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(54) **Title**: DETERMINING UPLINK TRANSMISSION POWER

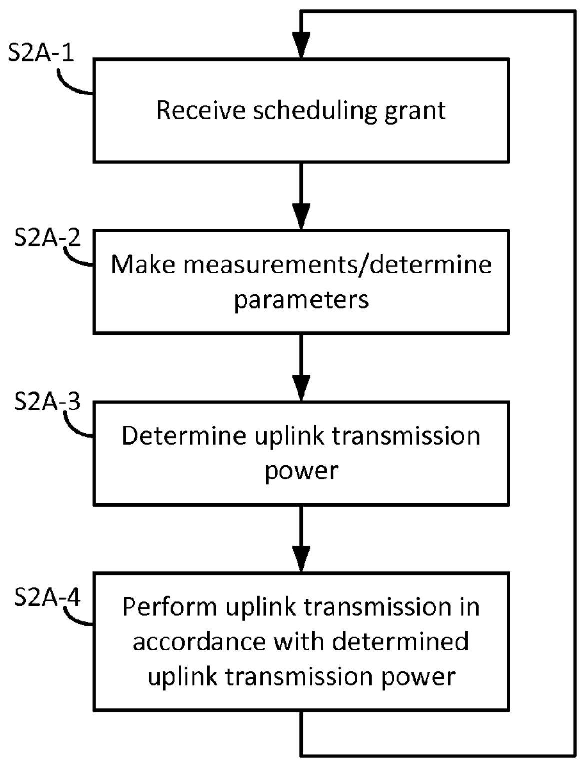

FIG. 2A

(57) **Abstract**: This specification describes a method comprising determining an uplink transmission power value for user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells.

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Determining Uplink Transmission Power

Field

This specification relates to determining uplink transmission power for user equipment in a radio access network.

Background

One of the aims with future E-UTRA (Advanced LTE) networks is the provision of extremely high data rates and a very high number of connected devices. In a network having high data rates and a high number of connected devices, interference between communicating entities can be problematic. One factor contributing to such interference is uplink transmission power.

Summary

In a first aspect, this specification describes a method comprising determining an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells.

The uplink transmission power value may be dependent on an interference of uplink transmission by the user equipment in respect of at least one of the neighbouring cells.

The uplink transmission power value may be dependent on an interference of uplink transmission by the user equipment in respect of only neighbouring cells which are serving at least one user equipment.

The uplink transmission power value may be dependent on a product of a channel gain between the at least one neighbouring cell and the user equipment and a measure of the load of the neighbouring cell. The method may further comprise estimating channel gain between the at least one neighbouring cell and the user equipment based on measurements in respect of downlink reference signals from the neighbouring cells, or estimating the channel gain between the at least one neighbouring cell and the user equipment based on a total interference measurement.

The uplink transmission power value may be dependent on a product of the channel gain between the serving cell and the user equipment and a measure of the load of the serving cell. The method may comprise estimating the channel gain between the serving cell and the user equipment based on measurements of downlink reference signals from the serving cell.

The method may further comprise receiving information indicative of the load of at least the serving cell from the serving cell. The information indicative of the load of the serving cell may be determined based on a transmission power of a reference signal received from the serving cell, the transmission power of the reference signal being modulated in dependence on the load of the serving cell. The information indicative of the load of the serving cell may be indicative of a product of the load of the serving cell and the channel gain between the serving cell and the user equipment. The method may comprise performing a measurement in respect of the reference signal received from the serving cell, thereby to determine the product of the load of the serving cell and the channel gain between the serving cell and the user equipment.

The information indicative of the load of the one or more neighbouring cells may be conveyed using a transmission power of respective reference signals received from respective neighbouring cells, the transmission power of each reference signal being modulated based on the load of the neighbouring cell from which the reference signal is received. The information indicative of the load of the one or more neighbouring cells may be indicative of a product of the load of the respective neighbouring cell and the channel gain between the neighbouring cell and the user equipment. The method may comprise performing a measurement in respect of the reference signal received from each neighbouring cell, thereby to determine the product of the load of the neighbouring cell and the channel gain between the neighbouring cell and the user equipment.

In some examples, the information indicative of the load of the serving cell may be included as data in a signalling message received from the serving cell. The information indicative of the loads of the one or more neighbouring cells may be included as data in a signalling message received from the serving cell.

The determining of the uplink transmission power value may be performed by the user equipment. When determining the uplink transmission power value, the user equipment may compute the uplink transmission power value based on the load of the serving cell and the load of the one or more neighbouring cells. Alternatively, when determining the uplink transmission power value, the user equipment may extract the uplink transmission power value from a look-up table locally-available to the user equipment.

Determining the uplink transmission power value may be performed in response to receiving uplink scheduling information from the serving cell.

The uplink transmission power value may be in accordance with an expression whereby, in certain circumstances, a larger product of a measure of a load of a neighbouring cell and the channel gain between the neighbouring cell and the user equipment results in a lower uplink transmission power value. The uplink transmission power value may, in certain circumstances, vary in accordance with one divided by a sum over N neighbouring cells of a product of a channel gain between a neighbouring cell and a measure of load of the neighbouring cell.

In a second aspect, this specification describes a method comprising modulating transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal.

An eNodeB may modulate the transmission power of a reference signal and the radio network cell may be operated by the eNodeB. The recipient of the reference signal may comprise one or more user equipments, at least one of which is being served by another radio network cell.

The reference signal may be configured such that the recipient is able to determine, based on the modulated transmission power of the reference signal, an indication of the product of channel gain between the recipient and the apparatus transmitting the reference signal and the load of the cell operated by the eNodeB.

The method may comprise, prior to transmission of the reference signal, causing transmission of a configuration information signal carrying configuration information for enabling the recipient to interpret the subsequently transmitted reference signal which has its transmission power modulated based on the load of the radio network cell. The method may comprise receiving at an eNodeB, which operates a first cell, configuration information relating to reference signals to be transmitted in relation to another cell, and including in the configuration information signal the configuration information relating to reference signals to be transmitted by the other cell in addition to configuration information relating to reference signals to be transmitted in relation to the first cell.

In a third aspect, this specification describes a computer program product containing a look-up table comprising uplink power transmission values for use by a user equipment being served by a serving cell in a radio access network comprising the serving cell and one or more neighbouring cells, wherein the uplink power transmission values have been determined on the basis of plural different notional loads of the serving cell and plural different notional loads of the one or more neighbouring cells.

The uplink transmission power values may have been determined on the basis of plural notional interference levels of uplink transmission by the user equipment in respect of at least one of the neighbouring cells. The uplink transmission power values may have been determined on the basis of a product of a notional channel gain between the at least one neighbouring cell and the user equipment and a measure of the notional load of the neighbouring cell.

The uplink transmission power values may have been determined on the basis of a product of a notional channel gain between the serving cell and the user equipment and a measure of the notional load of the serving cell.

In a fourth aspect, this specification describes user equipment including the computer program product according to third aspect.

In a fifth aspect, this specification describes apparatus configured to perform a method according to either of the first and second aspects.

In a sixth aspect, this specification describes computer-readable instructions which, when executed by processing apparatus, causes the processing apparatus to perform a method according to either of the first and second aspects.

In a seventh aspect, this specification describes apparatus comprising at least one processor and at least one memory including computer program code which, when executed by the at least one processor, causes the apparatus to determine an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells.

The uplink transmission power value may be dependent on an interference of uplink transmission by the user equipment in respect of at least one of the neighbouring cells.

The uplink transmission power value may be dependent on an interference of uplink transmission by the user equipment in respect of only neighbouring cells which are serving at least one user equipment.

The uplink transmission power value may be dependent on a product of a channel gain between the at least one neighbouring cell and the user equipment and a measure of the load of the neighbouring cell. The computer program code, when executed by the at least one processor, may cause the apparatus to estimate channel gain between the at least one neighbouring cell and the user equipment based on measurements in respect of downlink reference signals from the neighbouring cells, or to estimate the channel gain between the at least one neighbouring cell and the user equipment based on a total interference measurement.

The uplink transmission power value may be dependent on a product of the channel gain between the serving cell and the user equipment and a measure of the load of the serving cell. The computer program code, when executed by the at least one processor, may cause the apparatus to estimate the channel gain between the serving cell and the user equipment based on measurements of downlink reference signals from the serving cell.

The computer program code, when executed by the at least one processor, may cause the apparatus to receive information indicative of the load of at least the serving cell from the serving cell. The information indicative of the load of the serving cell may be determined based on a transmission power of a reference signal received from the serving cell, the transmission power of the reference signal being modulated in dependence on the load of the serving cell. The information indicative of the load of the serving cell may be indicative of a product of the load of the serving cell and the channel gain between the serving cell and the user equipment. The computer program code, when executed by the at least one processor, may cause the apparatus to perform a measurement in respect of the reference signal received from the serving cell, thereby to determine the product of the load of the serving cell and the channel gain between the serving cell and the user equipment.

The information indicative of the load of the one or more neighbouring cells may be conveyed using a transmission power of respective reference signals received from respective neighbouring cells, the transmission power of each reference signal being modulated based on the load of the neighbouring cell from which the reference signal is received. The information indicative of the load of the one or more neighbouring cells may be indicative of a product of the load of the respective neighbouring cell and the channel gain between the neighbouring cell and the user equipment. The computer program code, when executed by the at least one processor, may cause the apparatus to perform a measurement in respect of the reference signal received from each neighbouring cell, thereby to determine the product of the load of the neighbouring cell and the channel gain between the neighbouring cell and the user equipment.

The information indicative of the load of the serving cell may be included as data in a signalling message received from the serving cell. The information indicative of the loads of the one or more neighbouring cells may be included as data in a signalling message received from the serving cell.

The determining of the uplink transmission power value may be performed by the user equipment. When determining the uplink transmission power value, the user equipment may compute the uplink transmission power value based on the load of the serving cell and the load of the one or more neighbouring cells. Alternatively, when determining the uplink transmission power value, the user equipment may extract the uplink transmission power value from a look-up table locally-available to the user equipment.

The computer program code, when executed by the at least one processor, may cause the apparatus to determine the uplink transmission power value in response to receiving uplink scheduling information from the serving cell.

The uplink transmission power value may be in accordance with an expression whereby, in certain circumstances, a larger product of a measure of a load of a neighbouring cell and the channel gain between the neighbouring cell and the user equipment results in a lower uplink transmission power value. The uplink transmission power value, in certain circumstances, may vary in accordance with one divided by a sum over N neighbouring cells of a product of a channel gain between a neighbouring cell and a measure of load of the neighbouring cell.

In an eighth aspect, this specification describes apparatus comprising at least one processor, and at least one memory including computer program code, which when executed by the at least one processor, causes the apparatus to modulate transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal.

An eNodeB may modulate the transmission power of a reference signal and the radio network cell may be operated by the eNodeB. The recipient of the reference signal may comprise one or more user equipments, at least one of which is being served by another radio network cell. The reference signal may be configured such that the recipient is able to determine, based on the modulated transmission power of the reference signal, an indication of the product of channel gain between the recipient and the apparatus transmitting the reference signal and the load of the cell operated by the eNodeB.

The computer program code, when executed by the at least one processor, may cause the apparatus to, prior to transmission of the reference signal, cause transmission of a configuration information signal carrying configuration information for enabling the recipient to interpret the subsequently transmitted reference signal which has its transmission power modulated on the basis of the load of the cell from which the signal is transmitted. The computer program code, when executed by the at least one processor, may cause the apparatus to receive at an eNodeB, which operates a first cell, configuration information relating to reference signals to be transmitted in relation to another cell; and to include in the configuration information signal the configuration information relating to reference signals to be transmitted by the other cell in addition to configuration information relating to reference signals to be transmitted in relation to the first cell.

In a ninth aspect, this specification describes a computer-readable medium having computer-readable code stored thereon, the computer readable code, when executed by a least one processor, causing performance of at least determining an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells. The computer-readable code stored on the medium of the ninth aspect may further cause performance of any of the operations described with reference to the method of the first aspect.

In a tenth aspect, this specification describes a computer-readable medium having computer-readable code stored thereon, the computer readable code, when executed by a least one processor, causing performance of at least modulating transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal. The computer-readable code stored on the medium of the tenth aspect may further cause performance of any of the operations described with reference to the method of the first aspect.

In an eleventh aspect, this specification describes apparatus comprising means for determining an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells. The apparatus of the eleventh aspect may further comprise means for causing performance of any of the operations described with reference to method of the first aspect.

In a twelfth aspect, this specification describes apparatus comprising means for modulating transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal. The apparatus of the twelfth aspect may further comprise means for causing performance of any of the operations described with reference to method of the second aspect.

Brief Description of the Figures

For better understanding of the present application, reference will now be made by way of example to the accompanying drawings in which:

Figure 1 is an example of a mobile telecommunications radio access network including plural eNodeBs (eNBs) and one or more user equipments (UEs);

Figure 2A is a first example of various operations which may be performed by a UE operating within the network of Figure 1;

Figure 2B is a second example of various operations which may be performed by a UE operating within the network of Figure 1;

Figure 3A is a message flow illustrating an example of messages being passed between entities within the network of Figure 1 in addition to various operations performed by the entities;

Figure 3B is a message flow illustrating another example of messages being passed between entities within the network of Figure 1 in addition to various operations performed by the entities;

Figure 4 is a schematic illustration of an example configuration of the UEs of Figure 1;

Figure 5 is a schematic illustration of an example configuration of the eNBs of Figure 1;

Figure 6 is an example of various operations which may be performed by the eNBs operating within the network of Figure 1; and

Figure 7 is an example of a computer-readable medium which may store computer-readable code and/or a one or more look-up table.

Detailed Description of Embodiments

In the description and drawings, like reference numerals refer to like elements throughout.

Various methods and apparatuses are described in detail below, by way of example only, in the context of a mobile telecommunications radio access network 1, such as that illustrated in Figure 1. The network 1 comprises a plurality of base stations (eNodeBs, eNBs) 5-1 to 5-n (generally referred to by numeral 5). Only a small number of eNBs 5 are shown in FIG. 1, but a radio access network may typically comprise thousands of eNBs 5. Together, the eNBs 5 may provide radio coverage to one or more user equipment (UE) 4-1 to 4-n (generally referred to by numeral 4) over a wide geographical area.

Each eNB 5 operates one or more cells, which are denoted in Figure 1, for illustrative purposes only, by the dashed circles 6-1 to 6-n (generally referred to using numeral 6). Although most of the coverage areas of the cells are shown illustratively as circles in Figure 1, in reality, the coverage area of each cell depends on the transmission power and the directionality of the antenna (or antennas) by which the cell is operated. The coverage area of each cell may also depend on obstacles (such buildings) which are in the vicinity of the eNB 5, carrier frequency and channel propagation characteristics etc.

The configuration of the coverage area of the cells 6 may be selected so as to serve UEs 4 in a particular area while not providing coverage to other areas. For instance, the configuration of a coverage area of a cell may be selected so as to provide coverage for an area in which users are commonly present while not providing coverage for areas in which users are seldom present. For instance, in Figure 1, the first cell 6-1 operated by the first cell is depicted as only a sector of a circle. In one extreme example, an eNB 5 may be configured to provide coverage (via a cell) up and down a road but not either side of the road.

As mentioned above, a single eNB 5 may, in some examples, provide two or more cells. For instance, a first cell 6 may be provided in a first direction from the eNB 5 while a second cell 6 may be provided in a different direction. In Figure 1, this is illustrated by the second eNB 5-1 which is shown as operating two different cells 6-2A and 6-2B.

One or more of the UEs 4 may be configured for bi-directional communication with one or more of the eNBs 5. In such examples, the transmission of data from the eNB 5 to the UE 4 may be referred to as “downlink”. Transmission of data from the UE 4 to the eNB 5 may be referred to as “uplink”. The eNBs 5, or some other entity within the network 1, may be operable to schedule uplink timeslots for the UEs 4 within the cell 6 operated by the eNBs 5. The scheduled time slot, along with a number of resource blocks allocated for the UE 4, is then communicated to the UE 4, for instance by eNB 5 operating the cell.

As can be seen in Figure 4, the UE 4 comprises control apparatus 40 which is configured to control operation of other components forming part of the UE 4 to enable transmission of data, via uplink, to the eNBs 5 as well as receipt of data from the eNBs 5, via downlink. Example configurations of the control apparatus 40 and the UE 4 as a whole are discussed in more detail later in relation to Figure 4. Similarly, example configurations of apparatuses forming part of the eNBs 5 are discussed later with reference to Figure 5.

At any one time, a UE 4 may be said to be associated with or served by a particular cell 6 and the cell with which a UE is currently associated may be referred to as the “serving cell” for the UE 4. A UE that is being served by a particular cell may be synchronised with that cell for receiving downlink transmissions and providing uplink transmissions. The cells 6 of eNBs 5 having a coverage area within which a UE 4 currently resides but with which the UE 4 is not currently associated may be referred to as neighbouring cells. When a UE 4 is transmitting, via uplink, to its serving eNB 5, it may be causing interference to communications within the neighbouring cells. As such, neighbouring cells may also be referred to as victim cells.

Let us consider a first UE 4-1 as shown in Figure 1. In this example, the first UE 4-1 is currently associated with a first eNB 5-1, which is referred to as the serving eNB 5-1 and the cell 6-1 of which is referred to as the serving cell 6-1 for the first UE 4-1. The first UE 4-1 is also located within the cells associated with eNBs other than its serving eNB 5-1, which are, in this example, the cell 6-4 operated by a fourth eNB 5-4 and the cell 6-n operated by an n^{th} eNB 5-n. These eNBs 5-4, 5-n and corresponding cells 6-4, 6-n are referred to as neighbouring eNBs and neighbouring cells respectively. A UE 4 need not necessarily be located in the coverage area of a cell 6 for the cell to be called a neighbouring cell (or a neighbouring eNB). Instead, a neighbouring cell may be referred to as such if it is serving UEs which may experience interference as a result of transmissions by the UE 4-1 in question. For instance, in the example of Figure 1, the third cell 6-3 may be considered a neighbouring cell because it is serving the third UE 4-3 which may experience interference as a result of transmissions by the first UE 4-1. So, in summary, a neighbouring cell may be a cell in whose coverage area the UE in question is located and/or which is serving UEs which suffer interference (of a particular degree of severity) as a result of transmissions by the UE 4-1 in question.

A load of each cell (serving cells and neighbouring cells) is dependent at least in part on a number of UEs 4 that are currently associated with or served by that cell. For instance in Figure 1, the fourth eNB 5-4, which from the reference point of the first UE 4-1 is operating a neighbouring cell, is the serving cell for three other UEs, which in this example are the fourth to sixth UEs 4-4 to 4-6. In contrast, the n^{th} eNB 5-n, which from the reference point of the first UE 4-1 is also operating a neighbouring cell is currently the serving cell for no UEs. In the example of Figure 1, therefore, the load associated with the fourth cell 6-4 and eNB 5-4 (which are currently serving three UEs 4) is higher than the load associated with the n^{th} cell 6-n and eNB 5-n (which are currently serving no UEs 4). The load of a particular cell may also be dependent on the size of the uplink buffer of each associated UE, or in other words, the amount of data that needs to be transferred from the UE to its serving cell.

The mobile telecommunications radio access network 1 may be, but is certainly not limited to, an Evolved Universal Terrestrial Radio Access (E-UTRA) network, which may sometimes be referred to as LTE Advanced network. The eNBs 5 and UEs 4 in the network 1 may be configured to communicate with one another using an OFDM-based access scheme, such as orthogonal frequency division multiple access (OFDMA) and/or single carrier frequency division multiple access (SC-FDMA). For instance, in some non-limiting examples OFDMA may be used for downlink communications whereas SC-FDMA may be used for uplink communications.

As mentioned previously, one of the aims with future E-UTRA networks is the provision of extremely high data rates and a very high number of connected devices. In a network having high data rates and a high number of connected devices, interference between communicating devices can be problematic. One factor contributing to such interference is uplink transmission power.

The control apparatus 40 of the UE 4 is operable to modulate the transmit power utilised during uplink (uplink transmission power). To this end, the control apparatus 40 is configured to determine an uplink transmission power value for the UE 4 within a particular cell 6 (the serving cell) with which the UE is currently associated. The uplink transmission power value is dependent on both the load of the serving cell and the load (or loads) of one or more neighbouring cells. As is discussed in more detail below, the determination of the uplink transmission power value may be performed locally by the UE 4 (and not by the eNB 5).

By taking the load of the neighbouring cells into account along with the load on the serving cell, it is possible to obtain an uplink transmission power that is better in terms of maximising, as far as possible, its signal to interference plus noise ratio (SINR) within the serving cell while ensuring that its interference in respect of neighbouring cells is at an appropriate level. For instance, knowledge of the load of neighbouring cells enables the control apparatus 40 to increase the transmission uplink power of the UE 4, thus improving performance, if a neighbouring cell has a zero load (it is serving no UEs). This is because, if a neighbour cell has a zero load, the interference in respect of that neighbour cell can be disregarded. In contrast, if the neighbour cell has a high load, the transmission uplink power of the UE 4 may be reduced to ensure that the interference on that cell is not unduly detrimental to the performance within that neighbouring cell.

With regard to the load of the serving cell 6-1, the transmission uplink power of the UE 4 may be dependent on the load of the serving cell such that transmission power would (if any considerations regarding the neighbouring cells were ignored) be increased when the serving cell load is high and decreased when the serving cell load is low.

In some examples, when determining the uplink transmission power value, the control apparatus 40 of the UE 4 may be configured to compute (or calculate) the uplink transmission power value based on various parameters including the load of the serving cell and the load of the one or more neighbouring cells. In some other examples, when determining the uplink transmission power value, the user equipment may extract the uplink transmission power value from a look-up table that is locally-available to the user equipment. For instance, the look-up table may be stored in a local memory.

Because the UE is able to determine its own uplink transmission power, rather than being instructed by the eNB, the uplink transmission power can be adjusted more frequently. This is because the UE 4 does not have to rely on closed-loop power control commands from the eNB, which may take several transmission time intervals (TTIs) to converge to the desired transmit power, given the small dynamic range typically allowed for conventional closed-loop power control commands. As the uplink transmission power can be adjusted more frequently, the UE 4 may be operating with an ideal, or closer to an ideal, transmission power more of the time. As will, of course, be appreciated, although the UE 4 is configured to determine its own transmission power locally, closed-loop power control commands may, in some examples, still be issued by the eNBs 5, and the UEs 4 may be configured to respond to received closed-loop power control commands by modifying their transmission power accordingly.

As will of course be appreciated, the example scenario illustrated in Figure 1 is just a single snapshot in time and, in reality, at least some of the UEs 4 are mobile within the network 1 (others may be static). As such, the loads of the cells vary as do the identities of the serving and neighbouring cells. For this reason, the UE 4 may be configured to regularly determine its ideal transmission power, such that it is transmitting at the appropriate power as often as possible. For instance, the uplink transmission power value may be determined by the UE 4 in response to receiving uplink scheduling information, for instance in the form of a scheduling grant, from the serving eNB 5-1. The scheduling grant may provide an indication of the transmission time intervals and/or resource blocks that are allocated to the UE for its uplink. In this way, the UE 4 may be able to transmit with a near-ideal power each time it performs an uplink transmission.

As mentioned above, the determined uplink transmission power value takes into account the interference of the uplink transmission by the UE 4 in respect of at least one of the neighbouring cells 6-n, 6-4. More specifically, the uplink transmission power value may be dependent on a product of a channel gain in respect of the at least one neighbouring cell (which is indicative of a potential for interference by the UE on neighbouring cell) and a measure of the load of the neighbouring cell. The loads of the neighbouring cells may be considered to be respective multiplicative weights on the channel gains between the UE 4 and the neighbouring cells, which causes the “target SINR” to be lowered for the UE 4 when the neighbouring cell has a heavy load, thereby reducing the interference on neighbouring cells. Similarly, the target SINR for the UE 4 may be dependent on the total (sum of) channel gain to neighbouring cells of the UE 4 in such a way that higher values of the total channel gain result in a reduced target SINR, thereby to reduce the interference on neighbouring cells.

The “target SINR” is related to the uplink transmission power via the following expression: target SINR = uplink transmission power × channel gain to serving cell/(interference + noise). As such, it will be understood that a higher uplink transmission power results in a higher target SINR and vice versa.

As will be also be understood from the above discussion, the uplink transmission power value may be dependent on an interference level of uplink transmission by the user equipment in respect of only those neighbouring cells 6-n, 6-4 which are serving at least one UE 4. Put another way, if a neighbour cell is serving no UEs 4 (and so has no load), the determined uplink transmission power value is independent of interference in respect of that neighbour cell.

The control apparatus 40 may be configured to estimate the channel gain to the one or more neighbouring cells based on measurements of downlink reference signals received from those neighbouring cells. Alternatively, if the channel gain to the one or more neighbouring cells cannot be measured, the channel gain for the one or more neighbouring cells may be estimated based on a total interference measurement performed by the UE 4. The total interference measurement may be performed by the UE 4 measuring the total received power and subtracting the power received from the serving cell. The total interference measurement may be performed periodically by the UE 4. In some examples, the total interference measurement may be determined by subtracting from the total received power the power received from the serving cell and the power received from any neighbour cells which can be explicitly measured.

The uplink transmission power value may also be dependent on a product of the channel gain of the UE 4-1 to the serving cell 6-1 and a measure of the load of the serving cell 6-1. The control apparatus 40 may therefore be configured to estimate the channel gain of the UE 4-1 to the serving cell 6-1 based on measurements of downlink reference signals received by the UE 4-1 from the serving eNB 5-1.

With regard to estimating the channel gains to the serving cell and/or the neighbouring cells, Reference Signal Received Power (RSRP) and/or Reference Signal Received Quality (RSRQ) measurements which are made by the UE 4 for mobility purposes may be used to estimate one or both of these parameters.

Information indicative of the load of the serving cell 6-1 may be received at the UE 4-1 from the serving eNB 5-1. In some examples, a transmission power of a reference downlink signal transmitted by the serving eNB 5-1 may be modulated based on the load of the serving cell 6-1. As such, the information indicative of the load of the serving cell 6-1 may be determined by the control apparatus 40 based on the transmission power of the reference downlink signal. Similarly, the neighbouring eNBs 5-n, 5-4 may modulate the transmission power of their reference downlink signals based on their respective loads, thereby to enable the eNB 4-1 to determine information indicative of the load (or loads) of the one or more neighbouring cells.

By modulating the transmission power of the downlink reference signals, the loads of the eNBs 5 can be determined by the UE 4 without the need for transmission of any additional signalling information, thereby reducing use of bandwidth (among other benefits). Moreover, in some examples, the downlink reference signals from which the UE 4 determines the channel gains in respect of the various eNBs (both serving and neighbour) and corresponding cells may have their transmission power modulated based on the load of the respective cell. In this way, just a single downlink reference signal from each eNB may be used to indicate the load and channel gain for each eNB. For instance, the product of the load and channel gain for a particular eNB 5 may be determined based on a single signal received from that eNB 5.

In other examples, the information indicative of the load of the serving cell 6-1 is included as signalling data in a message received from the serving eNB 5-1. In some examples, information indicative of the loads of the one or more neighbouring cells, 6-n, 6-4 may additionally, or alternatively be included as signalling data in a message received from the serving eNB 5-1. For instance, the information indicative of the loads of both the serving and neighbouring cells may be included as signalling data in the message or the information indicative of the loads of the neighbouring cells may be included as signalling data in a message while the load of the serving cell 5-1 is indicated via modulation of the transmission power of that signal.

As will be understood from the detailed explanation below, in some examples, the uplink transmission power value for a particular uplink transmission may be the smaller of a maximum allowed power, P_{max}, and a transmission power function that is dependent on the load of the serving cell 6-1 and the load of one or more neighbouring cells 6-4, 6-n.

The transmission power function may be dependent on a result of an expression that is dependent on the channel gain in respect of the serving and neighbouring cells as well the loads of the serving and neighbouring cells. More specifically, the expression may be dependent on the product of channel gain to the serving cell g and a measure of load γ of the serving cell and on a product of channel gain g'_k to a particular neighbour cell K and measure of load β_k of the neighbour cell. Even more specifically, the expression may be dependent on the product of channel gain to the serving cell g and a measure of load γ of the serving cell divided by a sum over N neighbouring cells of a product of the channel gain g'_k to a neighbour cell K and a measure of the load β_k of the neighbour cell K. The expression may further include an exponent in the form of a cell-wide parameter α.

The transmission power function may be equal to a closed loop power control command value Δ_{CL} multiplied by a factor, which is dependent on the number of resource blocks N_{RB} divided by the channel gain g to the serving cell, multiplied by a nested function that is itself dependent on the above-described expression that is dependent on the channel gains and loads of the serving and neighbouring cells. More specifically, nested function may be the greater of the result of the expression and a lower bound on channel quality Q_{min}.

The closed loop power control command value Δ_{CL} may be received from the serving eNB. The closed loop power control command Δ_{CL} can be used by the serving eNB to ensure that the uplink transmission SINR does not exceed a maximum allowed SINR.

In some examples, the determined uplink transmission power value P_{TX} (in the linear domain) across all scheduled resource blocks (N_{RB}) may be defined by:

$$P_{\mathrm{TX}} = \min\left[\Delta_{CL} N_{RB} \frac{P_0}{g} \max\left\{\left(\frac{\gamma g}{\sum_{k=0}^{N-1} \beta_k g_k'}\right)^{\alpha}, Q_{\min}\right\}, P_{\max}\right]$$

Equation 1

where:

- $\left(\frac{\gamma g}{\sum_{k=0}^{N-1} \beta_k g_k'}\right)^{\alpha}$ is the expression that is dependent on the channel gains and loads of the serving and neighbouring cells;
- g is the channel gain of the UE to its serving cell over its scheduled RBs;
- $0 < \gamma <= 1$ represents the load of the UE's serving cell and is a multiplicative weight on the channel gain to the serving cell ;
- g'_k is the channel gain to neighbouring cell k;
- $0 <= \beta_k <= 1$ is a multiplicative weight that represents the load of the neighbouring cell k;
- $Q_{\min}$ is a configurable constant to ensure that the target SINR of the UE 4 is not set too small, for instance, below the SINR of even the lowest modulation and coding scheme (MCS). $Q_{\min}$ may, for instance, be indicated to the UE 4 as a

broadcast parameter, or as a parameter sent during connection setup with, for instance, the serving eNB 5;

- Δ_{CL} represents a linear closed-loop power control command received from the eNB, which can be used by the eNB to ensure that the received packet SINR does not exceed a maximum SINR ($SINR_{max}$), for instance that required for the largest MCS. The closed-loop power control command may be indicated to the UE as part of the scheduling grant message (for example, whenever a UE gets scheduled in the uplink, the UE may receive a scheduling grant message, in which this parameter Δ_{CL} is embedded);
- N_{RB} is the number of resource blocks allocated to the UE in the current TTI, which is the TTI for which the uplink transmission power is being determined. This may be indicated to the UE via the received uplink scheduling information;
- P_o and α are configurable cell-wide parameters P_o *and* α may, for instance, be indicated to the UE 4 as a broadcast parameter, or as a parameter sent during connection setup with the serving eNB 5 (for instance, along with parameter Q_{min});
- P_{max} is the maximum allowed UE transmit power. The maximum allowed UE transmit power may be pre-programmed into the UE, for instance, during initialization or a subsequently-performed update. The maximum allowed UE transmit power may, in some examples be specified by a relevant standard.

A neighbouring cell which is currently not serving any UEs will not be impacted by interference from a UE's uplink transmission and, as such, the multiplicative weight that represents the load of that neighbouring cell β_k may be set to zero for such neighboring cells.

As will be appreciated from the above equation, the determined uplink transmission power is such that a larger serving cell load results in a larger target SINR, even if it may imply larger interference on the neighbouring cells.

Uplink transmission power values may be based on Equation 1 above in situations when the UE 4 is able to determine the individual channel gains for the neighbouring cells. However, when this is not possible, the uplink transmission power values may be based on Equation 2 below, which is dependent on the sum of channel gains to N of the neighbouring cells. This may be computed using a total interference measurement performed by the UE 4.

$$P_{\mathrm{TX}} = \min\left[\Delta_{CL} N_{RB} \frac{P_0}{g} \max\left\{\left(\frac{\gamma g}{\beta g'}\right)^{\alpha}, Q_{\min}\right\}, P_{\max}\right]$$

Equation 2

where:

- $\beta = \frac{1}{N}\sum_{k=0}^{N-1}\beta_k, \quad 0 < \beta \le 1$ and is the average cell load of its neighbouring cells; and
- $g' = \sum g'_k$ = the sum of the channel gains to its neighboring victim cells.

In Equation 2, the impact/interference on only the UE's top N neighbouring cells is considered when determining the UE's uplink transmission power. A neighbouring cell with no active UEs will not be affected by interference from the UE's uplink transmission, and thus that victim cell's contribution to β may be set to nil.

Typically, for UEs that are located near the boundary of their serving cell, Q_{min} is expected to dominate the term $\gamma g/\beta g'$ in the above equation. As such, larger values of Q_{min} will likely increase the target SINR of such UEs as this will be larger than the result of the expression that is dependent on the channel gains and loads of the serving and neighbouring cells.

In some examples, the control apparatus 40 may be configured to compute the uplink transmission power value using either Equation 1 or Equation 2. In other examples, the control apparatus may switch between using Equation 1 and Equation 2 in dependence on whether or not it is able to determine the channel gains for the individual neighbour cells.

In other examples, rather than actively computing the uplink transmission power value using Equation 1 or 2, the control apparatus 40 may simply extract the value from a locally stored look-up table which includes values derived using the one or both of the equations. The look-up table or tables are multi-dimensional. As such, it may be a function of serving cell channel gain, neighbouring cell channel gain(s), serving cell load, neighbouring cell load(s), number of resource blocks allocated and closed-loop power control value Δ_{CL}. The look-up tables may also have high resolution such that the performance gains (resulting from the modulation of the uplink transmission power) are not lost (or diluted too much) by quantization error within the table.

Figures 2A and 2B are flow charts illustrating examples of various operations which may be performed by the control apparatus 40 of the UE in relation to determination of the uplink transmission power value.

First let us consider the example of Figure 2A. In operation S2A-1, the control apparatus 40 receives an indication of an uplink scheduling grant (or, more generally speaking, information indicative of uplink scheduling) having been received by the UE 4. The information indicative of uplink scheduling may include a transmission time interval (TTI) and a number of resource blocks allocated for that TTI.

In operation S2A-2, in response to receiving the information indicative of uplink scheduling, the control apparatus 40 responds by making the necessary measurements/parameter determinations to enable the uplink transmission power to be determined.

For instance, the control apparatus 40 may determine the serving cell and neighbouring cell channel gains g, g'_k based on measurements of downlink reference signals. For instance, the control apparatus may cause Reference Signal Received Power (RSRP) and/or Reference Signal Received Quality (RSRQ) measurements to be made thereby to enable the serving cell and neighbouring channel cell gains g, g'_k to be determined.

Similarly, the measures indicative of the loads of the serving cell and the neighbouring cells may be determined in response to receiving the information indicative of uplink scheduling. This may be performed by measuring a transmission power modulation on the downlink reference signals from respective eNBs. The reference signals which have their transmission power modulated on the basis of the load information and from which the channel gains g, g'_k can be derived may be referred to as Power Control Reference Signals (PCRS).

As discussed above, the measurements in respect of the reference signals may yield parameters/information that is indicative of respective products of the load and channel gains of respective cells (neighbouring and serving).

In other examples, the load information with respect to the serving and neighbouring cells may be provided to the UE via data included in a message (such as a MAC Control Element) received from the serving eNB 5-1. In some examples, the measures of the loads of the serving and neighbouring cells may be explicitly conveyed to the UE 4 in the scheduling grant.

Subsequently, once the control apparatus 40 has determined/estimated all the required parameters, it may proceed to operation S2A-3 in which the uplink transmission power value is determined. This may be determined based on the collated parameters/information and may, for instance, be in accordance with either of Equations 1 and 2 described above.

In some examples, the control apparatus 40 may actively compute the uplink transmission power value based on one of the Equations 1 and 2. Alternatively, the control apparatus 40 may extract the value from a look-up table, whose constituent elements are derived using the above equations (or similar).

In some examples, a determination as to which equation (or corresponding look-up table) to use may be made by the control apparatus 40 in dependence on whether it has been able to determine the individual channel gains for the neighbouring cells.

After the uplink transmission value has been determined, in operation S2A-4, the control apparatus causes an uplink transmission to the serving eNB 5-1 to be performed with a transmission power that is in accordance with the determined value.

Now let us consider the example of Figure 2B. In operation S2B-1, the control apparatus 40 determines the parameters necessary for determining the uplink transmission power value. This may be substantially as described with respect to operation S2A-2 of Figure 2A, except that is not performed in response to receiving the uplink scheduling information/grant.

In some examples, the parameter determinations may be ongoing and performed periodically by the control apparatus 40. The most recent determinations of the parameters/information may then be used to determine the uplink transmission power when required. Alternatively, the control apparatus 40 may filter and/or average a number of the periodically determined parameters (for instance the N most recent) and may use the result of this to determine the uplink transmission power when required. By periodically performing the parameter determinations, the uplink transmission power may be determined more quickly when required, thereby increasing the chance that the UE can use an appropriate uplink transmission more of the time.

In operation S2B-2, it is determined whether uplink scheduling information/grant has been received. If not, the control apparatus 40 returns to performance of operation S2B-1. If, however, scheduling information/grant has been received, the control apparatus 40 responds by proceeding to performance of operation S2B-3.

In operation S2B-3, the control apparatus 40 determines the uplink transmission power value. This may be performed in any of the ways described with reference to operation S2A-3 of Figure 2A.

Finally, in operation S2B-4, the control apparatus 40 causes performance of the uplink transmission in accordance with the determined power.

The determination of the uplink transmission power value may be determined each time an uplink transmission slot is scheduled for the UE. As such, after operation S2A-1 (in Figure 2A) and operation S2B-1 (in Figure 2B), the control apparatus may return to performance of operations S2A-1 and S2B-1 respectively. Alternatively, some other trigger even may cause the determination to be made.

Although the examples of Figures 2A and 2B show the parameter determination being performed before or after receiving the scheduling grant, in some examples some parameters may be determined in an ongoing fashion prior to the receiving the scheduling grant, while others may be performed in response to receiving the scheduling grant.

In some examples, the UE 4 may be configured to determine certain parameters (for instance, the channel gains g and g') less frequently than it determines the uplink transmission power value. For instance, the UE may be configured to re-use certain parameters for n (where n may be plural) uplink power determinations before performing new parameter measurements. The value of n may be dependent on, for instance, whether or not the UE is moving (which may be determined by the UE through any suitable means). For instance, if the UE 4 determines that it is not moving (or is moving with a speed below a threshold), it may reduce the frequency with which it determines the parameters (or, put another, way may increase the number n of uplink power determinations performed before re-measuring the parameters). In this way, the power consumed by the UE 4 may be reduced.

Figures 3A and 3B are examples of message flows (and resulting operations) which may occur in relation to the determination of the uplink transmission power for instance as described with reference to Figures 1 to 2B.

In the first example of Figure 3A, in a first operation (S3A-1), a first message is transmitted from neighbouring eNBs to the serving eNB 5-1. The message carries information indicative of the loads of the cells operated by the eNB that transmits it. Messages carrying cell load information may in fact be received at the serving cell from all the neighbouring eNBs. In fact, the serving eNB 5-1 may additionally send its own cell load information to the neighbouring eNBs via a message of the same type (for use by the UEs served by those cells in determining their uplink transmission power). The messages which carry the cell load information between eNBs may, in some examples, be X2 messages.

In a second operation (S3A-2), the serving eNB 5-1 calculates values of the cell load parameters β_k for each neighbouring cell based on the cell load information received in operation S3A-1. As mentioned previously, the neighbouring cell load parameter may be between 0 and 1 and may be indicative of the load on the cell. As such, the serving eNB 5-1 will calculate that a cell that is operating at maximum capacity may have a cell load parameter β_k equal to 1, whereas a cell which is serving no UEs (and so has no load) may be assigned a cell load parameter β_k equal to 0.

Additionally, the serving eNB may calculate its own serving cell load parameter γ. This may be performed similarly to the neighbouring cell load parameters such that if the serving cell is operating at capacity it will be assigned a serving cell load parameter of 1.

Subsequently, in operation S3A-3, the serving eNB 5-1 transmits a signalling message to the UE 4. This signalling message, which may in some examples be a MAC control element, includes signalling data indicative of the calculated cell load parameters (for both the serving and neighbouring cells). Although not shown in Figure 3A, the cell load parameters are extracted from the signalling messages and are stored by the UE 4 for future use.

In operation S3A-4, the serving eNB 5-1 transmits a cell reference signal to the UE 4.

In operation S3A-5, based on measurements (for instance, RSRP or RSRQ measurements) performed in respect of the received reference signal, the UE computes the channel gain parameter g for the serving cell. This is then stored for future use.

In operation S3A-6, the neighbouring eNBs transmit a cell reference signal to the UE which receives it.

In operation S3A-7, based on measurements (for instance, RSRP or RSRQ measurements) performed in respect of the reference signal received from the neighbouring eNBs, the UE 4 computes the channel gain parameter g'_k for each of the neighbouring cells. The channel gain parameter(s) is/are then stored for future use.

In operation S3A-8, the serving eNB 5-1 transmits an uplink scheduling grant for the UE 4. This may indicate the TTI for an uplink transmission by the UE 4 as well as the number of resource blocks allocated.

In response to receiving the uplink scheduling grant, the UE 4 (in operation S3A-9) determines the uplink transmission power value based on the channel gain parameters g, g'_k relating to the serving and neighbouring eNBs and based on the cell load parameters β_k, γ for the serving and neighbouring cells. The determination of the uplink transmission power value may be performed as described previously, for instance with reference to Figures 2A and 2B.

Finally, in operation S3A-10, the UE 4 performs the uplink transmission in respect of the serving eNB 5-1 in accordance with the determined transmission power value.

For fast varying traffic loads, the approach of the example of Figure 3A may result in large X2 & control information overhead. This overhead may be reduced by utilising an approach as illustrated by the example of Figure 3B.

In Figure 3B, in a first operation (S3B-1), a first message is transmitted from the neighbouring cells to the serving cell 6-1. The first message from each neighbouring cell may include configuration information for use by the UE 4 to enable the UE 4 to understand a subsequent message received from the neighbouring cell. The first message, in this example, may be referred to as a PCRS configuration message. As with operation S3A-1 of Figure 3A, the serving cell 6-1 may send its own version of the first message to the neighbouring cells. In operation S3B-1, the first messages may be in the form of X2 messages.

In operation S3B-2, the serving cell 6-1 may send a message to the UE 4 which includes the configuration information (for instance, PCRS configuration information) received from the neighbouring cells. The serving cell may additionally send its own configuration information to the UE 4. This may be sent in the same message as the neighbouring cell configuration information or in a different message. The information included in the configuration information may include the locations, in the time-frequency tile, of the PCRS of the neighbouring cells and the cell IDs of the neighbouring cells. This enables the UE 4 to know what pilot sequence is to be transmitted by the neighbouring cells.

The configuration information transmitted in operation S3B-3 is received and stored by the UE 4 for future use. The message(s) sent in operation S3B-2 may, for instance, be a radio resource control (RRC) message.

In operation S3B-3, the serving cell 6-1 transmits to the UE 4, a reference signal the transmission power of which has been modulated by the serving cell, thereby to indicate the cell load of the serving cell to the UE 4. In some examples, the reference signal which has its transmission power modulated may be a dedicated PCRS signal, while in other examples it may be another reference signal such as those transmitted in S3A-4 and S3A-6 of Figure 3A.

By modulating the power of the reference signal, the UE 4, through measurements performed on the received reference signal, may be able to determine directly the product ($\gamma.g$) of the serving cell load parameter γ and the serving cell channel gain g.

In operation S3B-4, the UE performs measurements (e.g. RSRP or RSRQ measurements) on the received reference signal to determine the product of the ($\gamma.g$) of the serving cell load parameter γ and the serving cell channel gain parameter g. The product of the serving cell load and channel gain parameters may be determined using the previously received configuration information. The product $\gamma.g$ of the serving cell load and channel gain is then saved for later use.

In operation S3B-5, the neighbouring cells transmit to the UE4, reference signals the transmission power of which has been modulated by the neighbouring cell, thereby to indicate to the UE 4 the cell load of the sending neighbouring cell. In some examples, the reference signal which has its transmission power modulated on the basis of the cell load may be a dedicated PCRS signal, while in other examples it may another reference signal such as those transmitted in S3A-4 and S3A-6 of Figure 3A.

In operation S3B-6, the UE performs measurements (e.g. RSRP or RSRQ measurements) on the reference signals received from the neighbouring eNBs to determine the respective products of the ($\beta_k.g'_k$) of the neighbouring cell load parameters β_k and the respective neighbouring cell channel gain parameter g'_k. The products $\beta_k.g'_k$ may be determined using the previously received configuration information. The products $\beta_k.g'_k$ are then stored for later use.

The reference signal transmit power modulation in operations S3B-3 and S3B-5 may be controlled such that, when a neighbour/serving cell is fully loaded, it may use the reference signal's nominal (full) power setting for transmission of the reference signal. The UE 4 will then measure its actual path/channel gain g'_k or g (with β_k or γ =1) to the neighbour/serving cell. When neighbour/serving cell is lightly loaded, the transmit power of the reference signal shall be lower than the nominal setting. The receiving UE will then calculate its path gain g'_k or g to the cell to be lower than it actually is, reflecting the fact that β_k or γ is less than 1 (<1).

With regard to neighbour cells, the consequence of the above reference signal transmit power modulation scheme is that, when determining the uplink transmission power value, target SINR for the UE is higher when a neighbour cell is lightly loaded than when the neighbour cell is heavily loaded.

In contrast, with regard to the serving cell, the consequence of the above modulation scheme is that, when determining the uplink transmission power value, the target SINR for the UE is lower when the serving cell is lightly loaded than when the serving cell is heavily loaded. This ensures that when the serving cell is lightly loaded, the interference on neighbouring cells is minimised.

In operation S3B-7, the serving eNB 5-1 transmits an uplink scheduling grant for the UE 4. This may indicate the TTI for an uplink transmission by the UE 4 as well as the number of resource blocks allocated.

In response to receiving the uplink scheduling grant, the UE 4 (in operation S3B-8) determines the uplink transmission power value based on the channel gain parameters g,

g'_k relating to the serving and neighbouring cells and based on the cell load parameters β_k, γ for the serving and neighbouring cells. More specifically, this may be determined based on the previously determined products $\beta_k.g'_k$, $\gamma.g$ of cell load and channel gain for the neighbouring and serving cells. The determination of the uplink transmission power value may be as described previously, for instance with reference to Figures 2A and 2B.

Finally, in operation S3B-10, the UE performs the uplink transmission in respect of the serving cell 5-1 in accordance with the determined transmission power value.

A benefit of an approach as illustrated by the example of Figure 3B is that method can operate on a fast timescale, and no X2 information needs to be regularly exchanged between neighbour cells. It should be noted here that it may be sufficient for the configuration information of operation S3B-1 to be transmitted only once. In addition, there is no need for the transmission of signalling message indicating the cell loads (such as those transmitted in operation S3A-3 of the approach of Figure 3A).

Figure 6 is a flow chart illustrating various operations which may be performed by one or more of the eNBs 5 described herein, for instance with reference to Figures 1 to 3A.

In operation S6-1, the eNB 5 (e.g. the serving eNB 5-1), receives configuration information from another (a second) eNB 5 (e.g. a neighbouring eNB 5-4). The configuration information is for enabling the UEs 4 being served by the serving eNB 5-1 to interpret signals received by those UEs from the neighbouring eNBs. The configuration information may be in the form of, for instance, an X2 message. This operation may correspond to operation S3B-1 of Figure 3B.

In operation S6-2, the serving eNB 5-1 causes transmission of a message, for instance (but not limited to) a radio resource control (RRC) message, to the UEs 4 it is serving. The message contains the configuration information received from the neighbouring cell 6-4 in addition to configuration information relating to the serving cell for enabling the recipient UE 4-1 to interpret signalling messages subsequently received from the serving cell 6-1. This operation may correspond to operation S3B-2 of Figure 3B.

In operation S6-3, the serving eNB 5-1 modulates the transmission power for a downlink reference signal based on a load of the cell 6-1 by which the UE 4 is currently being served. For instance, the transmission power may be lower if the load is low and higher if the load is high. In addition, the serving eNB 5-1 transmits the reference signal with the modulated transmission power to the UE 4. The reference signal may be configured such that the UE is able to determine a product of the load of the serving cell and the channel gain between the UE and the serving cell. The reference signal may be referred to as a power control reference signal. Determination of the product of the load of the serving cell and the channel gain between the UE and the serving cell may be performed using at least some of the configuration information received from the serving eNB 5-1.

As will be appreciated, operation S6-3 may correspond to operation S3B-2 of Figure 3B.

In addition to being received by the UE 4 that is currently being served by the eNB 5-1, the reference signal transmitted in operation S6-3 may further be received by UEs not being served by the serving eNB 5-1 (for which the serving cell is only a neighbouring cell). This may be used by those UEs 4 to determine their uplink transmission power for their uplink transmissions to their serving eNB.

In operation S6-4, the serving eNB 5-1 transmits uplink scheduling grants to the UEs that it is serving. This may correspond to operation S3B-7 of Figure 3B.

In operation S6-5, the serving eNB 5-1 receives the uplink transmission from the UE 4 with the power regulated in accordance with the load of the serving cell and the loads of the neighbouring cells. This may correspond to operation S3B-8 of Figure 3B.

As will be understood, the message flows of Figures 3A and 3B and flow chart of Figure 6 include performance of the parameter determinations and relevant signalling prior to transmitting/receiving the uplink scheduling grant (as per the example of Figure 2B). However, it will be appreciated that the flows of Figure 3B, 3A and 6 may modified for conformity with the flow chart of Figure 2A in which the performance of the parameter determinations and relevant signalling occurs subsequent to the uplink scheduling grant. Alternatively, some signalling/parameter estimation may be performed before the uplink scheduling grant with the remainder being performed afterwards.

Figure 4 is a schematic illustration of an example configuration of the UEs 4 depicted in Figure 1, which may be used for communicating with the eNBs 5 via a wireless interface. The UE 4 may be any device capable of at least sending or receiving radio signals to or from the eNBs 5 and of performing operations as described above with respect to Figures 1 to 3B.

The UE 4 may communicate via an appropriate radio interface arrangement 405 of the UE 4. The interface arrangement 405 may be provided for example by means of a radio part 405-2 (e.g. a transceiver) and an associated antenna arrangement 405-1. The antenna arrangement 405-1 may be arranged internally or externally to the UE 4.

As discussed above, the UE 4 comprises control apparatus 40 which is operable to control the other components of the UE 4 in addition to performing any suitable combinations of the operations described in connection with UE 4 with reference to Figures 1 to 3B. The control apparatus 40 may comprise processing apparatus 401 and memory 402. Computer-readable code 402-2A may be stored on the memory, which when executed by the processing apparatus 401, causes the control apparatus 40 to perform any of the operations described herein in relation to the UE 4.

The memory 402 may also have stored thereon one or more look-up table 402-2B (as discussed above) including data uplink transmission power values which may be extracted from the look-up table when required and utilised to modulate uplink transmission power. In some examples, the look-up table(s) 402-B may be provided for storing on the UE via a separate computer program product 42, 70 (as shown in Figures 4 and 7) of any suitable type (for instance, but certainly not limited to an optical memory device or a flash memory device). The look-up tables may be multi-dimensional based on one or more of, for instance, a function of serving cell channel gain, neighbouring cell channel gain(s), serving cell load, neighbouring cell load(s), number of resource blocks allocated and closed-loop power control value Δ_{CL}. In other examples, the look-up table(s) may be provided to a UE 4 via a wireless RF message (or messages).

Example configurations of the memory 402 and processing apparatus 401 will be discussed in more detail below

The UE 4 may be, for example, a device that does not need human interaction, such as an entity that is involved in Machine Type Communications (MTC). Alternatively, the UE may be a device designed for tasks involving human interaction such as making and receiving phone calls between users, and streaming multimedia or providing other digital content to a user. Non-limiting examples include a smart phone, and a laptop computer/notebook computer/tablet computer/e-reader device provided with a wireless interface facility.

Where the UE 4 is a device designed for human interaction, the user may control the operation of the UE 4 by means of a suitable user input interface UII 404 such as key pad, voice commands, touch sensitive screen or pad, combinations thereof or the like. A display 403, a speaker and a microphone may also be provided. Furthermore, the UE 4 may comprise appropriate connectors (either wired or wireless) to other devices and/or for connecting external accessories, for example hands-free equipment, thereto.

FIG. 5 shows an example of apparatus 50 which may form part of each of the eNBs 5 of FIG. 1. The apparatus 50 comprises a radio frequency antenna array 501 configured to receive and transmit radio frequency signals. Although the apparatus in Figure 5 is shown as having an array 501 of four antennas, this is illustrative only. The number of antennas may vary, for instance, from one to many hundreds.

The apparatus 50 further comprises radio frequency interface circuitry 503 configured to interface the radio frequency signals received and transmitted by the antenna 501 and a control apparatus 506. The radio frequency interface circuitry 503 may also be known as a transceiver. The apparatus 50 may also comprise an interface 509 via which, for example, it can communicate (e.g. via X2 messages) with other network elements such as the other eNBs 5.

The control apparatus 506 is configured to process signals from the radio frequency interface circuitry 503, control the radio frequency interface circuitry 503 to generate suitable RF signals to communicate information to the UE 5 via the wireless communications link, and also to exchange information with other network elements 5 via the interface 509. .

The control apparatus 506 may comprise processing apparatus 502 and memory 504. Computer-readable code 504-2A may be stored on the memory 504, which when executed by the processing apparatus 502, causes the control apparatus 506 to perform any of the operations assigned to the serving or neighbouring eNBs 5 and described above, for instance with reference to any of Figures 1 to 6

As should of course be appreciated the apparatuses 4, 50 shown in each of FIGS. 4 and 5 described above may comprise further elements which are not directly involved with processes and operations in respect which this application is focussed.

Some further details of components and features of the above-described apparatus/entities/apparatuses 4, 5, 40, 50, 506 and alternatives for them will now be described.

The control apparatuses 40, 506 may comprise processing apparatus 401, 502 communicatively coupled with memory 402, 504. The memory 402, 504 has computer readable instructions 402-2A, 504-2A stored thereon, which when executed by the processing apparatus 401, 502 causes the control apparatus 40, 506 to cause performance of various ones of the operations described with reference to Figures 1 to 5. The control apparatus 40, 506 may in some instance be referred to, in general terms, as “apparatus”.

The processing apparatus 401, 502 may be of any suitable composition and may include one or more processors 401A, 502A of any suitable type or suitable combination of types. For example, the processing apparatus 401, 502 may be a programmable processor that interprets computer program instructions 402-2A, 504-2A and processes data. The processing apparatus 401, 502 may include plural programmable processors. Alternatively, the processing apparatus 401, 502 may be, for example, programmable hardware with embedded firmware. The processing apparatus 401, 502 may be termed processing means. The processing apparatus 401, 502 may alternatively or additionally include one or more Application Specific Integrated Circuits (ASICs). In some instances, processing apparatus 401, 502 may be referred to as computing apparatus.

The processing apparatus 401, 502 is coupled to the memory (which may be referred to as one or more storage devices) 402, 504 and is operable to read/write data to/from the memory 402, 504. The memory 402, 504 may comprise a single memory unit or a plurality of memory units, upon which the computer readable instructions (or code) 402-2A, 504-2A is stored. For example, the memory 402, 504 may comprise both volatile memory 402-1 and non-volatile memory 402-2. For example, the computer readable instructions/program code 402-2A, 504-2A may be stored in the non-volatile memory 402-2, 504-2 and may be executed by the processing apparatus 401, 502 using the volatile memory 402-1, 504-1 for temporary storage of data or data and instructions. Examples of volatile memory include RAM, DRAM, and SDRAM etc. Examples of non-volatile memory include ROM, PROM, EEPROM, flash memory, optical storage, magnetic storage, etc. The memories in general may be referred to as non-transitory computer readable memory media. The look-up table(s) 402-2B described above may be stored in the non-volatile memory 402-2 of the UE 4.

The term 'memory', in addition to covering memory comprising both non-volatile memory and volatile memory, may also cover one or more volatile memories only, one or more non-volatile memories only, or one or more volatile memories and one or more non-volatile memories.

The computer readable instructions/program code 402-2A, 504-2A may be pre-programmed into the control apparatus 20. Alternatively, the computer readable instructions 402-2A, 504-2A (and/or the look-up table) may arrive at the control apparatus 40, 506 via an electromagnetic carrier signal or may be copied from a physical entity such as a computer program product (as illustrated by reference numeral 42 in Figure 4), a memory device or a record medium such as a CD-ROM or DVD. The computer readable instructions 402-2A, 504-2A may provide the logic and routines that enables the entities devices/apparatuses 4, 5, 40, 50, 506 to perform the functionality described above. The combination of computer-readable instructions stored on memory (of any of the types described above) may be referred to as a computer program product.

Embodiments of the present invention may be implemented in software, hardware, application logic or a combination of software, hardware and application logic. The software, application logic and/or hardware may reside on memory, or any computer media. In an example embodiment, the application logic, software or an instruction set is maintained on any one of various conventional computer-readable media. In the context of this document, a "memory" or "computer-readable medium" may be any media or means that can contain, store, communicate, propagate or transport the instructions for use by or in connection with an instruction execution system, apparatus, or device, such as a computer.

Reference to, where relevant, "computer-readable storage medium", "computer program product", "tangibly embodied computer program" etc., or a "processor" or "processing apparatus" etc. should be understood to encompass not only computers having differing architectures such as single/multi-processor architectures and sequencers/parallel architectures, but also specialised circuits such as field programmable gate arrays FPGA, application specify circuits ASIC, signal processing devices and other devices. References to computer program, instructions, code etc. should be understood to express software for a programmable processor firmware such as the programmable content of a hardware device as instructions for a processor or configured or configuration settings for a fixed function device, gate array, programmable logic device, etc.

If desired, the different functions discussed herein may be performed in a different order and/or concurrently with each other. Furthermore, if desired, one or more of the above-described functions may be optional or may be combined. Similarly, it will also be appreciated that flow diagrams of Figures 2A, 2B, 3A and 3B are examples only and that various operations depicted therein may be omitted, reordered and or combined.

Although the method and apparatus have been described in connection with an E-UTRA network, it will be appreciated that they are not limited to such networks and are applicable to radio networks of various different types.

Although various aspects of the invention are set out in the independent claims, other aspects of the invention comprise other combinations of features from the described embodiments and/or the dependent claims with the features of the independent claims, and not solely the combinations explicitly set out in the claims.

It is also noted herein that while the above describes various examples, these descriptions should not be viewed in a limiting sense. Rather, there are several variations and modifications which may be made without departing from the scope of the present invention as defined in the appended claims.

Claims

1. A method comprising:

determining an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells.

2. The method according to claim 1, wherein the uplink transmission power value is dependent on an interference of uplink transmission by the user equipment in respect of at least one of the neighbouring cells.

3. The method according to either of claims 1 or 2, wherein the uplink transmission power value is dependent on an interference of uplink transmission by the user equipment in respect of only neighbouring cells which are serving at least one user equipment.

4. The method according to any preceding claim, wherein the uplink transmission power value is dependent on a product of a channel gain between the at least one neighbouring cell and the user equipment and a measure of the load of the neighbouring cell.

5. The method according to claim 4, further comprising:

estimating channel gain between the at least one neighbouring cell and the user equipment based on measurements in respect of downlink reference signals from the neighbouring cells; or

estimating the channel gain between the at least one neighbouring cell and the user equipment based on a total interference measurement.

6. The method according to any preceding claim, wherein the uplink transmission power value is dependent on a product of the channel gain between the serving cell and the user equipment and a measure of the load of the serving cell.

7. The method according to claim 6, comprising estimating the channel gain between the serving cell and the user equipment based on measurements of downlink reference signals from the serving cell.

8. The method according to any preceding claim, further comprising receiving information indicative of the load of at least the serving cell from the serving cell.

9. The method according to claim 8, wherein the information indicative of the load of the serving cell is determined based on a transmission power of a reference signal received from the serving cell, the transmission power of the reference signal being modulated in dependence on the load of the serving cell.

10. The method according to claim 9, wherein the information indicative of the load of the serving cell is indicative of a product of the load of the serving cell and the channel gain between the serving cell and the user equipment.

11. The method according to claim 10, comprising:

performing a measurement in respect of the reference signal received from the serving cell, thereby to determine the product of the load of the serving cell and the channel gain between the serving cell and the user equipment.

12. The method according to any preceding claim, wherein the information indicative of the load of the one or more neighbouring cells is conveyed using a transmission power of respective reference signals received from respective neighbouring cells, the transmission power of each reference signal being modulated based on the load of the neighbouring cell from which the reference signal is received.

13. The method according to claim 12, wherein the information indicative of the load of the one or more neighbouring cells is indicative of a product of the load of the respective neighbouring cell and the channel gain between the neighbouring cell and the user equipment.

14. The method according to claim 13, comprising:

performing a measurement in respect of the reference signal received from each neighbouring cell, thereby to determine the product of the load of the neighbouring cell and the channel gain between the neighbouring cell and the user equipment.

15. The method according to claim 8, wherein the information indicative of the load of the serving cell is included as data in a signalling message received from the serving cell.

16. The method according to claim 8 or claim 15, wherein the information indicative of the loads of the one or more neighbouring cells is included as data in a signalling message received from the serving cell.

17. The method according to any preceding claim, wherein the determining of the uplink transmission power value is performed by the user equipment

18. The method according to claim 17, wherein, when determining the uplink transmission power value, the user equipment computes the uplink transmission power value based on the load of the serving cell and the load of the one or more neighbouring cells.

19. The method according to claim 17 wherein, when determining the uplink transmission power value, the user equipment extracts the uplink transmission power value from a look-up table locally-available to the user equipment.

20. The method according to any of claims 17 to 19, comprising:
determining the uplink transmission power value in response to receiving uplink scheduling information from the serving cell.

21. The method according to any preceding claim wherein the uplink transmission power value is in accordance with an expression whereby, in certain circumstances, a larger product of a measure of a load of a neighbouring cell and the channel gain between the neighbouring cell and the user equipment results in a lower uplink transmission power value.

22. The method according to claim 21, wherein the uplink transmission power value, in certain circumstances, varies in accordance with one divided by a sum over N neighbouring cells of a product of a channel gain between a neighbouring cell and a measure of load of the neighbouring cell.

23. A method comprising modulating transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal.

24. The method according to claim 23, wherein an eNodeB modulates the transmission power of a reference signal and the radio network cell is operated by the eNodeB.

25. The method according to claim 24, wherein the recipient of the reference signal comprises one or more user equipments, at least one of which is being served by another radio network cell.

26. The method according to any of claims 23 to 25, wherein the reference signal is configured such that the recipient is able to determine, based on the reference signal, an indication of the product of channel gain between the recipient and the apparatus transmitting the reference signal and the load of the cell operated by the eNodeB.

27. The method according to any of claims 23 to 26, comprising, prior to transmission of the reference signal, causing transmission of a configuration information signal carrying configuration information for enabling the recipient to interpret the subsequently transmitted reference signal which has its transmission power modulated based on the load of the radio network cell.

28. The method of claim 27, comprising:

receiving at an eNodeB, which operates a first cell, configuration information relating to reference signals to be transmitted in relation to another cell; and

including in the configuration information signal the configuration information relating to reference signals to be transmitted by the other cell in addition to configuration information relating to reference signals to be transmitted in relation to the first cell.

29. A computer program product containing a look-up table comprising uplink power transmission values for use by a user equipment being served by a serving cell in a radio access network comprising the serving cell and one or more neighbouring cells, wherein the uplink power transmission values have been determined on the basis of plural different notional loads of the serving cell and plural different notional loads of the one or more neighbouring cells.

30. The computer program product according to claim 29, wherein the uplink transmission power values have been determined on the basis of plural notional interference levels of uplink transmission by the user equipment in respect of at least one of the neighbouring cells.

31. The computer program product according to claim 30, wherein the uplink transmission power values have been determined on the basis of a product of a notional

channel gain between the at least one neighbouring cell and the user equipment and a measure of the notional load of the neighbouring cell.

32. The computer program product according to any of claims 29 to 31, wherein the uplink transmission power values have been determined on the basis of a product of a notional channel gain between the serving cell and the user equipment and a measure of the notional load of the serving cell.

33. A user equipment including the computer program product according to any of claims 29 to 32.

34. Apparatus configured to perform the method according to any of claims 1 to 28.

35. A computer-readable instructions which, when executed by processing apparatus, causes the processing apparatus to perform a method according to any of claims 1 to 28.

36. Apparatus comprising:

at least one processor; and

at least one memory including computer program code which, when executed by the at least one processor, causes the apparatus to determine an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells.

37. The apparatus according to claim 36, wherein the uplink transmission power value is dependent on an interference of uplink transmission by the user equipment in respect of at least one of the neighbouring cells.

38. The apparatus according to either of claims 36 or 37, wherein the uplink transmission power value is dependent on an interference of uplink transmission by the user equipment in respect of only neighbouring cells which are serving at least one user equipment.

39. The apparatus according to any of claims 36 to 38, wherein the uplink transmission power value is dependent on a product of a channel gain between the at least one neighbouring cell and the user equipment and a measure of the load of the neighbouring cell.

40. The apparatus according to claim 39, wherein the computer program code, when executed by the at least one processor, causes the apparatus to:

estimate channel gain between the at least one neighbouring cell and the user equipment based on measurements in respect of downlink reference signals from the neighbouring cells; or

estimate the channel gain between the at least one neighbouring cell and the user equipment based on a total interference measurement.

41. The apparatus according to any of claims 36 to 40, wherein the uplink transmission power value is dependent on a product of the channel gain between the serving cell and the user equipment and a measure of the load of the serving cell.

42. The apparatus according to claim 41, wherein the computer program code, when executed by the at least one processor, causes the apparatus to estimate the channel gain between the serving cell and the user equipment based on measurements of downlink reference signals from the serving cell.

43. The apparatus according to any of claims 36 to 42, wherein the computer program code, when executed by the at least one processor, causes the apparatus to receive information indicative of the load of at least the serving cell from the serving cell.

44. The apparatus according to claim 43, wherein the information indicative of the load of the serving cell is determined based on a transmission power of a reference signal received from the serving cell, the transmission power of the reference signal being modulated in dependence on the load of the serving cell.

45. The apparatus according to claim 44, wherein the information indicative of the load of the serving cell is indicative of a product of the load of the serving cell and the channel gain between the serving cell and the user equipment.

46. The apparatus according to claim 45, wherein the computer program code, when executed by the at least one processor, causes the apparatus to perform a measurement in respect of the reference signal received from the serving cell, thereby to determine the product of the load of the serving cell and the channel gain between the serving cell and the user equipment.

47. The apparatus according to any of claims 36 to 47, wherein the information indicative of the load of the one or more neighbouring cells is conveyed using a transmission power of respective reference signals received from respective neighbouring cells, the transmission power of each reference signal being modulated based on the load of the neighbouring cell from which the reference signal is received.

48. The apparatus according to claim 47, wherein the information indicative of the load of the one or more neighbouring cells is indicative of a product of the load of the respective neighbouring cell and the channel gain between the neighbouring cell and the user equipment.

49. The apparatus according to claim 48, wherein the computer program code, when executed by the at least one processor, causes the apparatus to:

perform a measurement in respect of the reference signal received from each neighbouring cell, thereby to determine the product of the load of the neighbouring cell and the channel gain between the neighbouring cell and the user equipment.

50. The apparatus according to claim 43, wherein the information indicative of the load of the serving cell is included as data in a signalling message received from the serving cell.

51. The apparatus according to claim 43 or claim 50, wherein the information indicative of the loads of the one or more neighbouring cells is included as data in a signalling message received from the serving cell.

52. The apparatus according to any of claims 36 to 51, wherein the determining of the uplink transmission power value is performed by the user equipment

53. The apparatus according to claim 52, wherein, when determining the uplink transmission power value, the user equipment computes the uplink transmission power value based on the load of the serving cell and the load of the one or more neighbouring cells.

54. The apparatus according to claim 52 wherein, when determining the uplink transmission power value, the user equipment extracts the uplink transmission power value from a look-up table locally-available to the user equipment.

55. The apparatus according to any of claims 52 to 54, wherein the computer program code, when executed by the at least one processor, causes the apparatus to:

determine the uplink transmission power value in response to receiving uplink scheduling information from the serving cell.

56. The apparatus according to any of claims 36 to 55 wherein the uplink transmission power value is in accordance with an expression whereby, in certain circumstances, a larger product of a measure of a load of a neighbouring cell and the channel gain between the neighbouring cell and the user equipment results in a lower uplink transmission power value.

57. The apparatus according to claim 56, wherein the uplink transmission power value, in certain circumstances, varies in accordance with one divided by a sum over N neighbouring cells of a product of a channel gain between a neighbouring cell and a measure of load of the neighbouring cell.

58. Apparatus comprising:

at least one processor; and

at least one memory including computer program code which, when executed by the at least one processor, causes the apparatus to modulate transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal.

59. The apparatus according to claim 58, wherein an eNodeB modulates the transmission power of the reference signal and the radio network cell is operated by the eNodeB.

60. The apparatus according to claim 59, wherein the recipient of the reference signal comprises one or more user equipments, at least one of which is being served by another radio network cell.

61. The apparatus according to any of claims 58 to 60, wherein the reference signal is configured such that the recipient is able to determine, based on the reference signal which has its transmission power modulated based on the load of the radio network cell, an indication of the product of channel gain between the recipient and the apparatus transmitting the reference signal and the load of the cell operated by the eNodeB.

62. The apparatus according to any of claims 58 to 61, wherein the computer program code, when executed by the at least one processor, causes the apparatus to, prior to transmission of the reference signal, cause transmission of a configuration information signal carrying configuration information for enabling the recipient to interpret the subsequently transmitted reference signal which has its transmission power modulated based on the load of the radio network cell.

63. The apparatus of claim 62, wherein the computer program code, when executed by the at least one processor, causes the apparatus to:

receive at an eNodeB, which operates a first cell, configuration information relating to reference signals to be transmitted in relation to another cell; and

include in the configuration information signal the configuration information relating to reference signals to be transmitted by the other cell in addition to configuration information relating to reference signals to be transmitted in relation to the first cell.

64. A computer-readable medium having computer-readable code stored thereon, the computer readable code, when executed by a least one processor, causing performance of at least determining an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells.

65. A computer-readable medium having computer-readable code stored thereon, the computer readable code, when executed by a least one processor, causing performance of at least modulating transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal.

66. Apparatus comprising means for determining an uplink transmission power value for a user equipment being served by a serving cell in a radio access network, the uplink transmission power value being dependent on a load of the serving cell and a load of one or more neighbouring cells.

67. Apparatus comprising means for modulating transmission power of a reference signal based on a load of a radio network cell to provide information indicative of the load of the radio network cell to a recipient of the reference signal.

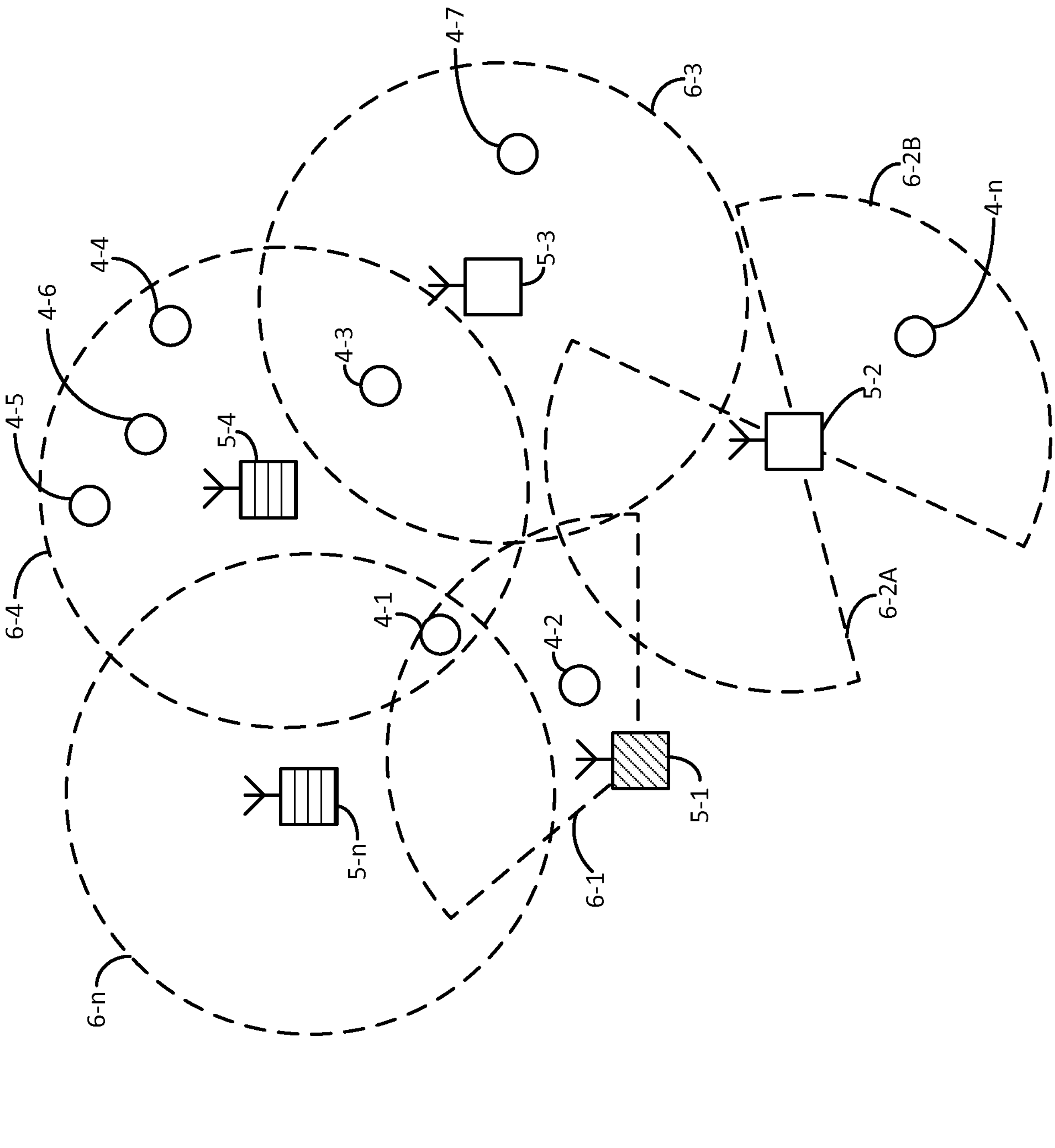

FIG. 1

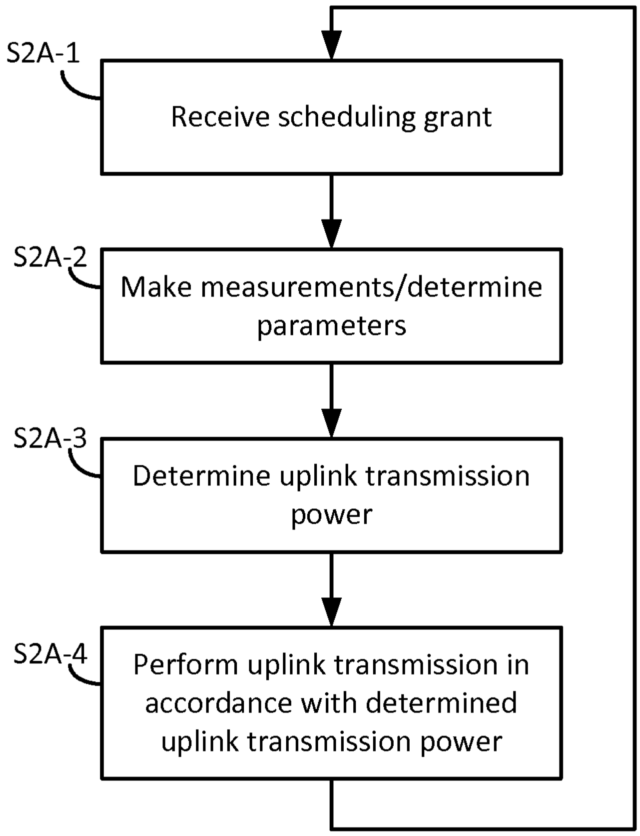
S2A-1
Receive scheduling grant
S2A-2
Make measurements/determine parameters
S2A-3
Determine uplink transmission power
S2A-4
Perform uplink transmission in accordance with determined uplink transmission power

FIG. 2A

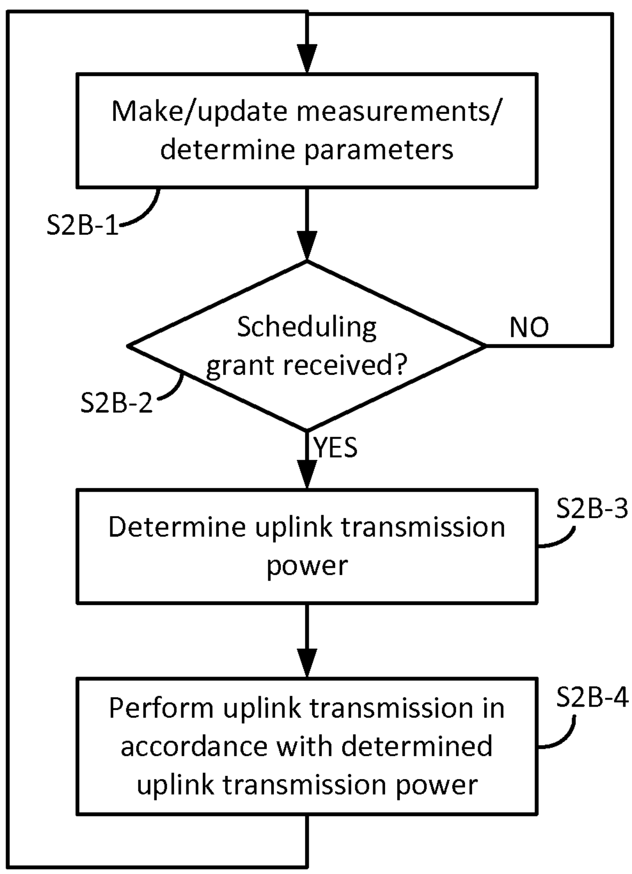
Make/update measurements/ determine parameters
S2B-1
Scheduling grant received?
NO
S2B-2
YES
Determine uplink transmission power
S2B-3
Perform uplink transmission in accordance with determined uplink transmission power
S2B-4

FIG. 2B

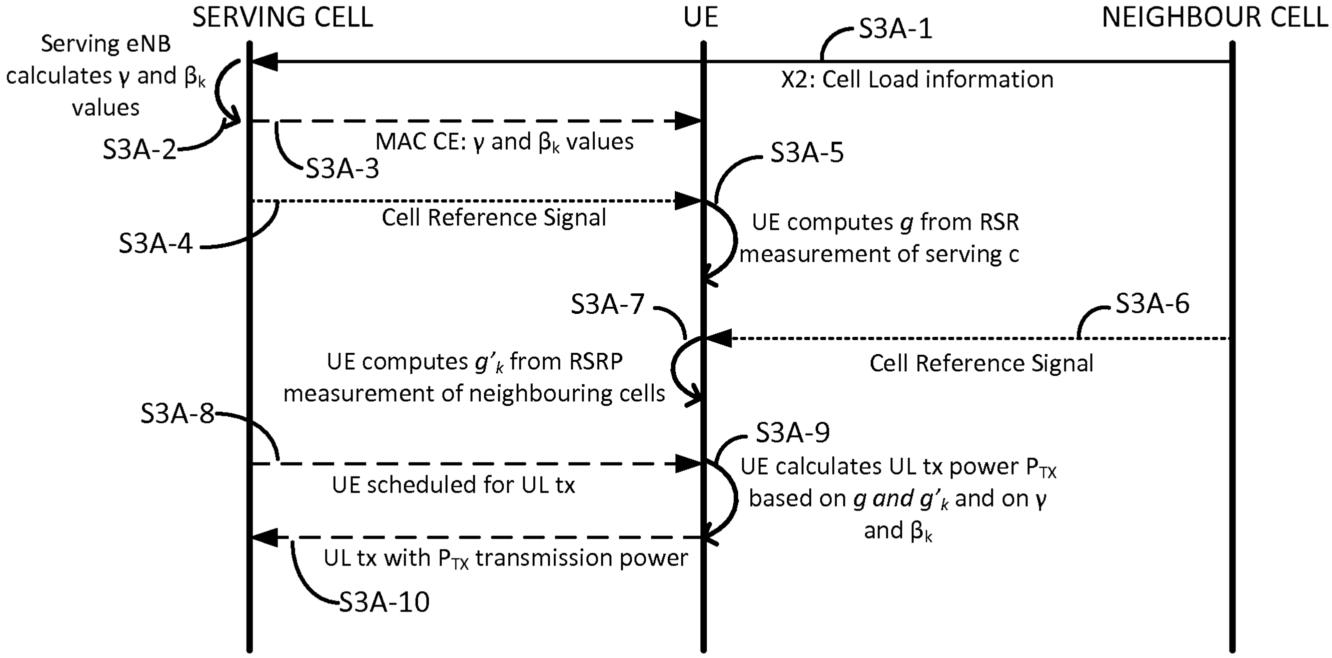
SERVING CELL
UE
NEIGHBOUR CELL
S3A-1
Serving eNB calculates γ and βk values
X2: Cell Load information
S3A-2
MAC CE: γ and βk values
S3A-3
S3A-5
Cell Reference Signal
S3A-4
UE computes g from RSR measurement of serving c
S3A-7
S3A-6
Cell Reference Signal
UE computes g'k from RSRP measurement of neighbouring cells
S3A-8
S3A-9
UE calculates UL tx power PTX based on g and g'k and on γ and βk
UE scheduled for UL tx
UL tx with PTX transmission power
S3A-10

FIG. 3A

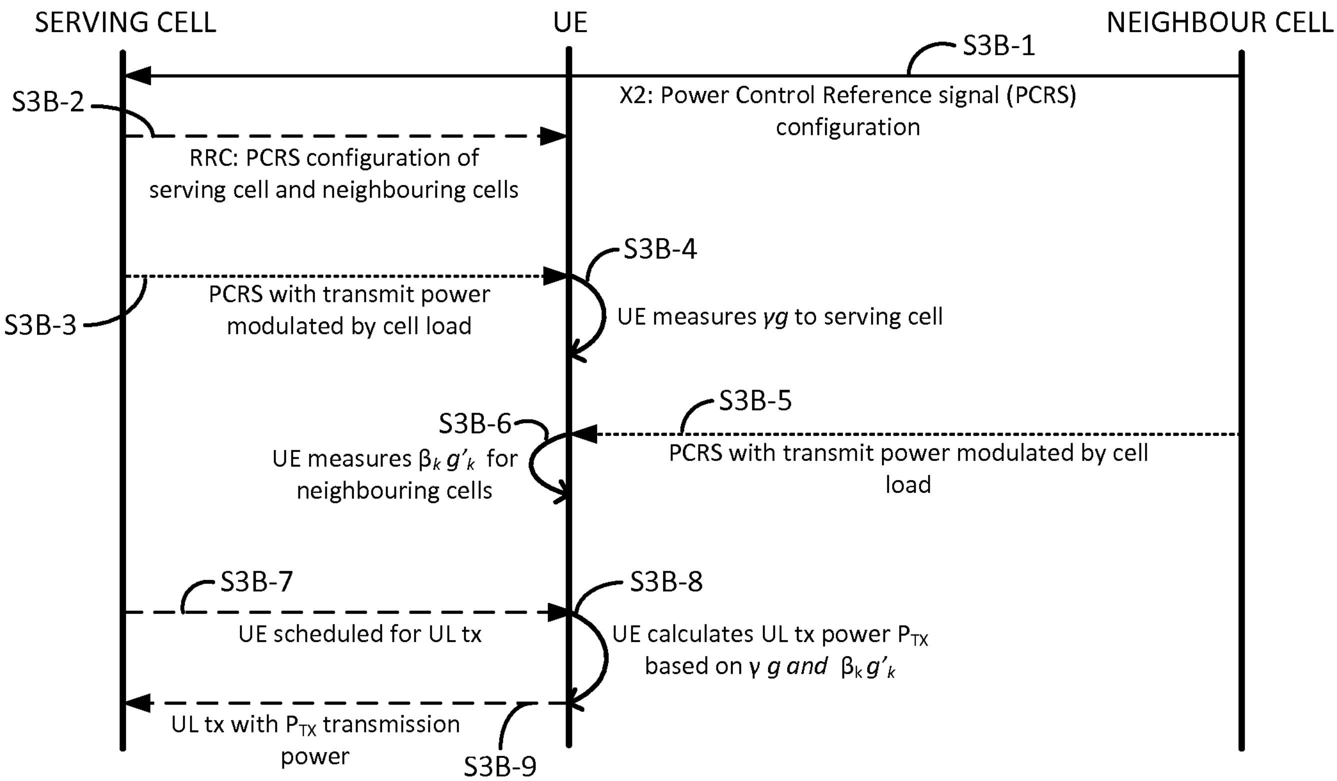
SERVING CELL
UE
NEIGHBOUR CELL
S3B-1
X2: Power Control Reference signal (PCRS) configuration
S3B-2
RRC: PCRS configuration of serving cell and neighbouring cells
S3B-4
PCRS with transmit power modulated by cell load
S3B-3
UE measures γg to serving cell
S3B-5
S3B-6
PCRS with transmit power modulated by cell load
UE measures βk g'k for neighbouring cells
S3B-7
S3B-8
UE scheduled for UL tx
UE calculates UL tx power PTX based on γ g and βk g'k
UL tx with PTX transmission power
S3B-9

FIG. 3B

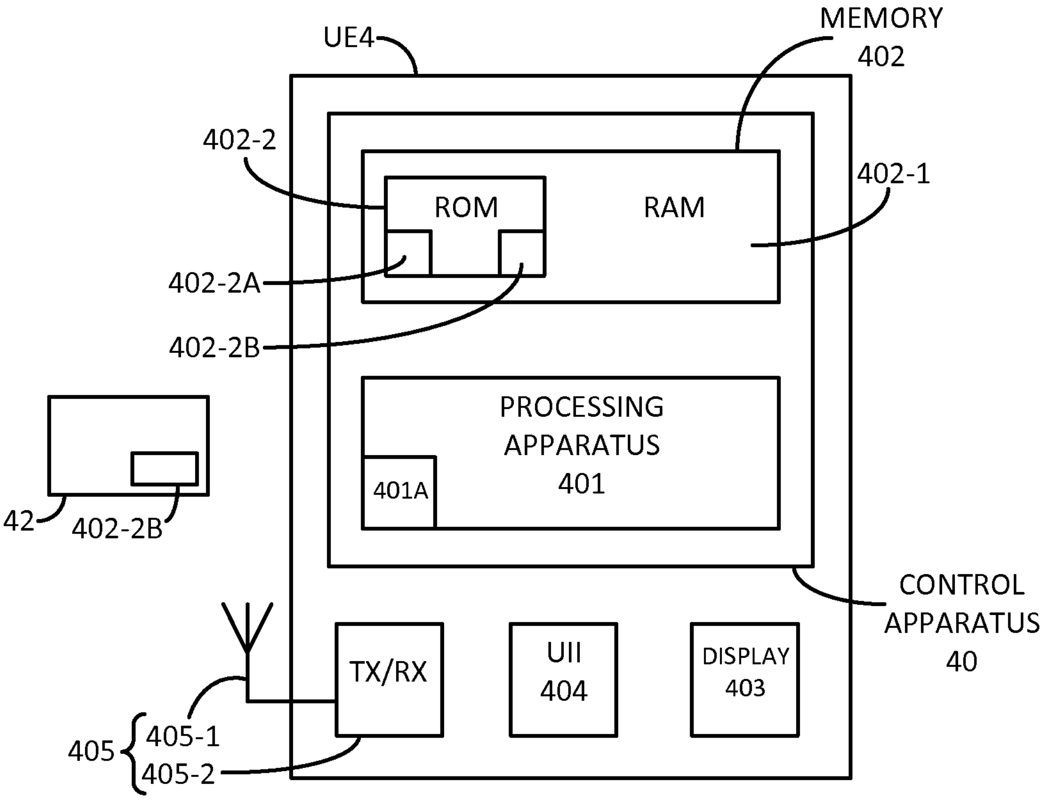
UE4
MEMORY
402
402-2
402-1
ROM
RAM
402-2A
402-2B
PROCESSING
APPARATUS
401
401A
42
402-2B
CONTROL
APPARATUS
40
TX/RX
UII
404
DISPLAY
403
405
405-1
405-2

FIG. 4

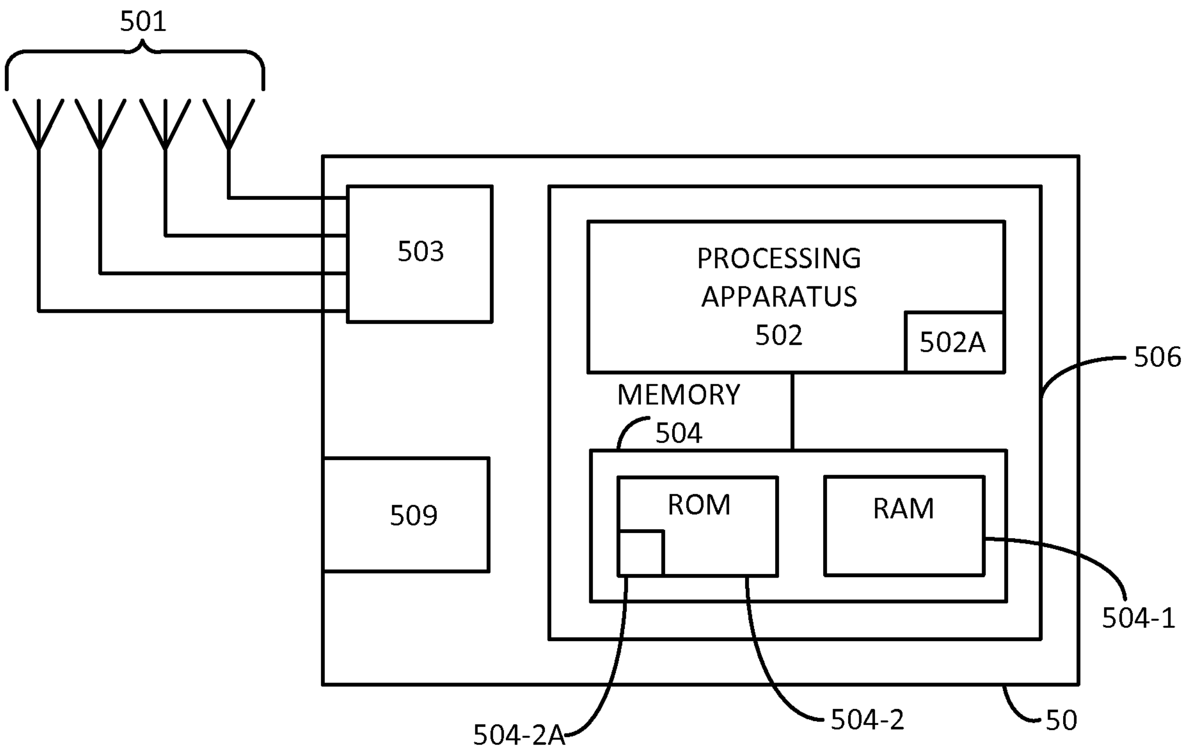
501
503
PROCESSING
APPARATUS
502
502A
506
MEMORY
504
509
ROM
RAM
504-1
504-2A
504-2
50

FIG. 5

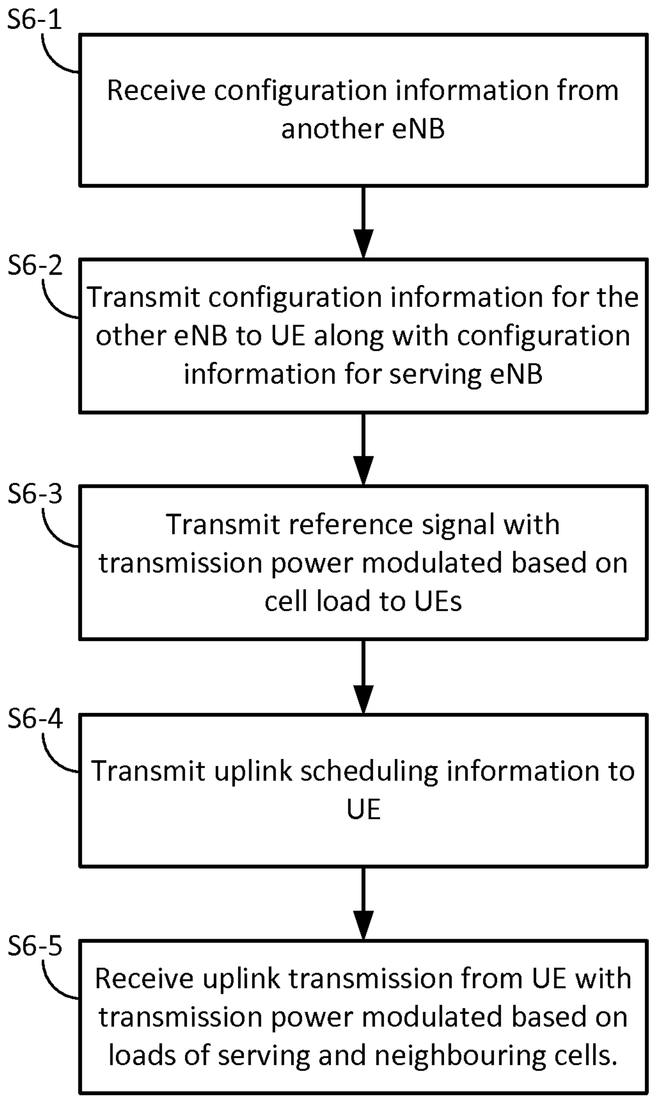
S6-1
Receive configuration information from another eNB
S6-2
Transmit configuration information for the other eNB to UE along with configuration information for serving eNB
S6-3
Transmit reference signal with transmission power modulated based on cell load to UEs
S6-4
Transmit uplink scheduling information to UE
S6-5
Receive uplink transmission from UE with transmission power modulated based on loads of serving and neighbouring cells.

FIG. 6

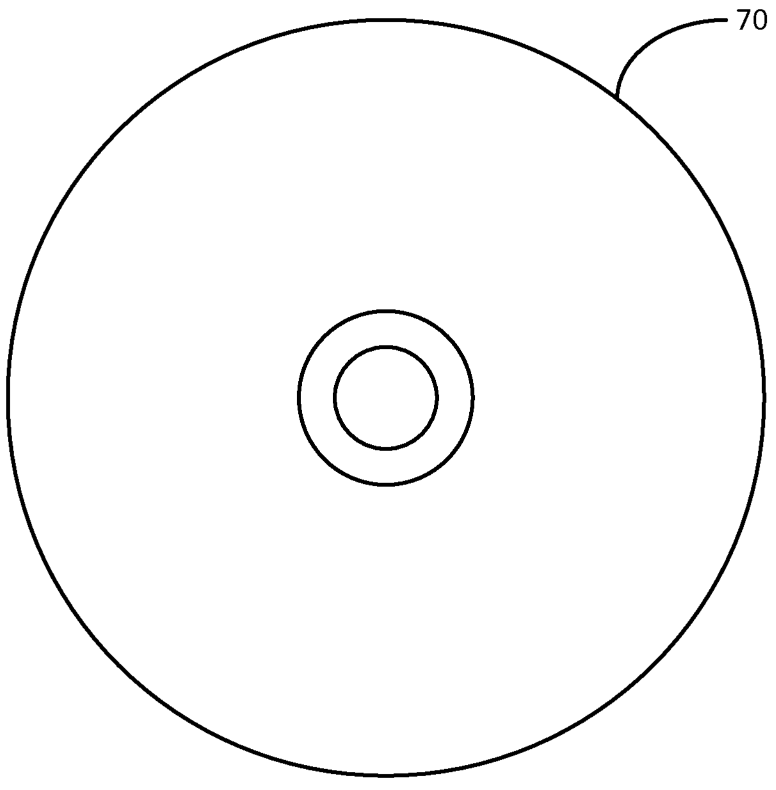

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI2016/050239

A. **CLASSIFICATION OF SUBJECT MATTER**

See extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H04W, H04J, H04B.

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

FI, SE, NO, DK

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

EPO-Internal, WPIAP, XP3GPP, XPAIP, XPESP, XPETSI, XPI3E, XPIEE, XPIETF, XPIOP, XPIPCOM, XPJPEG, XPMISC, XPRD, XPTK, COMPDX, INSPEC, NPL, Internet, ESPACENET

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013077586 A1 (DAMNJANOVIC ALEKSANDAR [US] et al.) 28 March 2013 (28.03.2013) Abstract, paragraphs [0008]-[0012], [0028], [0149]-[0159], [0163], [0167]-[0171], [0173], [0191], [0192], [0202], [0206]-[0209], [0221]-[0228], figures 4-6, 11, 16.	1-3, 8, 9, 23-25, 27, 29, 30, 33-38, 43, 44, 58-60, 62, 64-67
Y	paragraphs [0008]-[0012], [0028], [0149]-[0159], [0163], [0167]-[0173], [0191], [0192], [0206]-[0208], figures 4, 11, 16.	4-7, 10-20, 26, 31, 32, 39-42, 45-55, 61
Y	US 2014233416 A1 (BLACK PETER J [US] et al.) 21 August 2014 (21.08.2014) Abstract, paragraphs [0058]-[0060], [0072]-[0074], [0082]-[0084], [0110], [0118]-[0127], [0189], figures 8, 9	4-7, 31, 32, 39-42

☒ Further documents are listed in the continuation of Box C. ☒ 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
16 June 2016 (16.06.2016)	20 June 2016 (20.06.2016)

Name and mailing address of the ISA/FI
Finnish Patent and Registration Office
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Authorized officer
Harald Kaaja
Telephone No. +358 9 6939 500

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2010182903 A1 (PALANKI RAVI [US] et al.) 22 July 2010 (22.07.2010) Abstract, paragraphs [0040]-[0044], [0047]-[0072], [0113]-[0116], [0134], [0149], figures 7, 15, 19.	10-14, 26, 45-49, 61
Y	US 2010317385 A1 (KAZMI MUHAMMAD [SE] et al.) 16 December 2010 (16.12.2010) Abstract, paragraphs [0011], [0041], [0060], [0061], [0088], figure 1.	15, 50
Y	WO 2015094026 A1 (ERICSSON TELEFON AB L M [SE]) 25 June 2015 (25.06.2015) Abstract, paragraphs [0034]-[0036], [0048], [0056], [0057], [0064]-[0068] figures 1b, 1e, 1f.	16-18, 51-53
Y	US 2014036808 A1 (PELLETIER BENOIT [CA] et al.) 06 February 2014 (06.02.2014) Abstract, paragraphs [0009], [0118]-[0129], [0131].	19, 20, 54, 55
A	US 2011261673 A1 (LUO TAO [US] et al.) 27 October 2011 (27.10.2011) The whole document.	1-67

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