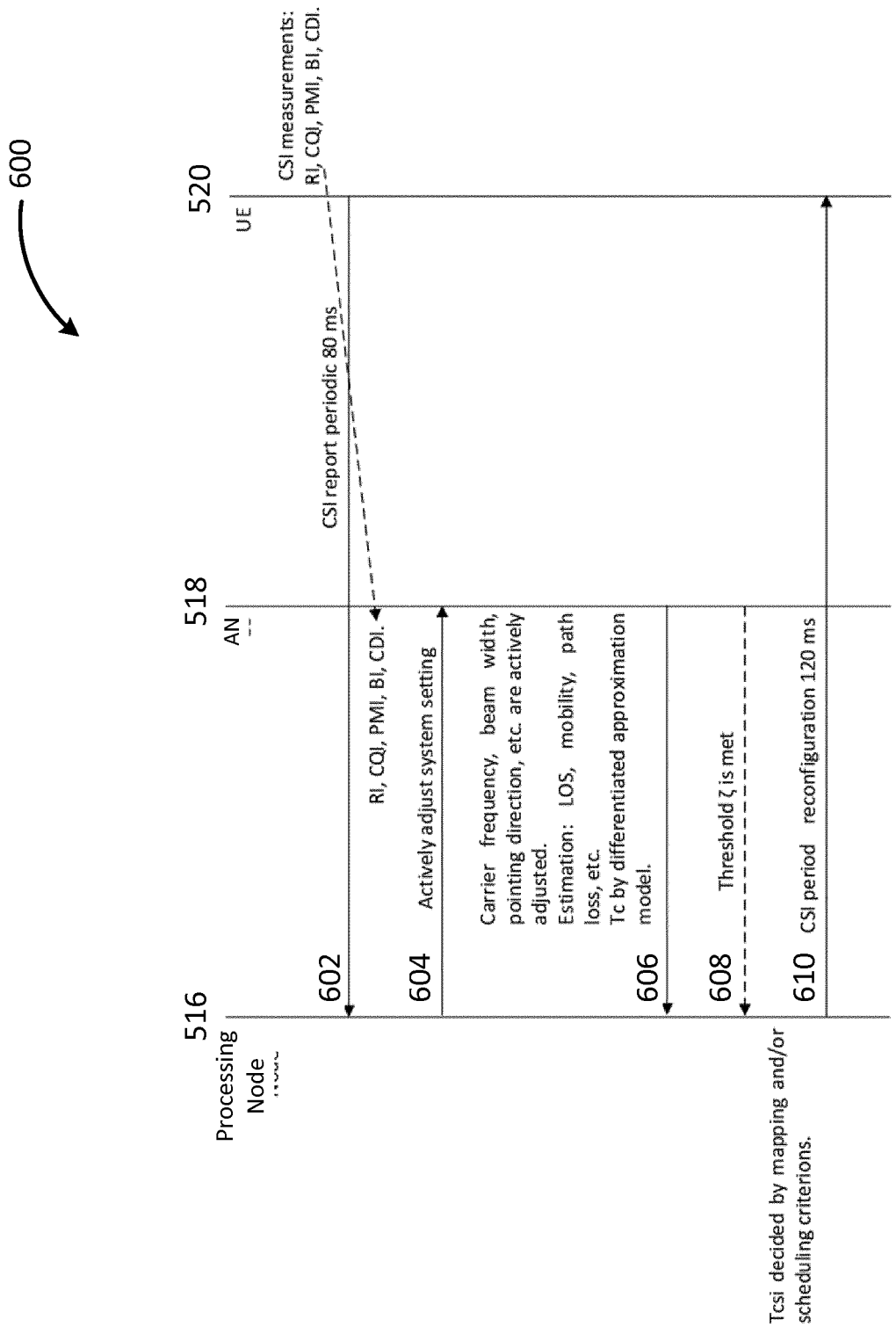
600
516
Processing Node
518
AN
520
UE
CSI measurements: RI, CQI, PMI, BI, CDI.
CSI report periodic 80 ms
602
RI, CQI, PMI, BI, CDI.
604
Actively adjust system setting
Carrier frequency, beam width, pointing direction, etc. are actively adjusted.
Estimation: LOS, mobility, path loss, etc.
Tc by differentiated approximation model.
606
608
Threshold ζ is met
610
CSI period reconfiguration 120 ms
Tcsi decided by mapping and/or scheduling criterions.

Figure 6

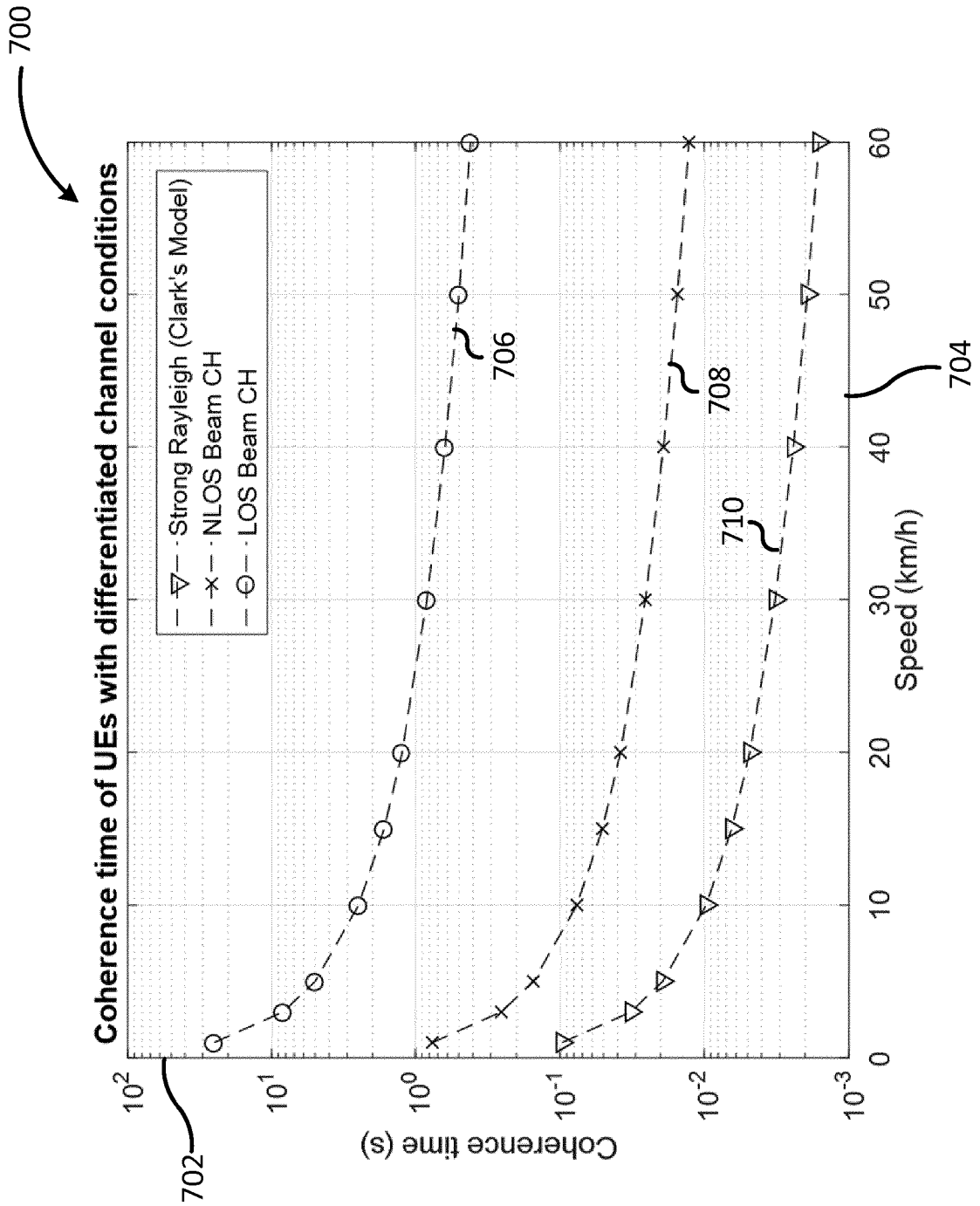
700
Coherence time of UEs with differentiated channel conditions
Strong Rayleigh (Clark's Model)
NLOS Beam CH
LOS Beam CH
Coherence time (s)
Speed (km/h)
702
704
706
708
710

Figure 7

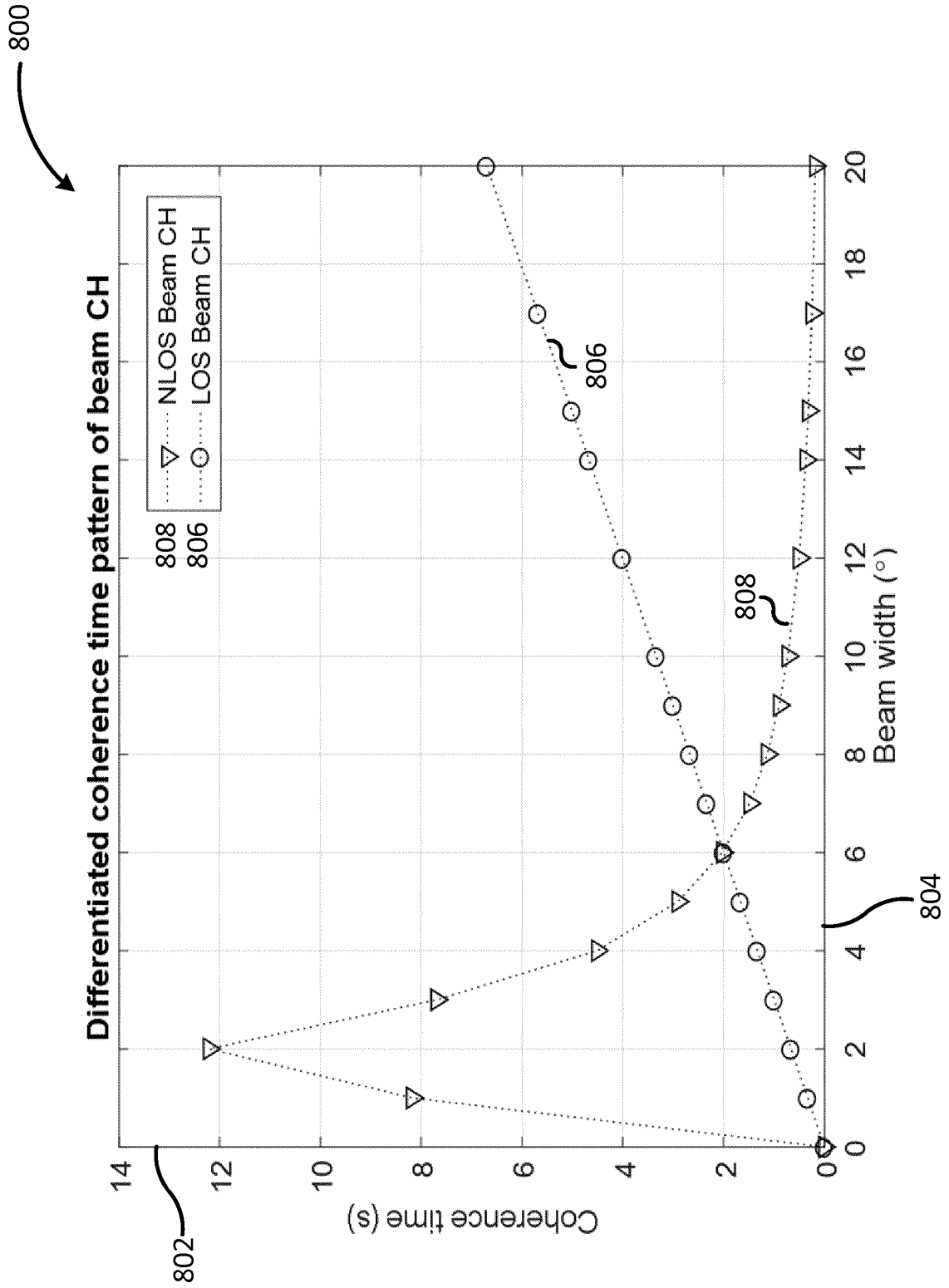
800
Differentiated coherence time pattern of beam CH
NLOS Beam CH
LOS Beam CH
808
806
806
808
802
804
Coherence time (s)
Beam width (°)
0
2
4
6
8
10
12
14
16
18
20

Figure 8

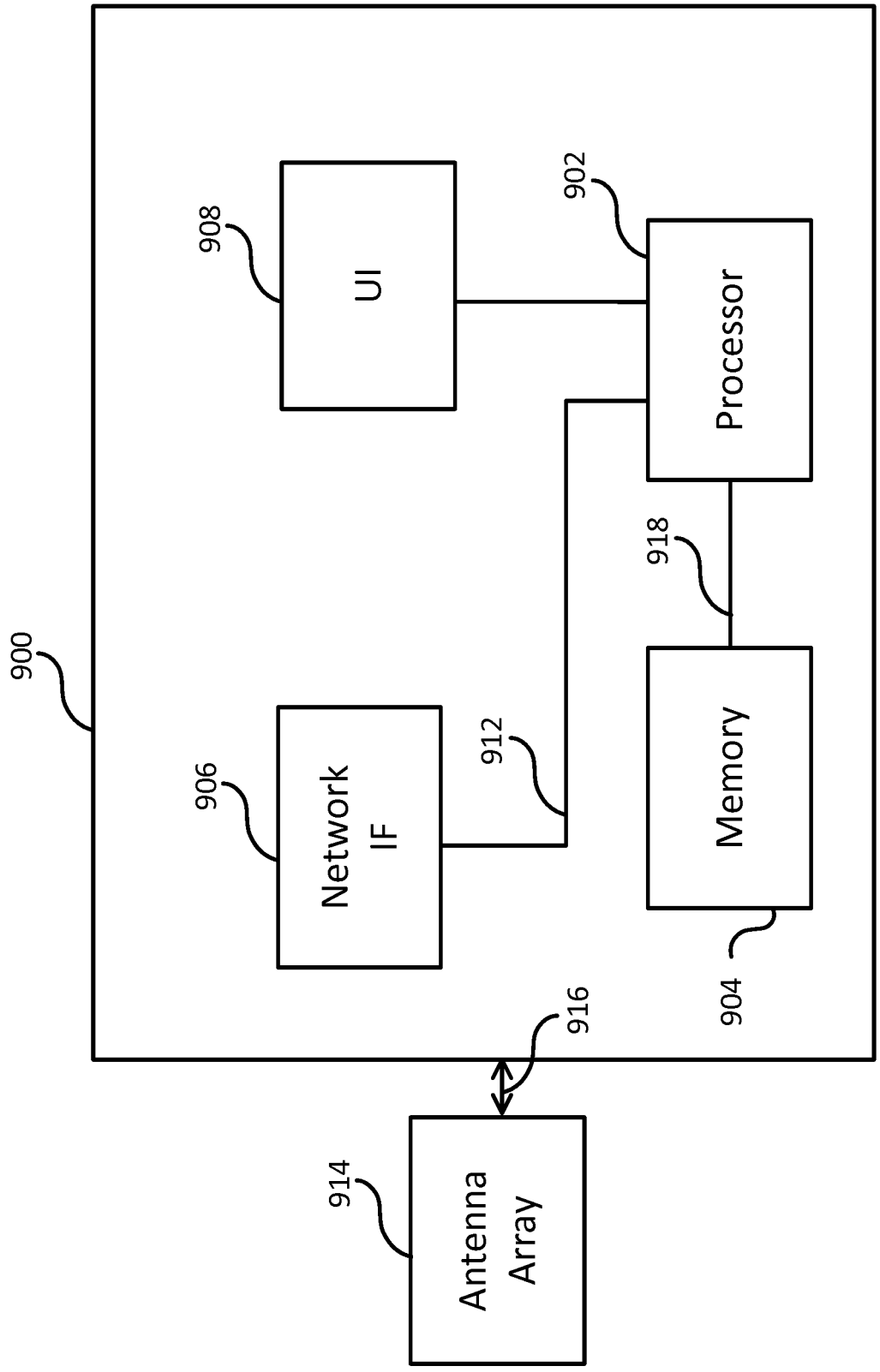
900
UI
908
Processor
902
Network IF
906
912
Memory
918
904
916
Antenna Array
914

Figure 9

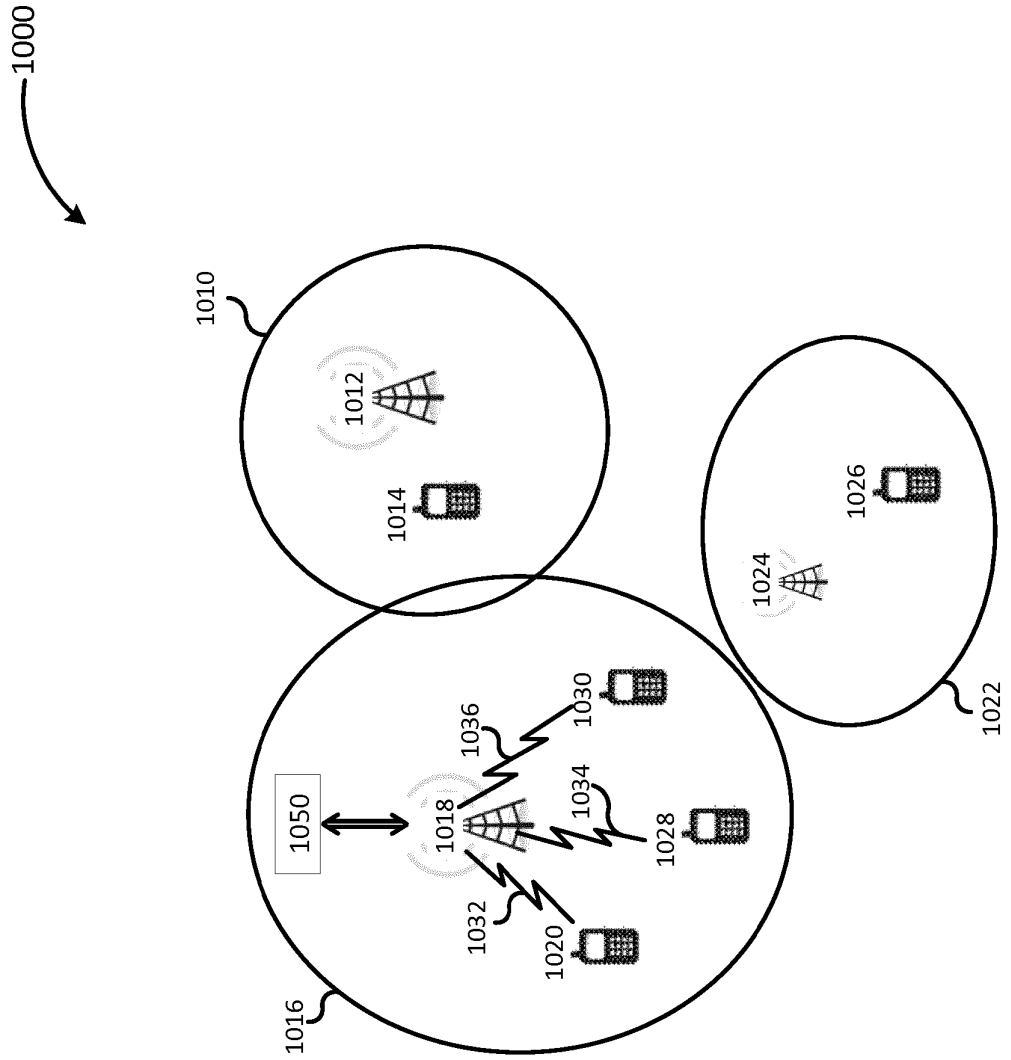
1000
1010
1012
1014
1016
1018
1020
1022
1024
1026
1028
1030
1032
1034
1036
1050

Figure 10

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2016048089 A1 **[0007]**

Non-patent literature cited in the description

- **HUAWEI et al.** Discussion on CSI Framework design. *3GPP Draft/RI-1706926 is a standardization document regarding CSI Framework design* **[0005]**
- **HUAWEI et al.** DL CSI-RAS Design for an NR CSI acquisition. *3GPP Draft/RI-1611241* **[0006]**