SUMMARY OF THE INVENTION

EmbodimentsOne object of the invention is to propose procedures that allow the eNodeB to recognize the power usage status of a user equipment in a mobile communication system using carrier aggregation.

The object is solved by the subject matter of the independent claims. Advantageous embodiments are subject to the dependent claims.

According to a first aspect, there is provided a method for informing an eNodeB of a transmit power status of a user equipment (UE) in a mobile communication system using component carrier aggregation, in which two or more component carriers (CCs) are aggregated, wherein the method comprises the following steps performed by the UE: generating a power status report that includes: (i) a power headroom report indicative of a difference between a nominal UE maximum transmit power and an estimated UE transmit power, per each configured and activated uplink CC, and (ii) a CC specific maximum transmission power, $P_{CMAX,c}$, which is said nominal UE maximum transmit power and which is obtained based on subtraction of a CC specific amount of power reduction from a higher bound of UE maximum transmit power, $P_{CMAX\ H,c}$, for each configured and activated uplink CC, wherein the CC specific maximum transmission power, $P_{CMAX,c}$, for each configured and activated CC is included in the power status report when the UE has a resource assignment for the configured and activated uplink CC, and transmitting the power status report to the eNodeB.

According to a second aspect, there is provided an user equipment (UE) for informing an eNodeB of a transmit power status of the UE in a mobile communication system using component carrier aggregation, in which two or more component carriers (CCs) are aggregated, wherein the UE comprises a processor configured to generate a power status report that includes: (i) a power headroom report indicative of a difference between a nominal UE maximum transmit power and an estimated UE transmit power, per each configured and activated uplink CC, and (ii) a CC specific maximum transmission power, $P_{CMAX,c}$, which is said nominal UE power reduction from a higher bound of UE maximum transmit power, $P_{CMAX\ H,c}$, for each configured and activated uplink CC, wherein the CC specific maximum transmission power, $P_{CMAX,c}$, for each configured and activated CC is included in the power status report when the UE has a resource assignment for the configured and activated uplink CC, and a transmitter configured to transmit the power status report to the eNodeB.

An embodiment~~first aspect~~ of the invention ~~is to~~ enables ~~to~~ user equipment to indicate to the eNodeB when it is potentially becoming power limited or is power limited, i.e. when being close to using its total maximum UE transmit power (also referred to as "user equipment's total maximum transmit power", "total maximum UE transmit power of the user equipment" or "user equipment's total maximum UE transmit power" in the following) or the resource allocations and power control commands of the eNodeB would require using a transmit power exceeding the total maximum transmit power of the user equipment.

In an embodiment~~line with this first aspect of the invention and in accordance with a first exemplary implementation~~ the user equipment uses an indicator in the MAC protocol data units (MAC PDUs) of each sub-frame to signal to the eNodeB, whether the user equipment applied power scaling to the transmission (of the MAC PDUs) within the respective sub-frame. The indicator(s) may be for example included in one or more MAC sub-headers of the MAC PDUs.

In an embodiment~~enhancement of the first exemplary implementation~~, an indicator is provided for each configured (or alternatively for each active) component carrier in the uplink so as to allow the indication of the use of power scaling for individual component carriers in the uplink. For example, this may be realized by multiplexing respective indicators to the MAC PDUs transmitted by the user equipment on the respective configured (or alternatively active) component carriers in the uplink, so that the indicator can be associated to the configured (or alternatively active) component carrier on which it is transmitted.

If the an indication of the power status of the user equipment should be made prior to the user equipment actually reaching its total maximum UE transmit power, a threshold value (e.g. a certain percentage) could be defined relative to the total maximum UE transmit power, that when exceeded, triggers the user equipment to set an indicator. In this case, when set, the indicator would indicate to the eNodeB that the user equipment is close to

using the total maximum UE transmit power (i.e. exceeded the threshold value). Also this indicator may be signaled for each configured uplink component carrier individually and may be for example included in one or more MAC sub-headers of the MAC PDUs.

In an embodiment~~Still in line with the first aspect and according to another, second exemplary implementation~~, if the user equipment needs to apply power scaling to a transmission of MAC PDUs in a given sub-frame, the user equipment is transmitting in this sub-frame a power headroom report for each configured (or alternatively for each active) uplink component carrier (also referred to as per-component carrier power headroom report(s)) together with an indicator that the per-component carrier power headroom report(s) are triggered by the estimated transmit power required for transmitting the MAC PDUs within the given sub-frame exceeding the total maximum transmit power of the user equipment (alternatively, the indicator could also be interpreted as an indication of power scaling having been applied to the transmissions within the given sub-frame by the user equipment due to this event).

Hence, in this embodiment~~second exemplary implementation~~, when the transmit power required for a transmission of the MAC PDUs on uplink component carriers within the respective sub-frame will exceed a total maximum transmit power of the user equipment, an aperiodic per-component carrier power headroom report for all the configured (or active) uplink component carrier(s) is triggered and sent by the user equipment. The indication of the trigger for the per-component carrier power headroom report(s) may be for example included in a MAC-sub header of a MAC PDU carrying a per-component carrier power headroom report in a MAC control element.

The above embodiment~~This second exemplary implementation~~ may also be modified so as to signal an indication of the power status of the user equipment should prior to the user equipment actually reaching its total maximum UE transmit power. Again, a threshold value (e.g. a certain percentage) could be defined relative to the total maximum UE transmit power, that when exceeded, triggers the user equipment to send a power headroom report for each configured uplink component carrier.

Furthermore, a power headroom report for each configured (or alternatively for each active) uplink component carrier may be optionally sent together with an indication that the respective power headroom report was triggered by exceeding the total maximum transmit power of the user equipment or a threshold relative thereto. For example, such indication could be comprised in a MAC sub-header of a MAC control element conveying

a power headroom report for a configured uplink component carrier of the user equipment.

According to a further embodiment~~, third exemplary implementation in line with the first aspect of the invention~~, the user equipment is indicating to the eNodeB the amount of power reduction applied to the maximum transmit power of a component carrier. Alternatively, instead of the power reduction, the maximum transmit power of each configured uplink component carrier (after having applied the component carrier-specific power reduction) could be signaled to the eNodeB.

The amount of power reduction may be for example signaled per configured or per active uplink component carrier.

In one further example, the amount of power reduction applied to the maximum transmit power of a component carrier is signaled together with a power headroom report for each configured uplink component carrier to the eNodeB.

The information on the user equipment's power status may be signaled in form of one or more MAC control elements that are comprised within the MAC PDU(s) of a given sub-frame. Furthermore, the signaled power status information enables the eNodeB to derive the power status for each user equipment that is signaling its power status information. The scheduler of the eNodeB may for example take into account the power status of the respective user equipments in its dynamic and/or semi-persistent resource allocations to the respective user equipments.

In another embodiment~~fourth exemplary implementation in line with the first aspect of the invention~~, the user equipment is enabled to indicate to the eNodeB when it is potentially becoming power limited or is power limited by defining a new MAC control element that is inserted by the user equipment to one or more protocol data units transmitted on respective (assigned) component carriers within a single sub-frame that is providing the eNodeB with a corresponding indication.

Furthermore, in addition to the indication of the user equipment approaching its total maximum UE transmit power, the control element inserted to the protocol data units may further indicate a per-user equipment (per-UE) power headroom. For example, the per-user equipment power headroom indicates the transmit power unused by the user equipment when transmitting the protocol data units (including the MAC control element) within the sub-frame relative to the user equipment's total maximum UE transmit power.

The MAC control element may be inserted to the protocol data units of a sub-frame. For example, the MAC control element may be inserted into one of the protocol data units transmitted by the user equipment within the sub-frame or all of the protocol data units transmitted by the user equipment within the sub-frame.

In another embodiment~~,exemplary, fifth implementation and in line with the first aspect of the invention, the object is solved by~~ the user equipment send~~ings~~ per-component carrier power headroom reports for all assigned component carriers within a single sub-frame when the user equipment is potentially becoming power limited or is power limited, i.e. when being close to using its total maximum UE transmit power or the resource allocations and power control commands of the eNodeB would require using a transmit power exceeding the user equipment's total maximum UE transmit power.

Another embodiment~~second aspect of the invention is to~~ suggests a definition for a per-component carrier power headroom when reporting the power headroom in a mobile communication system using carrier aggregation in the uplink. According to one embodiment~~exemplary definition~~, per-component carrier power headroom of a configured (or alternatively active) uplink component carrier is defined as the difference between the maximum transmit power of the configured uplink component carrier and the used uplink transmit power.

The used uplink transmit power is the power used (or emitted) by the user equipment for the transmission of the MAC PDUs within the given sub-frame. The used uplink transmit power may also be referred to as the transmitted PUSCH power. The used uplink transmit power is therefore considering power scaling (if applied to the transmission). Therefore, the used transmit power may be different from the estimated transmit power which is the transmit power required for a transmission of the MAC PDUs on uplink component carriers within the respective sub-frame as a result of the power control formula.

Alternatively, a power headroom of a configured uplink component carrier may be defined as the difference between the maximum transmit power of the configured uplink component carrier and an estimated PUSCH power. The PUSCH power is for example calculated by the power control formula for the respective component carrier.

Furthermore, the maximum transmit power of the (configured) uplink component carrier may take into according a power reduction due to simultaneous transmissions on another or other uplink component carriers in the sub-frame. Optionally, the power

headroom reports are sent for active uplink component carriers of the user equipment only.

The per-component carrier power headroom according to an embodiment~~the second aspect of the invention~~ may be provided in form of a per-component carrier power headroom report. The per-component carrier power headroom report is for example signaled in form of a MAC control element within a MAC PDU. As mentioned above, the MAC control element carrying the per-component carrier power headroom report may be associated to a MAC sub-header in a header section of the MAC PDU that can be further employed to indicate that the per-component carrier power headroom is triggered by a power limited situation of the user equipment requiring power scaling.

In all aspects of the invention and also in all embodiments~~ and exemplary implementations~~ described herein, the user equipment may optionally report only on configured component carriers that are active, which may be referred to as active component carriers (i.e. indicators, power headroom reports, etc. may only be signaled for active component carriers only). This may be for example advantageous, if the configuration and (de)activation of uplink component carriers of a user equipment can be controlled separately.

One embodiment of the invention relates to a method for informing an eNodeB on the transmit power status of a user equipment in a mobile communication system using component carrier aggregation. This method comprises the following steps performed by the user equipment for each sub-frame where the user equipment makes a transmission in the uplink. The user equipment determines whether an estimated transmit power required for a transmission of MAC protocol data units on the uplink component carriers within the respective sub-frame will exceed a total maximum transmit power of the user equipment. If so, the user equipment performs a power scaling of the transmit power to reduce the transmit power required for the transmission of the MAC protocol data units such that it is no longer exceeding the total maximum transmit power of the user equipment, and transmits the MAC protocol data units to the eNodeB within the respective sub-frame. The transmitted MAC protocol data units comprise an indicator that indicates to the eNodeB whether power scaling has been performed by the user equipment for transmitting the MAC protocol data units in the respective sub-frame.

The indicator may be for example comprised within a MAC header of at least one of the MAC protocol data units. For example, the indicator may be a flag within one or more of

In another embodiment of the invention, the format of the MAC control element signaling the amount of power reduction is identified by

- a predetermined logical channel identifier defined for MAC control elements signaling the amount of power reduction, or
- a predetermined logical channel identifier defined for MAC control elements signaling a power headroom report and one or more flags,

included in the MAC sub-header of the MAC control element.

The different exemplary embodiments of the method for informing an eNodeB on the transmit power status of a user equipment may – according to another embodiment of the invention – comprise the steps of receiving by the user equipment at least one uplink resource assignment, wherein each uplink resource assignment is assigning resources for the transmission of at least one of the MAC protocol data units on one of the plural component carriers to the user equipment, and generating for each received uplink resource assignment at least one of the MAC protocol data units for transmission on the respective assigned component carrier. Each MAC protocol data unit is transmitted via a corresponding one of the component carriers according to one of the received resource assignments (Please note that in case MIMO is used, two MAC PDUs may be transmitted via an uplink component carrier on which resources have been granted to the user equipment). The generation of the protocol data units may be for example performed by executing a logical channel prioritization procedure.

AIn line with the second aspect of the invention and according to another exemplary embodiment of the invention, a MAC control element for transmission from a user equipment to an eNodeB in a mobile communication system using component carrier aggregation is provided. According to this embodiment the MAC control element comprises a power headroom report for a configured uplink component carrier that reports the difference between the maximum transmit power of the configured uplink component carrier and a transmitted PUSCH power (or the used uplink transmit power).

In one example the transmitted PUSCH power $P^{PS}{}_{\mathrm{PUSCH},c}(i)$ of the sub-frame i is defined by

$$P^{PS}{}_{\mathrm{PUSCH},c}(i) = PSF_c \cdot \min\{P_{\mathrm{CMAX},c}, 10\log_{10}(M_{\mathrm{PUSCH},c}(i)) + P_{0_\mathrm{PUSCH},c}(j) + \alpha_c(j)\cdot PL_c + \Delta_{\mathrm{TF},c}(i) + f_c(i)\}$$

where PSF_c is the power scaling factor applied for the respective configured uplink component carrier c.

Furthermore, in another exemplary embodiment of the invention, the MAC control element may further comprise a power headroom report of the configured uplink component carrier that reports the difference between the maximum transmit power of the configured uplink component carrier and an estimated PUSCH power (or estimated uplink transmit power on the respective component carrier).

AStill in line with the second aspect of the invention and according to an alternative exemplary embodiment of the invention, another MAC control element for transmission from a user equipment to an eNodeB in a mobile communication system using component carrier aggregation is provided. This MAC control element comprises a power headroom report of the configured uplink component carrier that reports the difference between the maximum transmit power of the configured uplink component carrier and an estimated PUSCH power.

In both embodiments of the MAC control element, the maximum transmit power of the configured uplink component carrier considers a power reduction due to transmission(s) on other configured uplink component carrier(s) of the user equipment.

Another exemplary embodiment of the invention is related to a MAC protocol data unit for transmission from a user equipment to a eNodeB in a mobile communication system using component carrier aggregation. The MAC protocol data unit comprises a MAC control element including a power headroom report according to one of the different embodiments described herein and a MAC sub-header. The MAC sub-header comprises an indicator, that when set, indicates to the eNodeB that the power headroom report has been triggered by the transmit power required for a transmission of MAC protocol data units on uplink component carriers exceeding the total maximum transmit power of the user equipment.

Furthermore, embodiments of the invention also relates to the realization of the methods for informing an eNodeB on the transmit power status of a user equipment in hardware and/or by means of software modules. Accordingly, another embodiment of the invention is related to a user equipment for informing an eNodeB on the transmit power status of a user equipment in a mobile communication system using component carrier aggregation. The user equipment comprises a determination section that determines whether an estimated transmit power required for a transmission of MAC protocol data units on the uplink component carriers within the respective sub-frame will exceed a total maximum transmit power of the user equipment. Furthermore, the user equipment comprises a power

equipment and an indication of the power headroom report(s) having been triggered by the transmit power required for a transmission of MAC protocol data units on uplink component carriers exceeding the total maximum transmit power of the user equipment.

According to a further embodiment of the invention, a computer readable medium storing instructions is provided. The instructions, when executed by a processor of a user equipment, cause the user equipment to inform an eNodeB on the transmit power status of a user equipment for each sub-frame where the to be transmitted by the user equipment makes a transmission in the in the uplink within a mobile communication system using component carrier aggregation, by determining whether an estimated transmit power required for a transmission of MAC protocol data units on the uplink component carriers within the respective sub-frame will exceed a total maximum transmit power of the user equipment, and if so, performing a power scaling of the transmit power to reduce the transmit power required for the transmission of the MAC protocol data units such that it is no longer exceeding the total maximum transmit power of the user equipment, and transmitting the MAC protocol data units to the eNodeB within the respective sub-frame, wherein the transmitted MAC protocol data units comprise at least one MAC control element indicating the amount of power reduction applied to the maximum transmit power of the user equipment for the configured uplink component carriers.

Furthermore, according to another embodiment of the invention, the computer readable medium may further store instructions that when executed cause the user equipment to perform the steps of the methods for informing an eNodeB on the transmit power status of a user equipment according to one of the various embodiments described herein.

Another embodiment of the invention ~~related to the first aspect of the invention~~ provides a method for informing an eNodeB on the power status of a user equipment in a mobile communication system using component carrier aggregation. The user equipment determines whether an estimated transmit power required for transmitting protocol data units on respective component carriers within a sub-frame will exceed a threshold value relative to a total maximum UE transmit power of the user equipment. If the threshold value is exceeded, the user equipment multiplexes a MAC control element to the protocol data units and transmits the protocol data units including the MAC control element to the eNodeB within the sub-frame. The MAC control element indicates to the eNodeB that the transmit power spent by the user equipment for transmitting the generated protocol data units on uplink exceeded the threshold value, i.e. is reporting the

Claims

1. A method for informing an eNodeB of a transmit power status of a user equipment in a mobile communication system using component carrier aggregation, wherein the method comprises the following steps performed by the user equipment:

generating a power status report that includes a power headroom report and a component carrier specific maximum transmission power for each configured and activated uplink component carrier,

wherein the component carrier specific maximum transmission power takes into account an amount of power reduction on the respective configured and activated uplink component carrier and is generated when the user equipment has a resource assignment for the configured and activated uplink component carrier, and

transmitting the power status report to the eNodeB.

2. The method according to claim 1, wherein the transmission of the power status report is triggered at activation of a configured uplink component carrier.

3. The method according to claim 1 or 2, wherein the power status report takes into account a Physical Uplink Control Channel, PUCCH, power transmitted on the same sub-frame.

4. The method according to one of claims 1 to 3, wherein in case the power headroom report is to be transmitted for a configured and activated uplink component carrier for which there is no resource assignment available in the given sub-frame, the user equipment generates the power status report from the component carrier based on a predefined uplink grant or

respectively a predefined Physical Uplink Shared Channel, PUSCH, power.

5. The method according to one of claims 1 to 4, wherein the power headroom report and the component carrier specific maximum transmission power of each configured component carrier are included into a single, Media Access Control, MAC control element that is used for multiple power headroom reporting with a bitmap,

wherein a bit set at a certain position of the bitmap indicates that there is a power headroom report field for the associated component carrier including in the MAC control element.

6. The method according to claim 5, wherein the MAC control element for multiple power headroom reporting further includes indicators that indicate the presence of the associated component carrier specific maximum transmission power for the corresponding power headroom report respectively.

7. The method according to one of claims 1 to 6, wherein the component carrier specific maximum transmission power is a Pcmax,c.

8. A user equipment for informing an eNodeB of a transmit power status of the user equipment in a mobile communication system using component carrier aggregation, wherein the user equipment comprises

a processor for generating a power status report that includes a power headroom report and a component carrier specific maximum transmission power for each configured and activated uplink component carrier,

wherein the component carrier specific maximum transmission power takes into account an amount of power reduction on the respective configured and activated uplink component carrier and is generated when the user equipment has a resource assignment for the configured and activated uplink component carrier, and

a transmitter for transmitting the power status report to the eNodeB.

9. The user equipment according to claim 8, wherein the transmitting of the power status report is triggered at activation of a configured uplink component carrier.

10. The user equipment according to claim 8 or 9, wherein the power status report takes into account a Physical Uplink Control Channel, PUCCH, power transmitted on the same sub-frame.

11. The user equipment according to one of claims 8 to 10, wherein in case the power headroom report is to be transmitted for a configured and activated uplink component carrier for which there is no resource assignment available in the given sub-frame, the processor generates the power status report from the component carrier based on a predefined uplink grant or respectively a predefined Physical Uplink Shared Channel, PUSCH, power.

12. The user equipment according to one of claims 8 to 11, wherein the power headroom report and the component carrier specific maximum transmission power of each configured component carrier are included into a single, Media Access Control, MAC, control element that is used for multiple headroom reporting with a bitmap,

wherein a bit set at a certain position of the bitmap indicates that there is a power headroom report field for the associated component carrier including in the MAC control element.

13. The user equipment according to claim 12, wherein the MAC control element for multiple power headroom reporting further includes indicator that indicate the presence of the associated component carrier specific maximum transmission power for the corresponding power headroom report respectively.

14. The user equipment according to one of claims 8 to 13, wherein the component carrier specific maximum transmission power is a Pcmax,c.

CLAIMS

1. A method for informing an eNodeB of a transmit power status of a user equipment (UE) in a mobile communication system using component carrier aggregation, in which two or more component carriers (CCs) are aggregated, wherein the method comprises the following steps performed by the UE:

generating a power status report that includes: (i) a power headroom report indicative of a difference between a nominal UE maximum transmit power and an estimated UE transmit power, per each configured and activated uplink CC, and (ii) a CC specific maximum transmission power, $\mathbf{P}_{CMAX,c}$, which is said nominal UE maximum transmit power and which is obtained based on subtraction of a CC specific amount of power reduction from a higher bound of UE maximum transmit power, $\mathbf{P}_{CMAX_H,c}$, for each configured and activated uplink CC,

wherein the CC specific maximum transmission power, $\mathbf{P}_{CMAX,c}$, for each configured and activated CC is included in the power status report when the UE has a resource assignment for the configured and activated uplink CC, and transmitting the power status report to the eNodeB.

2. The method according to claim 1, wherein the transmission of the power status report is triggered at activation of a configured uplink CC.

3. The method according to claim 1, wherein the power status report takes into account a Physical Uplink Control Channel (PUCCH) power transmitted on the same sub-frame.

4. The method according to claim 1, wherein in case the power headroom report is to be transmitted for a configured and activated uplink CC for which there is no resource assignment available in the given sub-frame, the UE generates the power status report for the CC based on a predefined uplink grant or a predefined Physical Uplink Shared Channel (PUSCH) power.

5. The method according to claim 1, wherein the power headroom report and the CC specific maximum transmission power, $\mathbf{P}_{CMAX,c}$, of each configured and activated uplink CC are included into a single Media Access Control (MAC) control element that is used for multiple power headroom reporting with a bitmap, wherein a bit set at a certain position of the bitmap indicates that there is a power headroom report field included in the MAC control element for the associated CC.

6. The method according to claim 5, wherein the MAC control element for multiple power headroom reporting further includes indicators that indicate the presence of the associated CC specific maximum transmission power, $P_{CMAX,c}$, for the corresponding power headroom report, respectively.

7. A user equipment (UE) for informing an eNodeB of a transmit power status of the UE in a mobile communication system using component carrier aggregation, in which two or more component carriers (CCs) are aggregated, wherein the UE comprises

a processor configured to generate a power status report that includes: (i) a power headroom report indicative of a difference between a nominal UE maximum transmit power and an estimated UE transmit power, per each configured and activated uplink CC, and (ii) a CC specific maximum transmission power, $P_{CMAX,c}$, which is said nominal UE power reduction from a higher bound of UE maximum transmit power, $P_{CMAX_H,c}$, for each configured and activated uplink CC,

wherein the CC specific maximum transmission power, $P_{CMAX,c}$, for each configured and activated CC is included in the power status report when the UE has a resource assignment for the configured and activated uplink CC, and a transmitter configured to transmit the power status report to the eNodeB.

8. The UE according to claim 7, wherein the transmitting of the power status report is triggered at activation of a configured uplink CC.

9. The UE according to claim 7, wherein the power status report takes into account a Physical Uplink Control Channel (PUCCH) power transmitted on the same sub-frame.

10. The UE according to claim 7, wherein in case the power headroom report is to be transmitted for a configured and activated uplink CC for which there is no resource assignment available in the given sub-frame, the processor generates the power status report for the CC based on a predefined uplink grant or a predefined Physical Uplink Shared Channel (PUSCH) power.

11. The UE according to claim 7, wherein the power headroom report and the CC specific maximum transmission power, $P_{CMAX,c}$, of each configured and activated uplink CC are included into a single Media Access Control (MAC) control element that is used for multiple headroom reporting with a bitmap, wherein a bit set at a certain position of the bitmap indicates that there is a power headroom report field included in the MAC control element for the associated CC.

12. The UE according to claim 11, wherein the MAC control element for multiple power headroom reporting further includes indicators that indicate the presence of the associated CC specific maximum transmission power, $P_{CMAX,c}$, for the corresponding power headroom report, respectively.