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

(72) Inventors: **FRÖBERG OLSSON, Jonas**; Nilsbovägen 9, 590 74 Ljungsbro (SE). **CIRKIC, Mirsad**; Gullbergsgatan 2, 582 46 Linköping (SE). **BERGLUND, Joel**; Allmogegatan 102, 58 333 Linköping (SE).

(74) Agent: **ERICSSON**; Patent Development Torshamnsgatan 21-23, 164 80 STOCKHOLM (SE).

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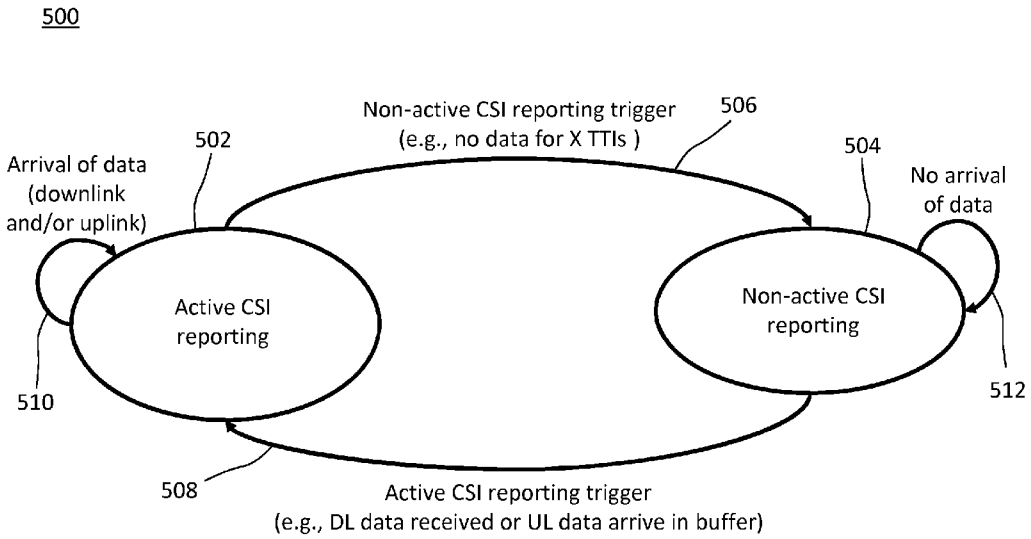

Fig. 5

(57) **Abstract:** A technique for reporting channel state information, CSI, from a wireless device to a radio node is described. The wireless device is wirelessly connected or connectable to the radio node. Different CSI configurations associated with different CSI states (502, 504) are stored at the wireless device. The CSI configurations comprise at least one transition criterion for a state transition (506; 508) between the CSI states (502, 504). As to a method aspect of the technique, the wireless device determines the state transition (506; 508) to a CSI state (502; 504) among the CSI states if the corresponding transition criterion is fulfilled and reports the CSI according to the CSI configuration that is associated with the CSI state (502; 504) resulting from the determination.

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Technique for reporting channel state information

Technical Field

The present disclosure generally relates to a technique for reporting channel state information (CSI). More specifically, methods and devices are provided for reporting and receiving CSI in a radio access network (RAN).

Background

In release 10 of Long Term Evolution (LTE) defined by the Third Generation Partnership Project (3GPP), channel state information (CSI) reference signals (CSI-RSs) were introduced. Based on the CSI reported from a user equipment (UE) to an LTE base station, downlink spatial multiplexing with up to eight layers was made possible. The CSI-RSs are used by the UE to acquire CSI when Demodulation Reference Signals (DM-RS) are being used. The CSI-RS can be transmitted by the base station with a periodicity ranging from 5 ms to 80 ms.

The reports from the CSI-RS can be periodic or aperiodic. The periodic reports are, as the name suggests, delivered with a certain periodicity. The periodic reports are in LTE transmitted on a physical uplink control channel (PUCCH) unless the UE has an uplink (UL) grant, which is transmitted on a physical downlink control channel (PDCCH). In the latter case, the CSI report is multiplexed with physical uplink shared channel (PUSCH) data.

In contrast, the aperiodic reports are delivered by the UE upon request from the radio access network (RAN) using an UL grant in which a CSI request flag is set. The RAN may grant the UE with a PUSCH transmission comprising CSI only or both data and CSI.

Once a CSI process with periodic CSI reports has been setup, the CSI reports are transmitted, even when no data is being transmitted, until the CSI process is reconfigured. Hence, although there is currently no downlink (DL) data to be transmitted to the UE, the UE continues transmitting the CSI on the PUCCH and the RAN receives the CSI, even if the RAN does not use the received CSI.

One approach to avoid unnecessary transmissions on the PUCCH may rely solely on aperiodic reports. However, such an approach has the disadvantage that when DL data to the UE appears at the base station, the CSI may be inaccurate (e.g., outdated), which may cause the RAN to trigger and wait for an updated CSI report until the DL data may be transmitted, thus increasing latency. Alternatively to waiting for a CSI update, the RAN may directly transmit the DL data based on the old CSI. However, such a transmission is not optimized for the current radio conditions, which in turn may lead to degraded performance and increased resource consumption, e.g., due to retransmission.

Another approach to avoid unnecessary transmissions on the PUCCH is that the RAN may trigger an aperiodic CSI report regularly (e.g. periodically) from the UE to receive an update of the CSI. However, this approach has the disadvantage that many scheduling grants must be transmitted, which increases the load on the PDCCH. In some state-of-the-art solutions periodic CSI reporting is configured in parallel with aperiodic CSI-reporting, wherein the aperiodic reports are triggered between the periodic reports when the UE has (DL) data. The difficulty, of choosing a period for the periodic reports that is short enough so that the CSI is not outdated even if no aperiodic reports have been granted in between periods and a period that is long enough not to cause too much overhead, still remains. If the period is too long, the network will anyway most often need to grant an aperiodic report to get updated CSI before starting the data transmission, which makes the periodic reporting superfluous.

For the technique described in the document WO 2016/116669 A1, a network node transmits to a UE a configuration of two aperiodic CSI reporting modes per DL component carrier. Based on the transmitted configuration, the network controls via a trigger indicator, which aperiodic CSI reporting mode the UE should use. The configuration trigger is defined in standardized tables, so that the CSI request from the network includes one, two or more bits, depending on the size of the table, which bits indicate which reporting mode should be used. This reduces the configuration information to be transmitted each time the reporting configuration needs to be changed, since the change can be indicated in the CSI request. However, it is the network that controls or triggers, which reporting configuration is required, so that the aforementioned overhead caused by scheduling grants for CSI reports remains.

Summary

Accordingly, there is a need for a technique that provides more accurate and/or more frequent channel state information at least in certain situations. Alternatively or in addition, there is a need for a technique that reduces the overhead caused by scheduling channel state information reports.

As to one aspect, a method of reporting channel state information (CSI) from a wireless device to a radio node is provided. The wireless device is wirelessly connected or connectable to the radio node. The method comprises or triggers a step of storing, at the wireless device, different CSI configurations associated with different CSI states. The CSI configurations comprise at least one transition criterion for a state transition between the CSI states. The method comprises or triggers a step of determining, by the wireless device, the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled. The method comprises or triggers a step of reporting the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

The radio node may comprise a radio access node of a radio access network (RAN). Alternatively or in addition, the radio node may comprise another wireless device in a device-to-device (D2D) communication with the wireless device.

By enabling the wireless device to determine if or when to transition between the CSI states, the associated CSI configuration can be applied more rapidly or the CSI configuration can be changed more frequently at least in some embodiments. Unnecessary CSI transmission on a physical uplink control channel (PUCCH) can be reduced, avoided or rapidly terminated by the wireless device. For example, scare resources on the PUCCH are not occupied by unused CSI reports. Alternatively or in addition, the radio node and/or the RAN can be provided with CSI more rapidly when need. For example, the CSI can be reported preemptively.

Same or further embodiments can reduce the signaling overhead for scheduling CSI reports. The wireless device may use shared radio resource for transmitting CSI reports. For example, the wireless device may use shared radio resource for reporting the CSI when the need for the CSI is not anticipated or cannot be anticipated by the radio node and/or the RAN.

The technique may be implemented as a technique for dynamically reporting the CSI. Particularly, the technique may be implemented for reporting the CSI at a level of detailedness, a temporal resolution and/or a periodicity that corresponds to the need for CSI updates at the radio node and/or the RAN.

The step of storing different CSI configurations at (or in) the wireless device, which are associated with different CSI states, may be implemented by providing the different CSI configurations in storage of the wireless device. The different CSI configurations associated with different CSI states may be stored, e.g., hard-coded, at manufacturing the wireless device. Alternatively or in addition, the different CSI configurations may be received and/or updated during operation of the wireless device, e.g., from the radio node and/or the RAN.

The step of determining the CSI state may be implemented by or may include transitioning (i.e. switching) the wireless device to the CSI state according to the determined state transition.

The step of reporting the CSI may comprise at least one of measuring the CSI, gathering or measuring one or more measurands underlying the CSI, evaluating CSI as a function of the measurands and transmitting the CSI. The reporting of the CSI may be different in the different CSI states according to the different CSI configurations associated with the respective CSI states. The reporting may be different in at least one of gathering the CSI at the wireless device, the content of the CSI and transmitting the CSI to the radio node and/or the RAN.

The CSI may be selectively reported according to the CSI configuration that is associated with the CSI state. Particularly, transmitting the CSI may be triggered or may be not triggered according to the CSI configuration.

The at least one transition criterion may comprise one or more criteria that are specific for one or more of the CSI states. Alternatively or in addition, the at least one transition criterion may comprise one or and/or one or more global transition criteria.

For each of the CSI states, the associated CSI configuration may comprise at least one of two different types of information. A first type among the types of information may comprise the corresponding transition criterion (also referred to as state-transition triggers). The first type of information may be used by the wireless device

in the determining step. A second type among the types of information may comprise parameters for the reporting of the CSI (also referred to as CSI-reporting rules). The second type of information may be used by the wireless device in the reporting step.

The step of determining the state transition to the CSI state may include determining, by the wireless device, for each of one or more of the CSI states whether the transition criterion for the state transition to the corresponding CSI state is fulfilled. The step of determining the state transition may include assessing the transition criterion for those CSI states that have a state transition originating from a current CSI state. The CSI state for which the transition criterion is fulfilled may be determined.

The transition criterion may depend on a current CSI state among the CSI states. The determined CSI state may be different from the current CSI state. The transition criterion for a transition from the current CSI state to another CSI state may depend on both the current CSI state (also referred to as source CSI state) and the other CSI state (also referred to as target CSI state). That is, the step of determining may include determining, by the wireless device, whether the transition criterion for a transition from the current CSI state among the CSI states to the other CSI state among the CSI states is fulfilled.

The wireless device may transition from a first CSI state to a second CSI state. The step of determining may include or trigger transitioning from the first CSI state among the CSI states to the second CSI state (e.g., as the determined CSI state) if the transition criterion for the state transition from the first CSI state to the second CSI state is fulfilled. Before the transitioning, the wireless device may, in the first CSI state, perform CSI reporting according to a first CSI configuration associated with the first CSI state (e.g., as the current CSI state). After the transitioning, the wireless device may, in the second CSI state, perform CSI reporting according to a second CSI configuration associated with the second CSI state (e.g., as the current CSI state).

The CSI states may include at least one active CSI state. For example, the active state may be a state within a radio resource control (RRC) connected state (RRC_CONNECTED state). The active state may encompass a situation when the wireless device has not been receiving and/or transmitting data for a certain time and is still RRC_CONNECTED.

The wireless device in the active state may periodically report the CSI according to the CSI configuration associated with the active CSI state. The CSI configuration associated with the active CSI state may be indicative of a periodicity for the reporting of the CSI. The active CSI state may also be referred to as an active CSI-reporting state.

In the active state, the wireless device may report the CSI according to a conventional periodic CSI. The periodic reporting of the CSI may be combined with further reporting modes, e.g., reporting the CSI upon request and/or event-driven reporting of the CSI.

The technique may be implemented as a method of conditionally reporting periodic CSI reports. The periodic CSI reporting may be conditional in that the condition for the wireless device being in the active state is fulfilled.

In the active CSI state of the wireless device, the CSI may be reported on a physical uplink control channel (PUCCH) and/or multiplexed with data on a physical uplink shared channel (PUSCH) of the RAN. According to the transition criteria, the wireless device may be in the active CSI state only if the CSI is used by the radio node and/or the RAN or is useful for the radio node and/or the RAN.

The transition criterion for the transition to the active state may include at least one of an arrival of uplink data and a reception of downlink data. Alternatively or in addition, the transition criterion for the transition to the active state may include a change of the CSI.

The CSI states may include at least one inactive CSI state. The CSI configuration associated with the inactive state may be different from the CSI configuration associated with the active state. The inactive CSI state may also be referred to as a non-active CSI state. The inactive CSI state may be related to an inactivity of a data communication (e.g., uplink, downlink and/or sidelink) between the wireless device and the radio node and/or the RAN.

The CSI may be reported more frequently in the active state than in the inactive CSI state. In one embodiment, the CSI may be periodically reported according to the CSI configuration associated with the inactive CSI state. The CSI configuration associated with the inactive CSI state may be indicative of a periodicity for the reporting of the CSI, which is longer than the periodicity of the active state.

Moreover, in one embodiment, the wireless device may refrain from periodically reporting the CSI in the inactive CSI state. For example, the inactive CSI state does not preclude aperiodic (e.g., requested) CSI reports.

In same or further embodiments, the wireless device may autonomously trigger CSI reports in the inactive CSI state. The reporting may be autonomously performed by the wireless device in that the transmission of the report is triggered or controlled by the wireless device. For example, autonomously reporting may encompass any reporting that is not triggered by a CSI request from the radio node and/or the RAN. Alternatively or in addition, the autonomous reporting may encompass periodically transmitting CSI reports and/or transmitting one or more CSI reports that are triggered by an event (e.g., a measurement) at the wireless device. The CSI may be reported responsive to events or results of measurements as defined by the CSI configuration associated with the inactive CSI state.

The reporting of the CSI by the wireless device in the inactive state may be triggered by a request received from the radio node and/or the RAN. For example, the CSI may be reported by the wireless device only upon request by the radio node and/or the RAN in the inactive state. The request may relate to a single CSI report or an aperiodic CSI report.

The reporting of the CSI by the wireless device in the inactive state may be triggered by an event according to the CSI configuration associated with the inactive CSI state. The event may be an event occurring at the wireless device and/or detected by the wireless device.

For example, the reporting of the CSI by the wireless device in the inactive state may be triggered by a change of the CSI according to the CSI configuration associated with the inactive CSI state. The change of the CSI may include or may be caused by a change of a measurand underlying the CSI or any other parameter influencing the CSI. The change of the CSI may include a change of at least one of a reference signal received power (RSRP), a channel quality indicator (CQI), a signal-to-noise ratio (SNR), and a precoding matrix index (PMI).

The triggered reporting may include a step of obtaining a radio resource of the radio node and/or the RAN for transmitting the CSI. The radio resource may be obtained by transmitting a scheduling request to the radio node and/or the RAN or by accessing a

shared uplink radio resource of the radio node and/or the RAN. The uplink radio resource of the radio node and/or the RAN may be shared among multiple wireless devices. Accessing the shared uplink radio resource may include a listen before talk (LBT) process.

The transition criterion for the transition to the inactive state may include an expiry of a timer at the wireless device. The timer may be indicative of the time elapsed since the latest transmission of data from the wireless device and/or the latest reception of data at the wireless device. The timer may be reset upon at least one of arrival of uplink data and reception of downlink data.

A status of a buffer at the wireless device or a scheduling grant from the radio node and/or the RAN may be indicative of the arrival. Alternatively or in addition, the downlink data may be received from the radio node and/or the RAN or a scheduling assignment from the radio node and/or the RAN may be indicative of the reception.

The method may further comprise or trigger a step of performing a deep packet inspection (DPI) or a stateful packet inspection (SPI) of at least one of the uplink data and the downlink data. An expected arrival or an expected reception of data, e.g., an acknowledgment message, may be indicative of the arrival or the reception.

The method may further comprise or triggering a step of performing a measurement for the CSI based on reference signals (RSs) for the CSI. The change of the CSI may relate to a change in, or a change detected based on, the CSI resulting from the CSI measurement. The RS for the CSI may comprise at least one of CSI-RSs and demodulation RSs (DM-RSs).

The wireless device may measure the CSI based on the RS. The radio node and/or the RAN may transmit the RS independent of the CSI state of the wireless device.

The change may include at least one of a change in a newly evaluated CSI compared to at least one of a previously evaluated CSI and a previously reported CSI. The comparison may be based on a difference between the newly evaluated CSI and the previously evaluated or reported CSI. The change may trigger the CSI reporting if the difference exceeds a relative threshold. Alternatively or in addition, the change may trigger the CSI reporting if the newly evaluated CSI exceeds an absolute CSI threshold.

The method may further comprise a step of receiving at least one configuration message from the radio node and/or the RAN. The at least one configuration message may comprise or may be indicative of one or more or all of the CSI configurations associated with the CSI states of the wireless device or an updated thereof. The same or a further one of the at least one configuration message may comprise or may be indicative of a control command controlling the wireless device to perform the method or at least the determining step.

The received control command that may control (e.g., instruct) the wireless device to perform at least the determining step and the reporting step. Alternatively or in addition, the received CSI configurations may be stored at the wireless device according to the storing step. For example, the received CSI configurations may augment, replace or update the stored CSI configurations.

The method may further comprise a step of receiving, from the radio node and/or the RAN, the configuration message or a further configuration message, which comprises or is indicative of the transition criterion for at least one of the CSI states stored or to be stored at the wireless device.

The radio node and/or the RAN may semi-persistently schedule radio resources (e.g., shared radio resources) to the wireless device for the CSI reporting. The radio resources may be shared by multiple wireless devices connected or connectable to the radio node and/or the RAN.

The reporting of the CSI may include transmitting the CSI on a shared radio resource of the radio node and/or the RAN. The method may further comprise a step of receiving a scheduling grant responsive to a collision on the shared radio resource. The method may further comprise a step of retransmitting the CSI according to the scheduling grant.

The technique (e.g., according the one method aspect) may be implemented at the wireless device. The wireless device may perform the method. The wireless device may encompass any station that is configured for wirelessly accessing the radio access node or the RAN.

As to another aspect, a method of receiving channel state information (CSI) from a wireless device at a radio node providing radio access to the wireless device is provided. The method comprises or triggers a step of transmitting at least one

configuration message to the wireless device. The at least one configuration message comprises or is indicative of different CSI configurations associated with different CSI states of the wireless device. The CSI configurations may comprise at least one transition criterion for a state transition between the CSI states. Alternatively or addition, the at least one configuration message comprises or is indicative of a control command controlling the wireless device to determine the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled based on the CSI configurations stored at the wireless device. The method further comprises or triggers a step of receiving the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

The control command may control the wireless device to perform the one method aspect.

The configuration message may comprise only the control command and/or may not comprise the CSI configurations. The CSI configurations may already be stored at the wireless device when the configuration message (e.g., the control command) is transmitted. For example, the CSI configurations may have been transmitted beforehand to the wireless device or may have been installed at the wireless device at manufacturing the wireless device.

Alternatively or in addition, the configuration message may comprise only the CSI configurations and/or may not comprise the control command. The configuration message may comprise the CSI configurations as an update of previously transmitted CSI configurations. The configuration message comprising the different CSI configurations may be implemented by an incremental update of the different CSI configurations stored at the wireless device. Alternatively or in addition, the different CSI configurations may be transmitted in multiple messages, each comprising a portion of the different CSI configurations.

Moreover, transmitting the CSI configurations may imply the control command. For example, the wireless device may be controlled to determine the state transition by the configuration message comprising at least one transition criterion for the state transition between the CSI states.

Furthermore, the CSI states may be implicitly defined by the CSI configurations. For example, each CSI configuration may define one of the CSI states.

The other method aspect may further comprise any feature or step that is disclosed in the context of the one method aspect, or a corresponding feature or a corresponding step. For example, the CSI may be received on a shared radio resource of the radio node (e.g., the radio access node) or the RAN. The method may further comprise a step of detecting a collision on shared radio resource. The method may further comprise a step of transmitting a scheduling grant responsive to the detected collision on the shared radio resource. The method may further comprise a step of receiving the CSI according to the scheduling grant.

Furthermore, the triggered reporting may include the step of granting a radio resource to the wireless device for transmitting the CSI. When an event is triggered by an arrival of data at the wireless device, a status of a buffer at the wireless device, a reception of a scheduling request from the wireless device and/or a scheduling grant from the radio access node may be indicative of the arrival of data at the wireless device. When an event is triggered by a reception of data at the wireless device, the transmission of downlink data by the radio node or a scheduling assignment from the radio node may be indicative of the reception.

The control command may further control a step of performing a deep packet inspection (DPI) or a stateful packet inspection (SPI) of at least one of the uplink data and the downlink data. An arrival or reception (e.g., of an acknowledgment message) expected based on the DPI or SPI may be indicative of the arrival or the reception. Alternatively or in addition, the control command may further control a step of performing a measurement for the CSI based on RS for the CSI.

The transmission from the radio node to the wireless device may apply a radio configuration that depends on the CSI. As long as the radio node has not received a report from the wireless device, the radio node may apply a radio configuration that is based on a previously reported CSI. Optionally, the radio node may apply a radio configuration that assumes that the current CSI is within a limit, e.g., relative to the previously received CSI. The limit may correspond to, or may be consistent with, the relative or absolute thresholds defined by the CSI configuration for triggering a CSI report. For example, the radio node may assume that the quality of the channel has not dropped by more than the relative threshold and/or not below the absolute threshold.

The technique (e.g., according the other method aspect) may be implemented at the radio node and/or the RAN. The radio access node or a cell of the RAN may perform

the method. The radio access node may encompass any station that is configured to provide radio access to the wireless device. Alternatively, the technique (e.g., according the other method aspect) may be implemented at another wireless device. The other wireless device may perform the method, e.g., for a device-to-device (D2D) communication, particularly for a vehicle-to-vehicle (V2V) communication. For example, the other wireless access node may perform the function of the "radio access node" at least as far as required for the subject technique. Particularly, the "uplink" and the "downlink" may be implemented by a link from the wireless device to the other wireless device and vice versa, respectively.

In any aspect, the radio access node or the cell of the RAN may serve a plurality of wireless devices, e.g., a plurality of embodiments of the wireless device performing the one method aspect. The wireless device may be configured for peer-to-peer communication (e.g., on a sidelink) and/or for accessing the RAN (e.g. for uplink, UL, and/or downlink, DL, communication).

The wireless device may be a terminal, a user equipment (UE, e.g., a 3GPP UE), a mobile or portable station (STA, e.g. a Wi-Fi STA), a device for machine-type communication (MTC), a narrowband Internet of Things (NB-IoT) device or a combination thereof. Examples for the UE and the mobile station include a mobile phone and a tablet computer. Examples for the portable station include a laptop computer and a television set. Examples for the MTC device and the NB-IoT device include robots, sensors and/or actuators, e.g., in manufacturing, automotive communication and home automation. The MTC device or the NB IoT device may be implemented in household appliances and consumer electronics. Examples for the MTC device or the combination include a self-driving vehicle, a door intercommunication system and an automated teller machine.

Examples for the radio access node may include a 3G base station or Node B, 4G base station or eNodeB, a 5G base station or gNodeB, an access point (e.g., a Wi-Fi access point) and a network controller (e.g., according to Bluetooth, ZigBee or Z-Wave).

The RAN may be implemented according to the Global System for Mobile Communications (GSM), the Universal Mobile Telecommunications System (UMTS), Long Term Evolution (LTE) and/or New Radio (NR).

The technique may be implemented on a Physical Layer (PHY), a Medium Access Control (MAC) layer, a Radio Link Control (RLC) layer and/or a Radio Resource Control (RRC) layer of a protocol stack for the radio communication.

According to a still further aspect, a method of reporting channel state information (CSI) from one wireless device to another wireless device is provided. The wireless devices are wirelessly connected or connectable to each other. The method comprises or triggers a step of storing, at the one wireless device, different CSI configurations associated with different CSI states, wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states. The method further comprises or triggers a step of determining, by the one wireless device, the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled. The method further comprises or triggers a step of reporting the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

According to a still further aspect, a method of receiving channel state information (CSI) from one wireless device at another wireless device is provided. The method comprises or triggers a step of transmitting at least one configuration message to the one wireless device. The at least one configuration message comprises or is indicative of at least one of different CSI configurations associated with different CSI states of the one wireless device, wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states; and a control command controlling the one wireless device to determine the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled based on the CSI configurations stored at the wireless device. The method further comprises or triggers a step of receiving the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

The aforementioned aspects may be referred to as device-to-device (D2D) aspects. Any of the D2D aspects may further comprise any feature or step that is disclosed in the context of the one method aspect or the other method aspect, or a feature or step corresponding thereto.

As to another aspect, a computer program product is provided. The computer program product comprises program code portions for performing any one of the steps of the method aspects disclosed herein when the computer program product is executed by one or more computing devices. The computer program product may be

stored on a computer-readable recording medium. The computer program product may also be provided for download via a data network, e.g., via the RAN, via the Internet and/or by the radio node. Alternatively or in addition, the method may be encoded in a Field-Programmable Gate Array (FPGA) and/or an Application-Specific Integrated Circuit (ASIC), or the functionality may be provided for download by means of a hardware description language.

As to one device aspect, a device for reporting channel state information, CSI, from a wireless device to a radio node is provided. The wireless device is wirelessly connected or connectable to the radio node. The device is configured to store, at the wireless device, different CSI configurations associated with different CSI states, wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states; to determine, by the wireless device, the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled; and to report the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

As to another device aspect, a device for receiving channel state information, CSI, from a wireless device at a radio node providing radio access to the wireless device is provided. The device is configured to transmit at least one configuration message to the wireless device. The at least one configuration message comprising or being indicative of at least one of different CSI configurations associated with different CSI states of the wireless device, wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states; and a control command controlling the wireless device to determine the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled based on the CSI configurations stored at the wireless device. The device is further configured to receive the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

As to a still further aspect, a device for reporting channel state information, CSI, from a wireless device to a radio node is provided. The wireless device is wirelessly connected or connectable to the radio node. The device comprising at least one processor and a memory, said memory comprising instructions executable by said at least one processor, whereby the device is operative to store, at the wireless device, different CSI configurations associated with different CSI states, wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states; to determine, by the wireless device, the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled; and to report the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

As to a still further aspect, a device for receiving channel state information, CSI, from a wireless device at a radio node providing radio access to the wireless device is provided. The device comprising at least one processor and a memory, said memory comprising instructions executable by said at least one processor, whereby the device is operative to transmit at least one configuration message to the wireless device. The at least one configuration message comprising or being indicative of at least one of different CSI configurations associated with different CSI states of the wireless device, wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states; and a control command controlling the wireless device to determine the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled based on the CSI configurations stored at the wireless device. The device is operative to receive the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

As to a still further aspect, a system comprising at least two devices for reporting CSI and receiving CSI, respectively, according to any of the aforementioned aspects is provided.

The device (or any node or station for embodying the technique) may further include any feature disclosed in the context of the method aspect. Particularly, any one of the units and modules, or a dedicated unit or module, may be configured to perform or trigger one or more of the steps of any one of the method aspect.

Brief Description of the Drawings

Further details of example embodiments of the technique are described with reference to the enclosed drawings, wherein:

Fig. 1 shows a schematic block diagram of a device for reporting channel state information;

Fig. 2 shows a schematic block diagram of a device for receiving channel state information;

Fig. 3 shows a flowchart for a method of reporting channel state information, which is implementable by the device of Fig. 1;

Fig. 4 shows a flowchart for a method of receiving channel state information, which is implementable by the device of Fig. 2;

Fig. 5 shows an example schematic state diagram of the device of Fig. 1;

Fig. 6 shows an example schematic second signaling diagram for a RAN including a device of Fig. 1;

Fig. 7 schematically illustrates an example time sequence resulting from an implementation of the method of Fig. 3;

Fig. 8 shows a schematic block diagram of a first embodiment of the device of Fig. 1;

Fig. 9 shows a schematic block diagram of a second embodiment of the device of Fig. 1;

Fig. 10 shows a schematic block diagram of a first embodiment of the device of Fig. 2; and

Fig. 11 shows a schematic block diagram of a second embodiment of the device of Fig. 2.

Detailed Description

In the following description, for purposes of explanation and not limitation, specific details are set forth, such as a specific network environment in order to provide a thorough understanding of the technique disclosed herein. It will be apparent to one skilled in the art that the technique may be practiced in other embodiments that depart from these specific details. Moreover, while the following embodiments are primarily described for a 5G New Radio (NR) implementation, it is readily apparent that the technique described herein may also be implemented in any other radio network, including 3GPP LTE or a successor thereof, Wireless Local Area Network (WLAN) according to the standard family IEEE 802.11, Bluetooth according to the Bluetooth Special Interest Group (SIG), particularly Bluetooth Low Energy and Bluetooth broadcasting, and/or ZigBee based on IEEE 802.15.4.

Moreover, those skilled in the art will appreciate that the functions, steps, units and modules explained herein may be implemented using software functioning in conjunction with a programmed microprocessor, an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), a Digital Signal Processor (DSP) or a general purpose computer, e.g., including an Advanced RISC Machine (ARM). It will also be appreciated that, while the following embodiments are primarily described in context with methods and devices, the invention may also be embodied in a computer program product as well as in a system comprising at least one computer processor and memory coupled to the at least one processor, wherein the memory is encoded with one or more programs that may perform the functions and steps or implement the units and modules disclosed herein.

Fig. 1 schematically illustrates a block diagram of a device for reporting channel state information (CSI) from a wireless device to a radio node, e.g., another wireless device and/or a radio access network (RAN) or a radio access node thereof. The wireless device is wirelessly connected or connectable to the RAN. The device is generically referred to by reference sign 100.

The device 100 comprises a CSI configuration module 102 that stores, at the wireless device, different CSI configurations associated with different CSI states. The CSI configurations comprise at least one transition criterion for a state transition between the CSI states. The device 100 further comprises a CSI state determination module 104 that determines, by the wireless device, the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled. The device

100 further comprises a CSI reporting module 106 that reports the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

The device 100 may be connected to and/or part of the wireless device. The device 100 may be embodied by or at the wireless device, a station connected to the wireless device or a combination thereof.

Any of the modules of the device 100 may be implemented by units configured to provide the corresponding functionality.

Fig. 2 schematically illustrates a block diagram of a device for receiving CSI from a wireless device at a radio node that provides radio access to the wireless device. The wireless device may be wirelessly connected or connectable to the radio node of a RAN. The device is generically referred to by reference sign 200.

Optionally, the device 200 comprises a CSI configuration module 202 that transmits at least one configuration message to the wireless device. The at least one configuration message comprises or is indicative of different CSI configurations associated with different CSI states of the wireless device. The CSI configurations comprise at least one transition criterion for a state transition between the CSI states.

Alternatively or in addition, the device 200 comprises a CSI control module 204 that transmits at least one configuration message to the wireless device. The at least one configuration message comprises or is indicative of a control command controlling the wireless device to determine the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled based on the CSI configurations, which are stored at the wireless device.

The modules 202 and 204 may be implemented by one module. Alternatively or in addition, the CSI configurations and the control command may be transmitted by the same at least one control message.

The device 200 further comprises a CSI reception module 206 that receives the CSI according to the CSI configuration associated with the CSI state resulting from the determination.

The device 200 may be connected to and/or part of the RAN or a core network (CN) connected to the RAN. The device 200 may be embodied by or at the radio access node (e.g., a base station) of the RAN, one or more nodes connected to the RAN for controlling the radio access node or a combination thereof.

Any of the modules of the device 200 may be implemented by units configured to provide the corresponding functionality.

In the context of any embodiment of the devices 100 and 200, the radio access node may encompass a network controller (e.g., a Wi-Fi access point) or a cellular base station (e.g. a 3G Node B, a 4G eNodeB or a 5G gNodeB) of the RAN. Alternatively or in addition, the one or more wireless devices may include a mobile or portable station or a radio device connectable to the RAN. Each wireless device may be a user equipment (UE), a device for machine-type communication (MTC) and/or an IoT device.

Furthermore, two or more wireless devices may be configured to wirelessly connect to each other, e.g., in an ad-hoc radio network or via 3GPP sidelink. At least one of the wireless devices may embody the device 100. At least one other wireless device may embody the device 200, e.g., in the role of the radio access node. Particularly, both the device 100 and the device 200 may be UEs. The one wireless device embodying the device 100 may report the CSI for 3GPP sidelink or Cellular Vehicle-to-Everything (V2X) communication to the other wireless device embodying the device 200.

Fig. 3 shows a flowchart for a method 300 of reporting CSI from a wireless device to a radio node, e.g., another radio device or a radio access node of a RAN. The wireless device is wirelessly connected or connectable to the radio node, e.g., to the RAN. The method comprises or triggers a step 302 of storing, at the wireless device, different CSI configurations associated with different CSI states. The CSI configurations comprise at least one transition criterion for a state transition between the CSI states. In a step 304, the wireless device determines the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled. The CSI is reported according to the CSI configuration that is associated with the CSI state resulting from the determination in a step 306 of the method 300.

The method 300 may be performed by the device 100, e.g., at or using the wireless device. For example, the modules 102, 104 and 106 may perform the steps 202, 204 and 206, respectively.

Fig. 4 shows a flowchart for a method 400 of receiving CSI from a wireless device at a radio node (e.g., another radio device or a radio access node that provides radio access to the wireless device). The method comprises or triggers an optional step 402 of transmitting at least one configuration message to the wireless device. The at least one configuration message comprises or is indicative of different CSI configurations associated with different CSI states of the wireless device. The CSI configurations comprise at least one transition criterion for a state transition between the CSI states. Alternatively or in addition, at least one configuration message is transmitted to the wireless device in a step 404, wherein the at least one configuration message comprises, is indicative of, or implies a control command controlling the wireless device to perform any of the steps of the method 300, e.g., to determine the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled based on the CSI configurations stored at the wireless device. In a step 406 of the method 400, the CSI is received according to the CSI configuration that is associated with the CSI state resulting from the determination.

The method 400 may be performed by the device 200, e.g., at or using the radio access node of the RAN. For example, the modules 202, 204 and 206 may perform the steps 402, 404 and 406, respectively.

Embodiments of the technique can maintain compatibility with the CSI reporting according to the document 3GPP TS 38.214, Release 15 or Version 1.2.0 (e.g., Section 5.2 therein), at least in one of an active CSI state and an inactive CSI state.

The technique may be embodied as a state-based CSI reporting, wherein the UE reports the CSI in the step 306 based on its current CSI state. The network (e.g., the RAN, the CN and/or node thereof) may configure the UE in the step 402 with the CSI configurations including transition criteria (also referred to as state-transition triggers or state-transition trigger criteria) and/or the CSI configurations including different CSI-reporting rules for the different CSI states.

In a first embodiment, the CSI-reporting rules may comprise a CSI configuration for periodic CSI reporting. For example, the UE may be configured with a first periodic CSI configuration for a first CSI state and a second periodic CSI configuration for a second

CSI state. A longer period may be defined by the second CSI configuration for the second CSI state as compared to the first CSI configuration for the first CSI state. Optionally, the CSI reporting in the first CSI state and the second CSI state perform the same CSI process at different reporting rates (e.g., periodicities or frequencies). The first CSI configuration may be used when there is downlink or uplink data traffic. The second CSI configuration may be used in an idle mode of the wirelesses device and/or when there has not been any data traffic for a certain time.

In a second embodiment, which is combinable with the first embodiment, the CSI states for the UE may comprise an active CSI state, in which the UE uses a first CSI-reporting rule included in a first CSI configuration associated with the active state. The CSI states for the UE further comprise a non-active (or inactive) CSI state, in which the UE uses a second CSI-reporting rule included in a second CSI configuration associated with the non-active state.

The CSI configurations further comprise state-transition trigger criteria. For the state transition from the active CSI state to the non-active CSI state, the transition criterion may include: the state transition is determined in the step 304, if no data has been received and/or transmitted for a certain time, e.g., for *x* transmission time intervals (TTIs). For the state transition from the non-active CSI state to the active CSI state, the transition criterion may include: the state transition is determined in the step 304, if downlink data is received and/or uplink data arrives in a buffer at the wireless device.

In one implementation of the first or second embodiment, the second CSI configuration comprises an event-based CSI reporting configuration, wherein the CSI is reported if (e.g., only if) one or more event-triggers are fulfilled. The one or more event-triggers may comprise a significant change of the CSI (e.g., as obtained at the wireless device). That is, the CSI is reported in the step 306 when the CSI has changed significantly. The change of the CSI may be significant relative to the last-reported CSI, and/or the change may include exceeding or falling below one or more threshold values.

For example, with a threshold event, such as a reference signal received power (RSRP) and/or a channel quality indication (CQI) being below a certain threshold, the UE only needs to report the CSI when the CSI is needed, rather than in a periodical manner or requested by the network.

Alternatively or in addition, the one or more event-triggers may comprise reception of a CSI request at the wireless device from the RAN. The CSI request may trigger an individual CSI report to the RAN.

In another implementation of the first or second embodiment that is combinable with the one implementation, the second CSI configuration is a periodic CSI configuration (i.e., the CSI-reporting rule requires period CSI reports) with a long periodicity (e.g., longer than a periodicity of the first CSI configuration). In any implementation, the second CSI configuration may allow the RAN to keep track of the UE or its radio channel (e.g., at a basic level of accuracy).

Embodiments or implementations of the technique allow a significant reduction of the overhead caused by the CSI reporting, without losing track of the UE, e.g., during periods of time when no data transmission is ongoing while the UE is still in active mode.

The switch to the event-based reporting (e.g., to the inactive CSI state) is determined in the step 304 based on the corresponding transition criterion without any additional signaling from the RAN, e.g., without additional radio resource control (RRC) signaling for reconfiguration of the UE. When data is being transmitted, the UE may switch back to the periodical reporting (e.g., to the active CSI state) in the step 304 based on the corresponding transition criterion without additional signaling from the RAN, e.g., without RRC signaling for reconfiguration of the UE.

In any embodiment or implementation, at configuration of a CSI process, e.g., by means of a control command, the radio access node (e.g., the base station serving the UE as the wireless device) may order the wireless device to perform state transitions according to the step 304, e.g., between the active and non-active CSI states defining the reporting of the CSI in the step 306. The state transitions are based on state-transition trigger criteria (or briefly: transition criteria). The device 100, e.g. the wireless device, may be implemented as a multi-state machine comprising the CSI states and performing the state transitions according to the transition criteria. For example, the UE may be in one of two CSI states, and state transitions can occur due to the state-transition triggers.

Fig. 5 shows an example schematic state diagram 500 of the device 100, e.g., of the wireless device. By way of example and not limitation, Fig. 5 illustrates state

transitions 506 and 508 between an active CSI state 502 and a non-active CSI state 504.

The active CSI state 502 may comprise a periodic CSI reporting and/or an aperiodic CSI reporting. The active CSI state 502 may be compatible with, or may correspond to, an existing or conventional CSI mode. The non-active CSI state 504 may comprise at least one of requested (e.g., aperiodic) CSI reporting, event-based CSI reporting and long-periodic CSI reporting.

The state transitions and the corresponding transition criteria (also referred to as state-transition trigger criteria) may comprise one or more of the following examples. A first example of a transition criterion includes expiry of a timer, e.g. as schematically illustrated at reference sign 506. The timer may represent the time since the last DL data transmission from the radio access node and/or the last scheduling assignment by the radio access node. A second example of a transition criterion includes one or more events at the wireless device, e.g., as illustrated at reference sign 508. The one or more events may comprise a change of a buffer status of an UL data buffer or a DL data buffer, a change in a session status of a session or link between the wireless device and the radio access node (e.g., on a higher layer of a communication protocol), and/or the change of the obtained CSI.

A third example of a transition criterion includes an arrival (or an availability) of UL data, e.g. as schematically illustrated at reference sign 508. The arrival or availability of UL data may imply that the CSI is useful for the radio access node (e.g., for precoding a DL transmission), e.g., since DL data needs to be sent for a transfer control protocol (TCP) acknowledge (ACK) and/or a radio link control (RLC) ACK (e.g., within few TTIs). In general, the arrival of UL data may transfer the wireless device to the active CSI state 502 in the step 304, since UL data transmissions typically imply upcoming DL data, which increases the need or is the reason for the need for an accurate CSI. The third example of the transition criterion may be based on a deep packet inspection (DPI). The DPI may determine if, for example, a TCP ACK is expected.

As schematically indicated at reference sign 510 in Fig. 5, as long as an UL or DL data transmission is (e.g., continuously) going on, periodic CSI reports with a first periodicity are transmitted according to the step 306 in the active CSI state 502 (which is also referred to as active CSI reporting state). If there has been a temporal gap without (e.g., DL) data transmission for a certain time period, *x*, or some other

predefined trigger criterion, the UE switches to the non-active CSI state 504 (which is also referred to as non-active CSI-reporting state) according to the state transition 506. The non-active CSI state 504 is maintained as long as no UL or DL arrives, as indicated at reference sign 512.

In order to keep the terminology short, the active CSI-reporting state 502 will be referred to as *active CSI state* 502, and the non-active CSI-reporting state 504 will be referred to as *non-active CSI state* 504. In some embodiments, the non-active state 504 is an *event-based state*, wherein the CSI is reported when triggered by one or more *event triggers*. In same or other embodiments, the non-active CSI state 504 uses a periodic CSI reporting with a second periodicity that is different from the first periodicity, e.g., longer than the first periodicity.

Within the non-active state, the event triggers that trigger the CSI transmissions according to the step 306 may be based on different criteria or reference value, e.g., representing an expiration of the CSI. The event triggers may comprise one or more of the following examples.

A first example for an event trigger compares a newly evaluated CSI relative to a previously evaluated CSI. In an implementation of the first example, if the evaluated CSI falls below a threshold compared to a previous CSI evaluation, the event (i.e., the CSI report) is triggered. The first example may trigger CSI reports when the CSI (e.g., obtained by the wireless device) is changing rapidly as a function of time.

A second example for an event trigger compares a newly evaluated CSI relative to a previously reported CSI. In an implementation of the second example, if the latest CSI evaluation would have resulted in a CQI index C in a CSI report, the event may be triggered when a CQI drops D indices below C. The second example may trigger CSI reports when the CSI at the RAN (e.g., the radio access node) has become inaccurate.

A third example for an event trigger compares a newly evaluated CSI relative to an (e.g., absolute) CSI threshold. In an implementation of the third example, the event may be triggered if the CQI falls below a minimum level. The third example may trigger CSI reports when a beamwidth and/or a number of layers in the DL has to be changed by the radio access node.

While above criteria and examples have been described as CSI-reporting rule within the non-active CSI state 504, at least one of the criteria and examples may be used,

alternatively or additionally, as a transition criterion, i.e., to trigger a state transition from the non-active CSI state 504 to the active CSI state 502. This state transition may cause a transmission of one or more CSI reports on the CSI reporting resource according to the step 306.

The comparison between newly and previously evaluated or reported CSI may also be formulated in the Signal to Interference plus Noise Ratio (SINR) domain. In other embodiments, the comparison may be in the spatial domain wherein preferred pre-coder for new and old CSI evaluation may be compared. For example, if the beamforming property of new pre-coder is significantly different from old pre-coder, the UE may enter the active state. A trigger can be a combination of listed criterions, both for the events and for the state-transitions.

When transmitting data in the DL, the radio access node may use an appropriate CQI indicated by the absence of the event-based report.

As mentioned above, for some embodiments, both the active CSI state 502 and the non-active CSI state 504 may be associated with CSI configurations for periodically reported CSI. The active CSI state 502 may be associated with a first CSI configuration for reporting the CSI with a first periodic time. The non-active CSI state 504 may be associated with a second CSI configuration for reporting the CSI with a second periodic time. The first periodic time may be less than second periodic time. In some other embodiments the non-active CSI reporting is a combination of periodic reporting and event-based reporting in the active CSI state 502 and the non-active CSI state 504, respectively. In a combination of such embodiments, in the non-active CSI state 504, the CSI is reported with the second periodic time and additionally when triggered by an event trigger.

In any embodiment or implementation, for an event-based non-active CSI state 504, some or all of the CSI-reporting triggers may be triggered only by the wireless device. It is at most the CSI configuration defining the CSI-reporting triggers which is configured by the radio access node, e.g., by means of the configuration message.

In some embodiments (e.g., including the above-mentioned embodiments) two or more wireless devices (e.g., each implementing the device 100) are assigned a shared CSI reporting resource, i.e., a radio resource for the reporting 306 of the CSI, e.g. on PUSCH or PUCCH. In such embodiments, a collision of CSI reports may occur due to two or more wireless devices triggering their transmission of a CSI report at the same

time and/or on the same resource. In at least some of such embodiments, the radio access node may detect the collisions, for example, if the DM-RSs used to demodulate the CSI reports are different for the wireless devices sharing CSI reporting resources.

When a collision occurs, the radio access node may determine which wireless devices are involved in the CSI report collision and transmit UL scheduling grants to at least one or all of the determined wireless devices. For example, the UL scheduling grants may be transmitted to wireless devices that cannot be spatially separated. The UL scheduling grants define dedicated radio resources (e.g., as opposed to the shared radio resources) for each of the wireless devices to transmit its CSI report.

The scheduling of dedicated resources responsive to detecting a collision can avoid a delay caused by the wireless device having to request for such a dedicated CSI reporting resource. Alternatively or in addition, the scheduling of dedicated resources responsive to detecting a collision can require less CSI reporting resources (e.g., on PUCCH and/or PUSCH) compared to each wireless device having its own unique (i.e., dedicated) CSI reporting resources.

In any embodiment, when UL data arrives from a higher layer, the wireless device may enter the active CSI state 502 according to the step 304 and start transmitting CSI reports according to the step 306. In some of such embodiments, when a scheduling request is received at the radio access node from the wireless device indicating that the wireless device has data to transmit, the radio access node may assume that the wireless device has entered the active CSI state 502 and prepare an UL scheduling grant knowing that the wireless device will multiplex (e.g., "piggyback") a CSI report together with data in the step 306.

Any embodiment or implementation of the device 100 (e.g., the wireless device) and/or the device 200 (e.g., the radio access node) may apply one or more of the following rules as to whether or not the CSI is multiplexed with data in the step 406.

According to a first rule, when receiving the UL transmission in the step 406 responsive the transmission of a requested UL scheduling grant, the radio access node may receive the UL transmission with the assumption that the CSI is multiplexed with the data transmission. Alternatively, the radio access node may perform two decoding attempts, one attempt assuming only data and another attempt assuming data and CSI being multiplexed.

According to a second rule, an event-based CSI report is only multiplexed (e.g., "piggybacked") in the UL, if there has not been any recent multiplexed aperiodic CSI report within a time *T* or according to some other rule.

According to a third rule, the event-based CSI report is transmitted in the step 306 on a CSI reporting resource dedicated for event-based CSI reports. The radio access node may decode UL data and event-base CSI on different resources, i.e. data and CSI are multiplexed, e.g., in the frequency domain.

Fig. 6 schematically illustrates an example of a time sequence 600 resulting from an implementation of the method 300 at the wireless device. The reception 602 of DL data and the arrival 604 of UL data is indicated by black and white bars, respectively.

In a first instance of the step 304, the active CSI state 502 is determined, resulting in a sequence 606 of periodic CSI reports according to the step 306. The time for the state transition 506 to the non-active state is reset to zero as the last UL data is transmitted. After *x* TTIs (or a certain time), the timer expires and the wireless device transitions to the non-active CSI state 504 according to a second instance of the step 304. While in the implementation of Fig. 6 the time *x* for triggering the state transition 506 depends on the availability of UL data, variants of the implementation depend on the reception of DL data, or on both UL and DL data.

In the non-active CSI state 504, an event 608 triggers the reporting 306 of the CSI. Optionally, a CSI request 610 from the RAN triggers an aperiodic CSI report 612.

The arrival of UL data 604 triggers, in a third instance of step 304, the state transition 508 to the active CSI state 502 of the wireless device. In the active CSI state 502, the periodic reporting 306 of the CSI is resumed.

Fig. 7 schematically illustrates an example flowchart of an implementation of the method 300 at the wireless device. For example, the network side (e.g., the RAN) transmits in the step 402 only the CSI configurations that include the trigger criterion, which are stored according to the step 302. Alternatively or in addition, the stored CSI configurations are activated by transmitting the corresponding control command in the step 404. The network does not need to send any state triggers or reporting triggers to the wireless device. It is the wireless device that is triggering the state-transitions internally based on the stored (e.g., received and/or predefined) transition

criteria included in the CSI configurations (which may be collectively referred to as state-based configuration).

The transition criteria are assessed in the step 304 and the resulting CSI state is executed in the step 306. The execution of the active CSI state 502 may include a short-periodic CSI reporting 702 and, optionally, aperiodic CSI reports 704 transmitted upon request. The execution of the non-active CSI state 504 may include an even-driven CSI reporting 706 and/or a long-periodic CSI reporting 708 and, optionally, aperiodic CSI reports 710 transmitted upon request.

Fig. 8 shows a schematic block diagram for an embodiment of the device 100. The device 100 comprises one or more processors 804 for performing the method 300 and memory 806 coupled to the processors 804. For example, the memory 806 may be encoded with instructions that implement at least one of the modules 102, 104 and 106.

The one or more processors 804 may be a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, microcode and/or encoded logic operable to provide, either alone or in conjunction with other components of the device 100, such as the memory 806, CSI reporting functionality. For example, the one or more processors 804 may execute instructions stored in the memory 806. Such functionality may include providing various features and steps discussed herein, including any of the benefits disclosed herein. The expression "the device being operative to perform an action" may denote the device 100 being configured to perform the action.

As schematically illustrated in Fig. 8, the device 100 may be embodied by a wireless device 800. The wireless device 800 comprises a radio interface 802 coupled to the device 100 for radio communication with a radio node, e.g., a radio access node or another wireless device.

In a variant, e.g., as schematically illustrated in Fig. 9, the functionality of the device 100 is provided by a node 900 linked to the wireless device. That is, the node 900 performs the method 300. The functionality of the device 100 is provided by the node 900 to the wireless device 800, e.g., via the interface 802 or a dedicated wired or wireless interface.

Fig. 10 shows a schematic block diagram for an embodiment of the device 200. The device 200 comprises one or more processors 1004 for performing the method 400 and memory 1006 coupled to the processors 1004. For example, the memory 1006 may be encoded with instructions that implement at least one of the modules 202, 204 and 206.

The one or more processors 1004 may be a combination of one or more of a microprocessor, controller, microcontroller, central processing unit, digital signal processor, application specific integrated circuit, field programmable gate array, or any other suitable computing device, resource, or combination of hardware, microcode and/or encoded logic operable to provide, either alone or in conjunction with other components of the device 200, such as the memory 1006, CSI receiving functionality. For example, the one or more processors 1004 may execute instructions stored in the memory 1006. Such functionality may include providing various features and steps discussed herein, including any of the benefits disclosed herein. The expression "the device being operative to perform an action" may denote the device 200 being configured to perform the action.

As schematically illustrated in Fig. 10, the device 200 may be embodied by a radio node 1000, e.g., a radio access node of a RAN or another wireless device wirelessly connected to the wireless device. The radio node 1000 comprises a radio interface 1002 coupled to the device 200 for radio communication with one or more wireless devices.

In a variant, e.g., as schematically illustrated in Fig. 11, the functionality of the device 200 is provided by a node 1100, e.g., a node of the RAN or a CN linked to the RAN. That is, the node 1100 performs the method 400. The functionality of the device 200 is provided by the node 1100 to the radio node 1000, e.g., via the interface 1002 or a dedicated wired or wireless interface.

As has become apparent from above description, embodiments of the technique can reduce the load on PUCCH, PUSCH and/or PDCCH. Hence, at least some of these embodiments can reduce interference or collisions on shared radio resources.

Same or further embodiments can make it possible to multiplex more UEs on the same CSI reporting resource. The UEs may be statistically multiplexed, since the events triggering the UEs to use the assigned resource for CSI reporting may not

happen at the same time for all UEs. Hence, several UEs may share the same resource for CSI reporting and still maintain an acceptable probability of a CSI report collision.

Moreover, the technique may enable the UE to autonomously report new or updated CSI based on a trigger-criterion, e.g., an expiration measure. The network may be provided with accurate information about the CSI that it is not outdated.

Many advantages of the present invention will be fully understood from the foregoing description, and it will be apparent that various changes may be made in the form, construction and arrangement of the units and devices without departing from the scope of the invention and/or without sacrificing all of its advantages. Since the invention can be varied in many ways, it will be recognized that the invention should be limited only by the scope of the following claims.

Claims

1. A method (300) of reporting channel state information, CSI, from a wireless device (800) to a radio node (1000), the wireless device (800) being wirelessly connected or connectable to the radio node (1000), the method comprising or triggering the steps of:

storing (302), at the wireless device (800), different CSI configurations associated with different CSI states (502; 504), wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states (502; 504);

determining (304), by the wireless device (800), the state transition to a CSI state among the CSI states (502; 504) if the corresponding transition criterion is fulfilled; and

reporting (306) the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

2. The method of claim 1, wherein the radio node (1000) comprises at least one of a radio access node of a radio access network, RAN, and another wireless device in a device-to-device, D2D, communication with the wireless device (800).

3. The method of claim 1 or 2, wherein the step (304) of determining the state transition to the CSI state includes:

determining, by the wireless device (800), for each of one or more of the CSI states (502; 504) whether the transition criterion for the state transition to the corresponding CSI state is fulfilled, wherein the CSI state for which the transition criterion is fulfilled is determined.

4. The method of any one of claims 1 to 3, wherein the transition criterion depends on a current CSI state among the CSI states (502; 504).

5. The method of any one of claims 1 to 4, wherein the CSI states (502; 504) include at least one active CSI state (502), and wherein, according to the CSI configuration associated with the active CSI state (502), the CSI is periodically reported by the wireless device (800) in the active CSI state (502).

6. The method of claim 5, wherein, in the active CSI state (502) of the wireless device (800), the CSI is reported on a physical uplink control channel, PUCCH, or multiplexed with data (604) on a physical uplink shared channel, PUSCH, of a RAN or the radio node (1000).

7. The method of claim 5 or 6, wherein the CSI configuration associated with the active CSI state (502) is indicative of a periodicity (606) for the reporting (306) of the CSI.

8. The method of any one of claims 5 to 7, wherein the transition criterion for the transition to the active CSI state (502) includes at least one of an arrival of uplink data (604) and a reception of downlink data (602).

9. The method of any one of claims 5 to 8, wherein the transition criterion for the transition to the active CSI state (502) includes a change of the CSI.

10. The method of any one of claims 1 to 9, wherein the CSI states (502; 504) include at least one inactive CSI state (504).

11. The method of claim 10 in conjunction with any one of claims 5 to 9, wherein the CSI is reported more frequently in the active CSI state (502) than in the inactive CSI state (504).

12. The method of claim 10 or 11, wherein the CSI is periodically reported according to the CSI configuration associated with the inactive CSI state (504).

13. The method of claim 12 in conjunction with any one of claims 5 to 9, wherein the CSI configuration associated with the inactive CSI state (504) is indicative of a periodicity for the reporting of the CSI, which is longer than the periodicity of the active CSI state (502).

14. The method of any one of claims 10 to 13, wherein the reporting (304) of the CSI by the wireless device (800) in the inactive CSI state (504) is triggered (710) by a request received from a RAN or the radio node (1000).

15. The method of any one of claims 10 to 14, wherein the reporting (304) of the CSI by the wireless device (800) in the inactive CSI state (504) is triggered (706) by an event according to the CSI configuration associated with the inactive CSI state (504).

16. The method of any one of claims 10 to 15, wherein the reporting (304) of the CSI by the wireless device (800) in the inactive CSI state (504) is triggered (706) by a change of the CSI according to the CSI configuration associated with the inactive CSI state (504).

17. The method of claim 9 or 16, wherein the change of the CSI includes a change of at least one of a reference signal received power, RSRP; a channel quality indicator, CQI; a signal-to-noise ratio, SNR; a precoding matrix index, PMI; and rank indicator, RI.

18. The method of any one of claims 15 to 17, wherein the triggered reporting (706; 710) includes the step of:

obtaining a radio resource of a RAN or the radio node (1000) for transmitting the CSI.

19. The method of any one of claims 10 to 18, wherein the transition criterion for the transition to the inactive CSI state (504) includes an expiry of a timer at the wireless device (800).

20. The method of claim 19, wherein the timer is reset upon at least one of arrival of uplink data (604) and reception of downlink data (602).

21. The method of claim 8 or 20, wherein a status of a buffer at the wireless device (800) or a scheduling grant from the radio node (1000) is indicative of the arrival, and/or wherein the downlink data (602) is received from the radio node (1000) or a scheduling assignment from the radio node (1000) is indicative of the reception.

22. The method of any one of claims 8, 20 and 21, further comprising or triggering the step of:

performing a deep packet inspection, DPI, or a stateful packet inspection, SPI, of at least one of the uplink data (604) and the downlink data (602), wherein an expected arrival or expected reception of an acknowledgment message is indicative of the arrival or the reception.

23. The method of any one of claims 1 to 22, further comprising or triggering the step of:

performing a measurement for the CSI based on reference signals, RS, for the CSI.

24. The method of any one of claims 1 to 23, further comprising at least one of the steps of:

receiving at least one configuration message from the radio node (1000), the at least one configuration message comprising or being indicative of at least one of

the CSI configurations associated with the CSI states (502; 504) of the wireless device (800) or an updated thereof, and

a control command controlling the wireless device (800) to perform at least the determining step (304); and

receiving, from the radio node (1000), the configuration message or a further configuration message, which comprises or is indicative of the transition criterion for at least one of the CSI states (502; 504) stored or to be stored at the wireless device (800).

25. The method of any one of claims 1 to 24, wherein the reporting (306) of the CSI includes transmitting the CSI on a shared radio resource of a RAN or the radio node (1000), the method further comprising the steps of:

receiving a scheduling grant responsive to a collision on the shared radio resource; and

retransmitting the CSI according to the scheduling grant.

26. A method (400) of receiving channel state information, CSI, from a wireless device (800) at a radio node (1000) providing radio access to the wireless device (800), the method comprising or triggering the steps of:

transmitting (402; 404) at least one configuration message to the wireless device (800), the at least one configuration message comprising or being indicative of at least one of

different CSI configurations associated with different CSI states (502; 504) of the wireless device (800), wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states (502; 504); and

a control command controlling the wireless device (800) to determine the state transition to a CSI state among the CSI states (502; 504) if the corresponding transition criterion is fulfilled based on the CSI configurations stored at the wireless device (800); and

receiving (406) the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

27. The method of claim 26, wherein the control command for determining the state transition to the CSI state controls:

determining, by the wireless device (800), for each of one or more of the CSI states (502; 504) whether the transition criterion for the state transition to the corresponding CSI state is fulfilled, wherein the CSI state for which the transition criterion is fulfilled is determined.

28. The method of claim 26 or 27, wherein the CSI is received on a shared radio resource of a RAN or the radio node (1000), the method further comprising the steps of:

detecting a collision on shared radio resource;

transmitting a scheduling grant responsive to the detected collision on the shared radio resource; and

receiving the CSI according to the scheduling grant.

29. The method of any one of claims 26 to 28, further comprising any step or a corresponding step according to any one of claims 2 to 25.

30. A computer program product comprising program code portions for performing the steps of any one of the claims 1 to 29 when the computer program product is executed on one or more computing devices (804; 1004).

31. The computer program product of claim 30, stored on a computer-readable recording medium (806; 1006).

32. A device (100) for reporting channel state information, CSI, from a wireless device (800) to a radio node (1000), the wireless device (800) being wirelessly connected or connectable to the radio node (1000), the device (100) being configured to:

store, at the wireless device (800), different CSI configurations associated with different CSI states (502; 504), wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states (502; 504);

determine, by the wireless device (800), the state transition to a CSI state among the CSI states (502; 504) if the corresponding transition criterion is fulfilled; and

report the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

33. The device of claim 32, further configured to perform the steps of any one of claims 2 to 25.

34. A device (200) for receiving channel state information, CSI, from a wireless device (800) at a radio node (1000) providing radio access to the wireless device (800), the device (200) being configured to:

transmit at least one configuration message to the wireless device (800), the at least one configuration message comprising or being indicative of at least one of

different CSI configurations associated with different CSI states (502; 504) of the wireless device (800), wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states (502; 504); and

a control command controlling the wireless device (800) to determine the state transition to a CSI state among the CSI states (502; 504) if the corresponding transition criterion is fulfilled based on the CSI configurations stored at the wireless device (800); and

receive the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination.

35. The device of claim 34, further configured to perform the steps of any one of claims 27 to 29.

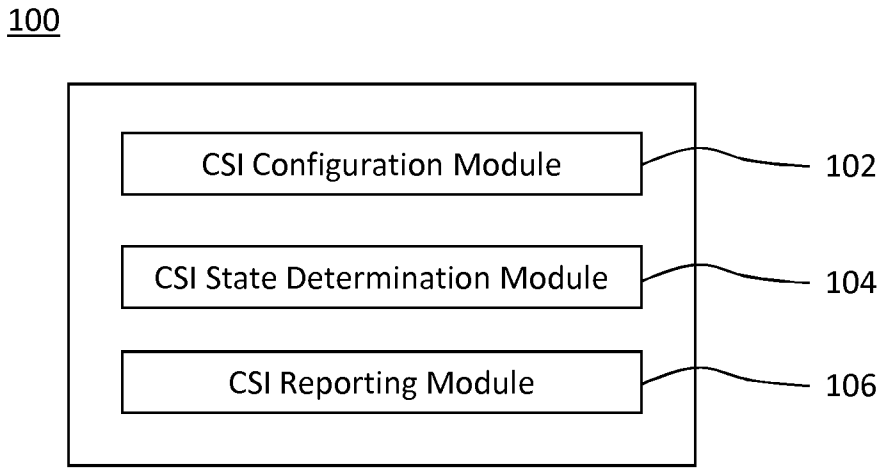
100
CSI Configuration Module
102
CSI State Determination Module
104
CSI Reporting Module
106

Fig. 1

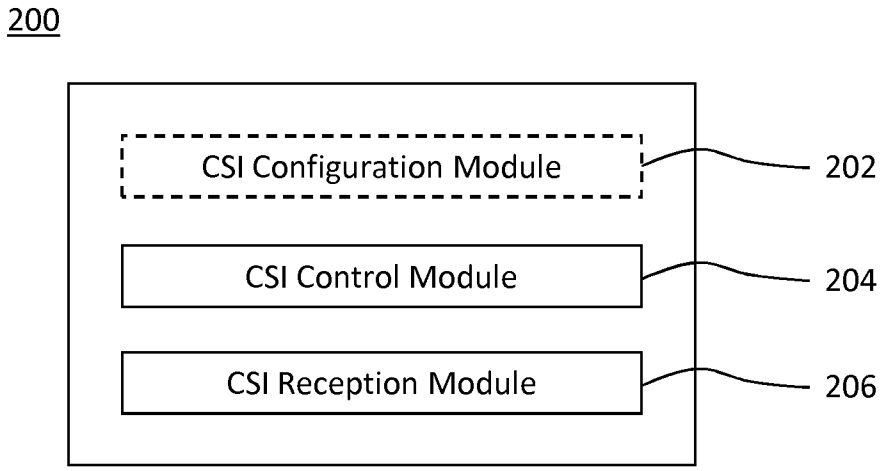
200
CSI Configuration Module
202
CSI Control Module
204
CSI Reception Module
206

Fig. 2

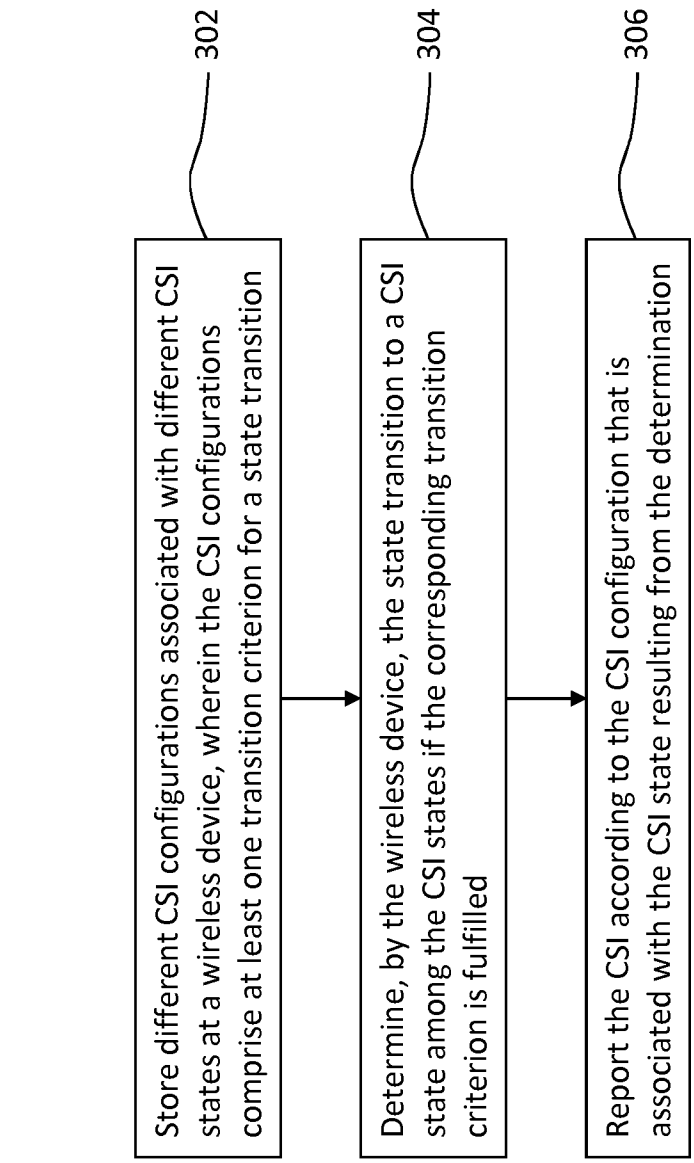
300
302
Store different CSI configurations associated with different CSI states at a wireless device, wherein the CSI configurations comprise at least one transition criterion for a state transition
304
Determine, by the wireless device, the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled
306
Report the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination

Fig. 3

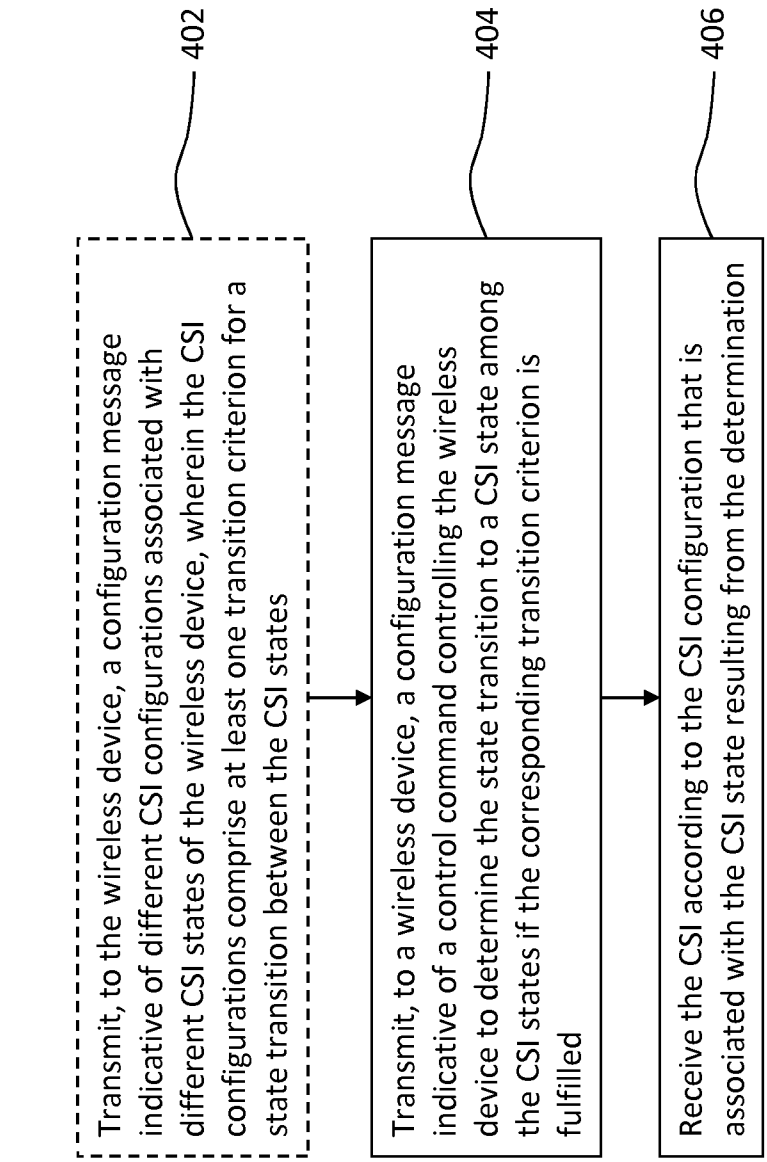
400
402
Transmit, to the wireless device, a configuration message indicative of different CSI configurations associated with different CSI states of the wireless device, wherein the CSI configurations comprise at least one transition criterion for a state transition between the CSI states
404
Transmit, to a wireless device, a configuration message indicative of a control command controlling the wireless device to determine the state transition to a CSI state among the CSI states if the corresponding transition criterion is fulfilled
406
Receive the CSI according to the CSI configuration that is associated with the CSI state resulting from the determination

Fig. 4

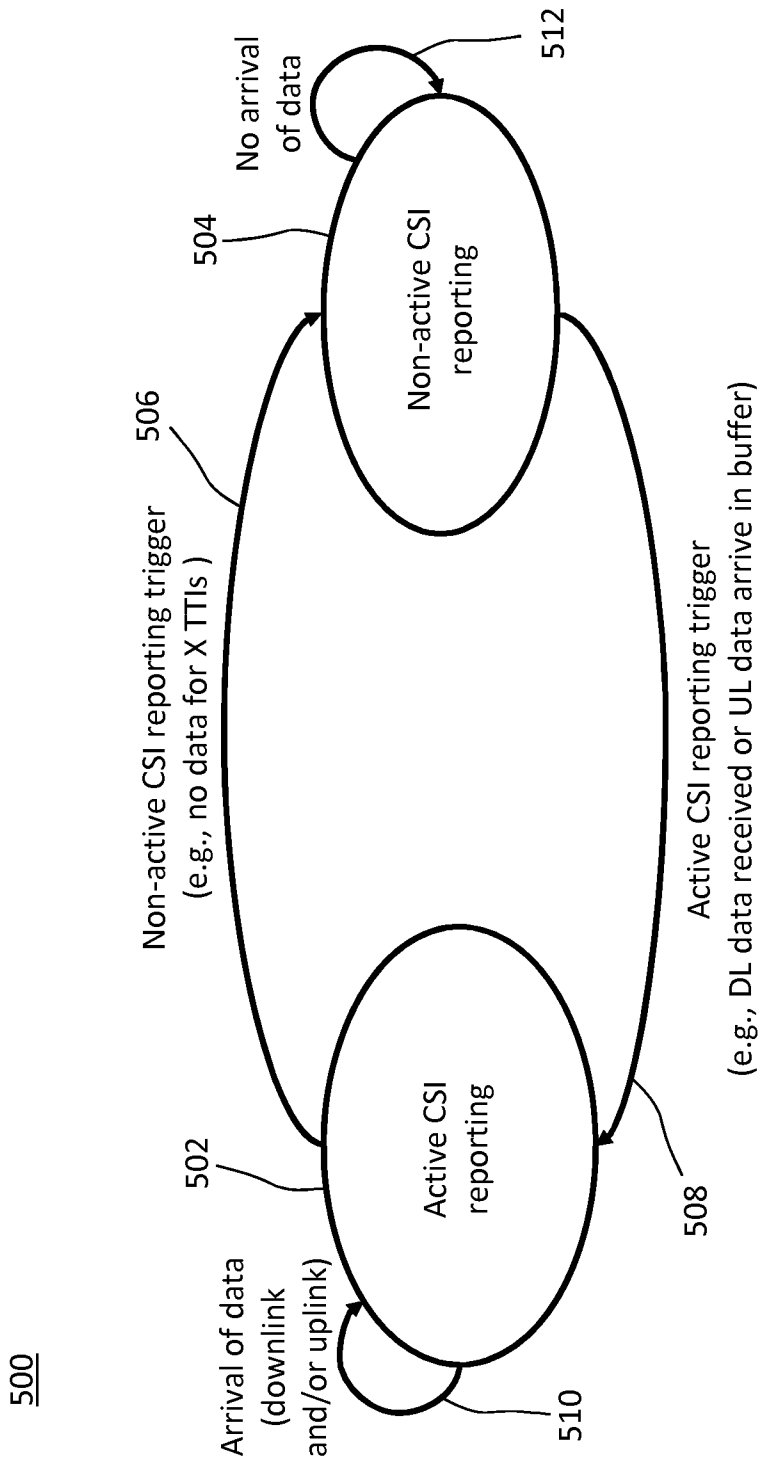
500
Non-active CSI reporting
Active CSI reporting
No arrival of data
Arrival of data (downlink and/or uplink)
Non-active CSI reporting trigger (e.g., no data for X TTIs)
Active CSI reporting trigger (e.g., DL data received or UL data arrive in buffer)
502
504
506
508
510
512

Fig. 5

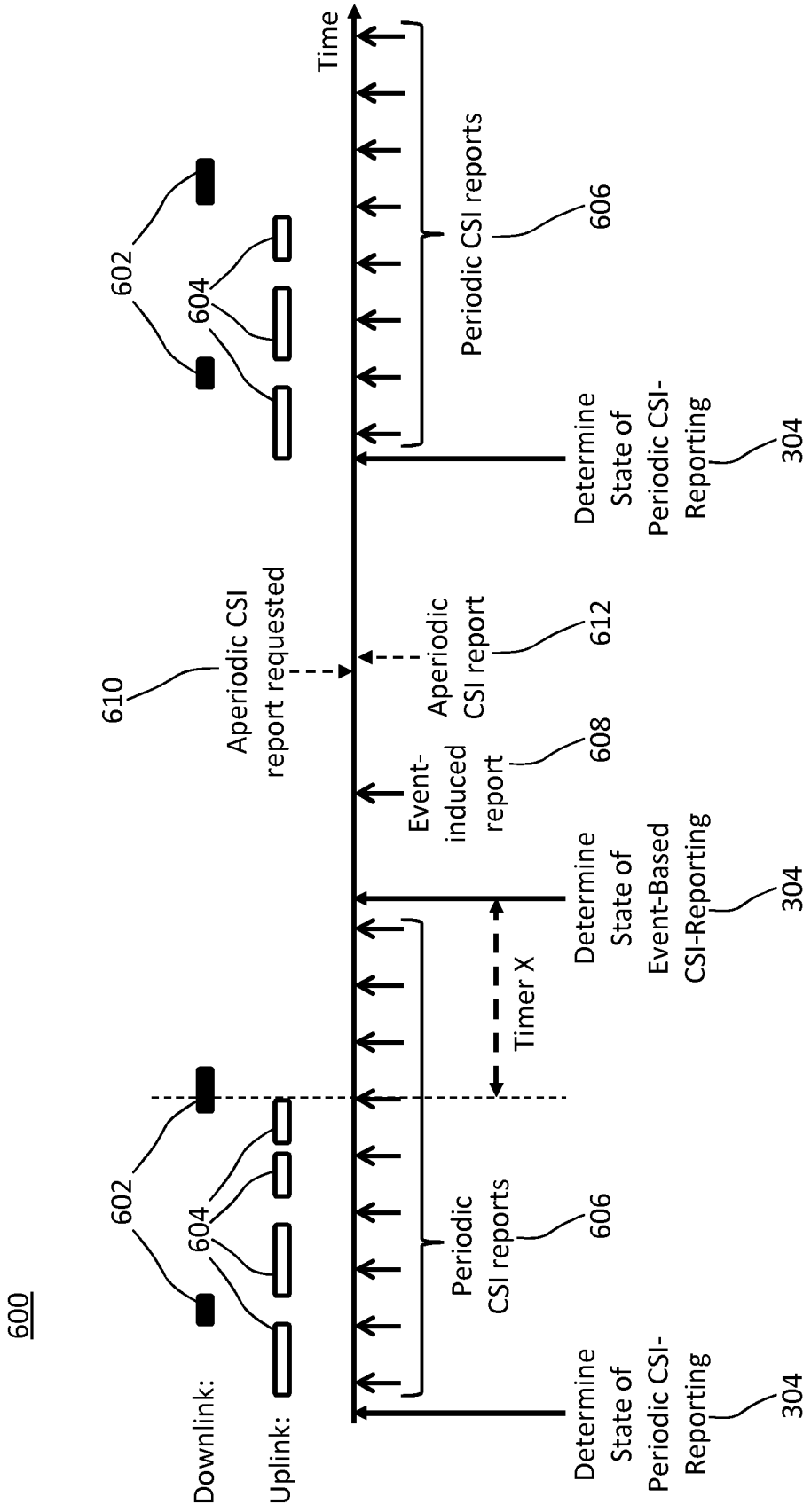
600
Downlink:
Uplink:
602
604
606
Periodic CSI reports
Determine State of Periodic CSI-Reporting
304
Timer X
608
Event-induced report
Determine State of Event-Based CSI-Reporting
610
Aperiodic CSI report requested
612
Aperiodic CSI report
Time

Fig. 6

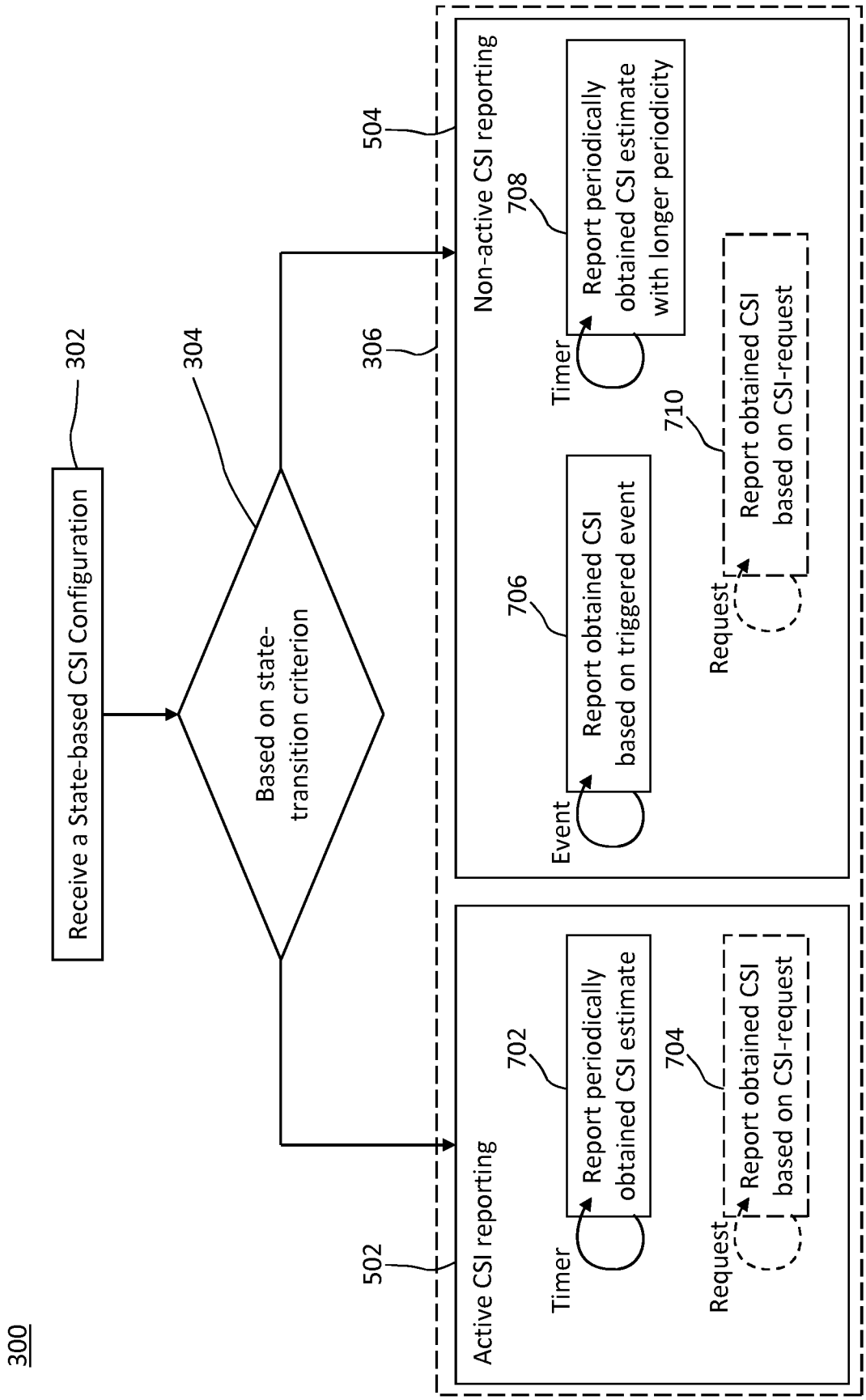
300
Receive a State-based CSI Configuration
302
Based on state-transition criterion
304
306
Active CSI reporting
502
Timer
Report periodically obtained CSI estimate
702
Request
Report obtained CSI based on CSI-request
704
Non-active CSI reporting
504
Event
Report obtained CSI based on triggered event
706
Timer
Report periodically obtained CSI estimate with longer periodicity
708
Request
Report obtained CSI based on CSI-request
710

Fig. 7

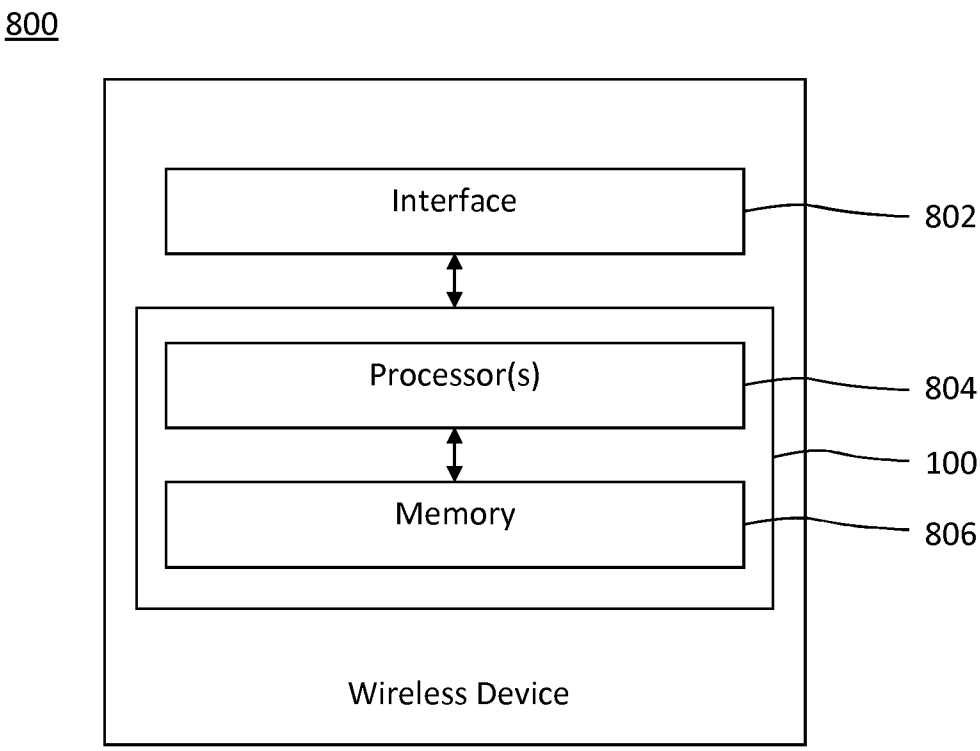
800
Interface
802
Processor(s)
804
100
Memory
806
Wireless Device

Fig. 8

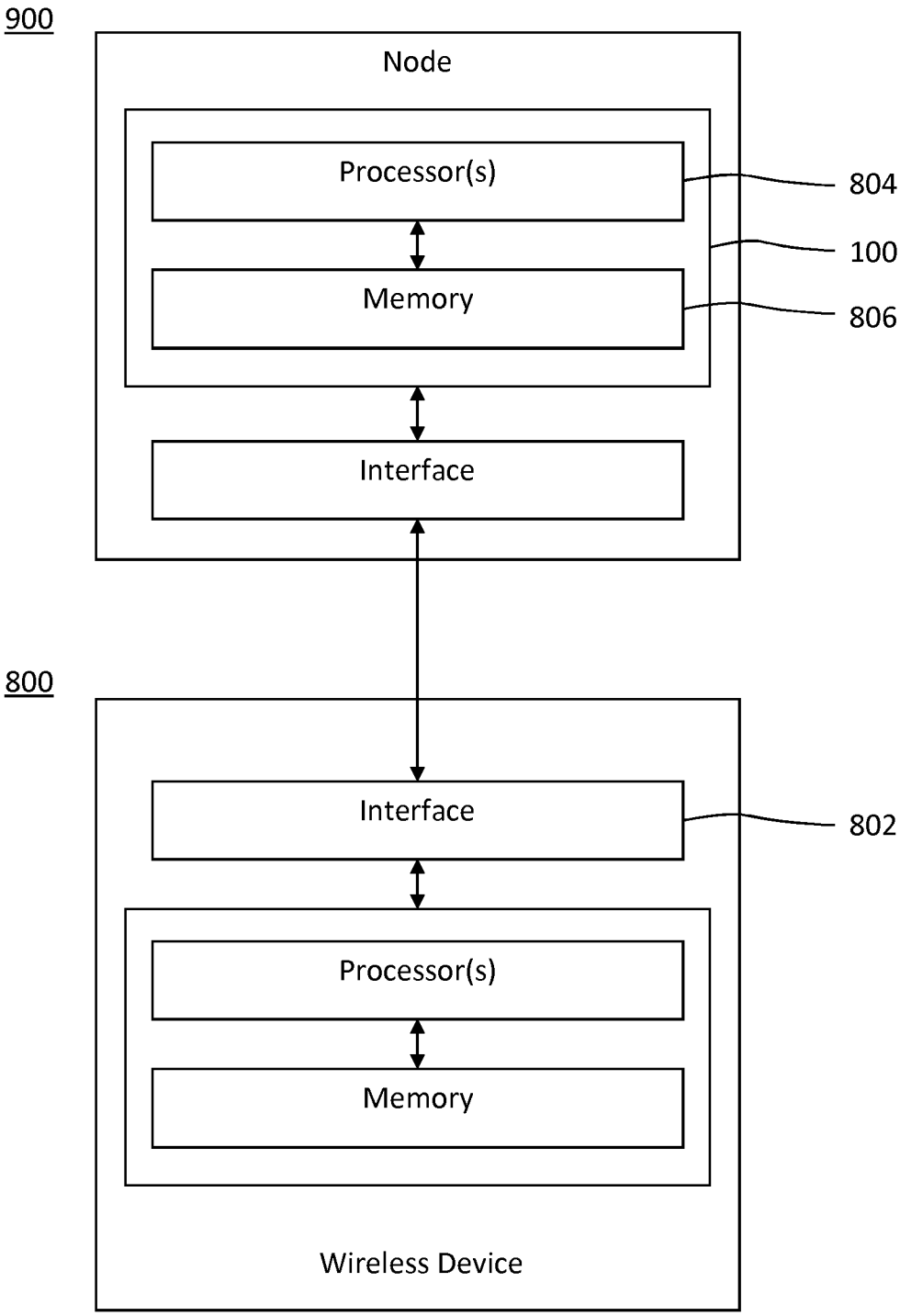
900
Node
Processor(s)
804
100
Memory
806
Interface
800
Interface
802
Processor(s)
Memory
Wireless Device

Fig. 9

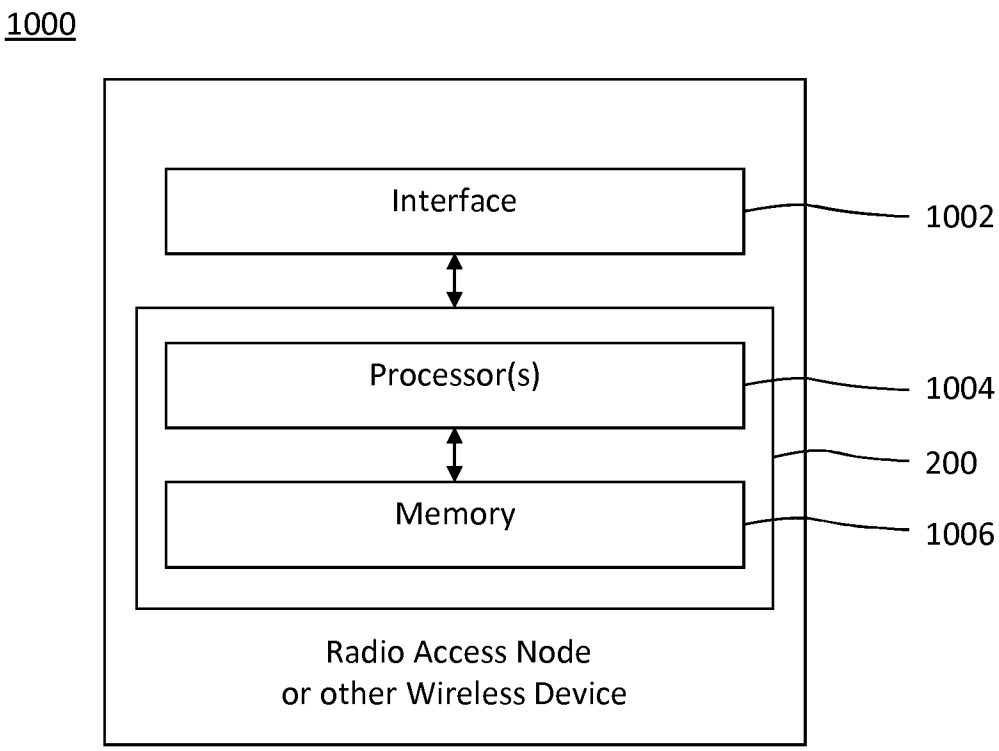
1000
Interface
1002
Processor(s)
1004
200
Memory
1006
Radio Access Node
or other Wireless Device

Fig. 10

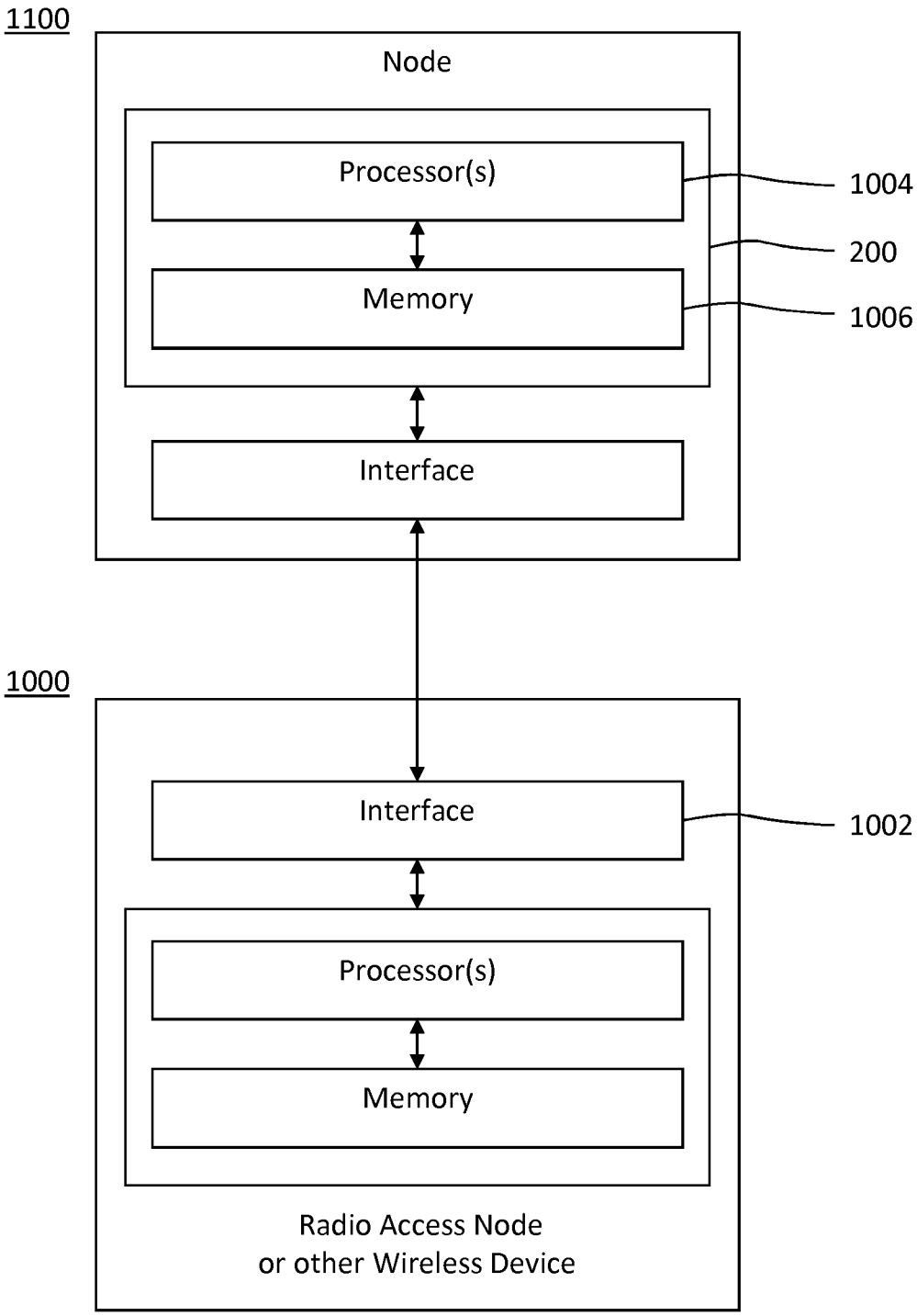
1100
Node
Processor(s)
Memory
Interface
1004
200
1006
1000
Interface
Processor(s)
Memory
Radio Access Node
or other Wireless Device
1002

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/083857

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L1/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L H04B H04W

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

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

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2011/127092 A1 (QUALCOMM INC [US]; LUO XILIANG [US]; ZHANG XIAOXIA [US]; GAAL PETER [U) 13 October 2011 (2011-10-13) abstract paragraph [0075] - paragraph [0076] figures 10, 11	1-24,26, 27,29-35
X	WO 2016/089106 A1 (LG ELECTRONICS INC [KR]) 9 June 2016 (2016-06-09) abstract paragraph [0109] paragraph [0142] - paragraph [0145] figure 15	1-24,26, 27,29-35

-/--

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 September 2018	12/11/2018

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

1

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	"3rd Generation Partnership Project; Technical Specification Group Radio Access Network; NR; Physical layer procedures for data (Release 15)", 3GPP DRAFT; RP-172416 38214-200, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , 17 December 2017 (2017-12-17), XP051365107, Retrieved from the Internet: URL:http://www.3gpp.org/Meetings_3GPP_SYNC/RAN/Docs/RP-172416 38214-200.doc [retrieved on 2017-12-17] * section 5.2 * -----	1-24,26, 27,29-35

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2017/083857

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

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

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-24, 26, 27, 29-32, 34(completely); 33, 35(partially)

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

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

1. claims: 1-24, 26, 27, 29-32, 34(completely); 33, 35(partially)

   the step of determining the state transition to the CSI state includes: determining, by the wireless device, for each of one or more of the CSI states whether the transition criterion for the state transition to the corresponding CSI state is fulfilled, wherein the CSI state for which the transition criterion is fulfilled is determined.

   ---

2. claims: 25, 28(completely); 33, 35(partially)

   the reporting of the CSI includes transmitting the CSI on a shared radio resource of a RAN or the radio node, the method further comprising the steps of: receiving a scheduling grant responsive to a collision on the shared radio resource; and retransmitting the CSI according to the scheduling grant.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/083857

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2011127092 A1	13-10-2011	BR 112012025057 A2	21-06-2016
		CN 102893546 A	23-01-2013
		EP 2556612 A1	13-02-2013
		JP 5529336 B2	25-06-2014
		JP 2013530559 A	25-07-2013
		KR 20130018850 A	25-02-2013
		US 2012076017 A1	29-03-2012
		WO 2011127092 A1	13-10-2011
WO 2016089106 A1	09-06-2016	EP 3228022 A1	11-10-2017
		KR 20170091604 A	09-08-2017
		US 2017294950 A1	12-10-2017
		WO 2016089106 A1	09-06-2016