

(51) International Patent Classification:
H04W 72/04 (2009.01)(21) International Application Number:
PCT/CN2013/070689(22) International Filing Date:
18 January 2013 (18.01.2013)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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(54) Title: METHOD AND APPARATUS FOR CONFIGURING AN ENHANCED PHYSICAL DOWNLINK CONTROL CHANNEL

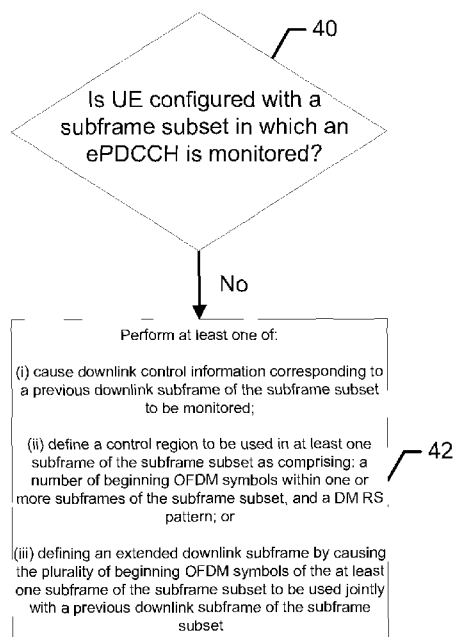


FIG. 4

(57) Abstract: Methods, apparatus and computer program products are provided for providing enhanced Physical Downlink Control Channel (e PDCCH) configurations which may, for example, be used in conjunction with a standalone new carrier type (SA-NCT). For example, a method is provided that includes, in an instance in which the UE is configured with a subframe subset in which the e PDCCH is not monitored, performing at least one of: (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored; (ii) defining a control region comprising a non-zero number of beginning orthogonal frequency-division multiplexing (OFDM) symbols and, according to a demodulation reference signal (DM RS) pattern, a number of demodulation reference signal (DM RS) symbols; or (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols to be used jointly with a previous downlink subframe of the subframe subset.



Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

METHOD AND APPARATUS FOR CONFIGURING AN ENHANCED PHYSICAL DOWNLINK CONTROL CHANNEL

TECHNOLOGICAL FIELD

[0001] Embodiments of the present invention relate generally to enhanced Physical
5 Downlink Control Channel (ePDCCH) configurations and, more particularly, to methods and
apparatus for providing ePDCCH configurations for use in a standalone new carrier type (SA-
NCT).

BACKGROUND

[0002] A standalone new carrier type (SA-NCT), e.g., a carrier type configured for
10 standalone operation and which may not be backwards compatible with prior releases, has been
identified as a work item in Long Term Evolution Release 12 (LTE Rel-12). In the proposed SA-
NCT, it may be very likely that legacy signals such as the Physical Downlink Control Channel
(PDCCH) and Cell-specific Reference Signal (CRS) signals are dropped, meaning the downlink
control channel may be based on ePDCCH, which uses a Demodulation Reference Signal
15 (DMRS) for channel estimation and demodulation.

[0003] However, this may introduce certain problems, as ePDCCH resources may not be
sufficient in certain cases, such as in Time Division Duplex (TDD) special subframes with
special subframe configuration #0 or #5, in subframes used for a Physical Multicast Channel
(PMCH), or in subframes with too many Channel State Information Reference Signal (CSI-RS)
20 resources. These problems may be compounded due to the lack of a fallback component carrier
in an SA-NCT, which may lead to issues sending uplink or downlink grants and/or unused
resources being wasted. Thus, solutions to these issues are needed.

BRIEF SUMMARY

[0004] Methods, apparatus and computer program products are provided according to an
25 example embodiment for providing ePDCCH configurations for use in a standalone new carrier
type (SA-NCT). In one example, the methods, apparatus and computer program product provide
configurations which may allow uplink or downlink grants to be sent even when a current
subframe lacks sufficient resources for ePDCCH and which avoid resources being wasted.

[0005] In one embodiment, a method is provided that includes determining whether a user equipment (UE) is configured with a subframe subset in which an ePDCCH is not monitored. The method further includes performing, in an instance in which the UE is configured with the subframe subset in which the ePDCCH is not monitored, at least one of: (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored; (ii) defining a control region to be used in at least one subframe of the subframe subset, the control region comprising a non-zero number of beginning orthogonal frequency-division multiplexing (OFDM) symbols, the beginning OFDM symbols comprising a number of demodulation reference signal (DM RS) symbols, the number of DM RS symbols being determined based on a DM RS pattern; or (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset.

[0006] In another embodiment, an apparatus is provided that includes at least one processor and at least one memory including program code with the at least one memory and the program code being configured to, with the at least one processor, cause the apparatus at least to determine whether a user equipment (UE) is configured with a subframe subset in which an ePDCCH is not monitored. The apparatus is further caused to perform, in an instance in which the UE is configured with the subframe subset in which the ePDCCH is not monitored, at least one of: (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored; (ii) defining a control region to be used in at least one subframe of the subframe subset, the control region comprising a non-zero number of beginning orthogonal frequency-division multiplexing (OFDM) symbols, the beginning OFDM symbols comprising a number of demodulation reference signal (DM RS) symbols, the number of DM RS symbols being determined based on a DM RS pattern; or (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset.

[0007] In a further embodiment, a computer program product is provided that includes at least one computer-readable storage medium having computer-executable program code instructions stored therein with the computer-executable program code instructions being configured to, upon execution, cause an apparatus to at least determine whether a user equipment

(UE) is configured with a subframe subset in which an ePDCCH is not monitored. The apparatus is further caused to perform, in an instance in which the UE is configured with the subframe subset in which the ePDCCH is not monitored, at least one of: (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored; (ii) defining a control region to be used in at least one subframe of the subframe subset, the control region comprising a non-zero number of beginning orthogonal frequency-division multiplexing (OFDM) symbols, the beginning OFDM symbols comprising a number of demodulation reference signal (DM RS) symbols, the number of DM RS symbols being determined based on a DM RS pattern; or (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset.

[0008] In yet another embodiment, an apparatus is provided that includes means for determining whether a user equipment (UE) is configured with a subframe subset in which an ePDCCH is not monitored. The apparatus further includes respective means for performing, in an instance in which the UE is configured with the subframe subset in which the ePDCCH is not monitored, at least one of: (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored; (ii) defining a control region to be used in at least one subframe of the subframe subset, the control region comprising a non-zero number of beginning orthogonal frequency-division multiplexing (OFDM) symbols, the beginning OFDM symbols comprising a number of demodulation reference signal (DM RS) symbols, the number of DM RS symbols being determined based on a DM RS pattern; or (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset.

[0009] The above summary is provided merely for purposes of summarizing some example embodiments of the invention so as to provide a basic understanding of some aspects of the invention. Accordingly, it will be appreciated that the above described example embodiments are merely examples and should not be construed to narrow the scope or spirit of the invention in any way. It will be appreciated that the scope of the invention encompasses many potential embodiments, some of which will be further described below, in addition to those here summarized.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0010] Having thus described example embodiments the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

5 [0011] FIG. 1 illustrates a system including a mobile terminal which may benefit from an example embodiment of the present invention;

[0012] FIG. 2 is a block diagram of an apparatus which may be configured in accordance with an embodiment of the present invention;

10 [0013] FIG 3 illustrates an example of a Multicast-Broadcast Single Frequency Network signal;

[0014] FIG. 4 is a flowchart illustrating operations performed in accordance with one embodiment of the present invention;

[0015] FIG. 5 illustrates an example of a subframe subset according to one example embodiment of the present invention; and

15 [0016] FIG. 6 illustrates an example of a physical resource block (PRB) configured in accordance with one example embodiment of the present invention.

DETAILED DESCRIPTION

[0017] The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the inventions are
20 shown. Indeed, these inventions may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

[0018] As used in this application, the term ‘circuitry’ refers to all of the following:
25 (a) hardware-only circuit implementations (such as implementations in only analog and/or digital circuitry) and (b) to combinations of circuits and software (and/or firmware), such as (as applicable): (i) to a combination of processor(s) or (ii) to portions of processor(s)/software (including digital signal processor(s)), software, and memory(ies) that work together to cause an apparatus, such as a mobile phone or server, to perform various functions) and

(c) to circuits, such as a microprocessor(s) or a portion of a microprocessor(s), that require software or firmware for operation, even if the software or firmware is not physically present.

[0019] This definition of ‘circuitry’ applies to all uses of this term in this application, including in any claims. As a further example, as used in this application, the term “circuitry” would also cover an implementation of merely a processor (or multiple processors) or portion of a processor and its (or their) accompanying software and/or firmware. The term “circuitry” would also cover, for example and if applicable to the particular claim element, a baseband integrated circuit or applications processor integrated circuit for a mobile phone or a similar integrated circuit in server, a cellular network device, or other network device.

[0020] A method, apparatus and computer program product are disclosed for providing and/or implementing enhanced Physical Downlink Control Channel (ePDCCH) configurations and, more particularly, to methods and apparatus for providing and/or implementing ePDCCH configurations which may be used in a standalone new carrier type (SA-NCT), such as the SA-NCT proposed in LTE Rel-12. In this regard, the method, apparatus and computer program product of some example embodiments provide configurations that prevent wasted resources and ensure proper uplink or downlink grants in a wireless communication system which utilizes an SA-NCT. Although the method, apparatus and computer program product may be implemented in a variety of different systems, one example of such a system is shown in FIG. 1, which includes a first communication device (e.g., mobile terminal 10) that is capable of communication with a network 12 (e.g., a core network). While the network may be configured in accordance with LTE or LTE-Advanced (LTE-A), other networks may support the method, apparatus and computer program product of embodiments of the present invention including those configured in accordance with wideband code division multiple access (W-CDMA), CDMA2000, global system for mobile communications (GSM), general packet radio service (GPRS) and/or the like.

[0021] The network 12 may include a collection of various different nodes, devices or functions that may be in communication with each other via corresponding wired and/or wireless interfaces. For example, the network may include one or more base stations 11, such as one or more node Bs, evolved node Bs (eNBs), access points or the like, each of which may serve a coverage area divided into one or more cells. The base station 11 or other communication node

could be, for example, part of one or more cellular or mobile networks or public land mobile networks (PLMNs). In turn, other devices such as processing devices (e.g., personal computers, server computers or the like) may be coupled to the mobile terminal and/or the second communication device via the network. The network 12 may, according to example
5 embodiments, be an LTE network configured to utilize an SA-NCT, such as the SA-NCT proposed as a work item in LTE Rel-12. That is, the network 12 may, according to example embodiments, be an LTE network configured in accordance with Rel-12 to use a new carrier type which supports standalone operation. In accordance with certain example embodiments of the present invention, the network 12 may be a time division duplex (TDD) network or a
10 frequency division duplex (FDD) network.

[0022] A communication device, such as the mobile terminal 10 (also known as user equipment (UE)), may be in communication with other communication devices or other devices via the network 12. In instances in which the network 12 is a TDD or FDD network, the mobile terminal may be configured to support communications in accordance with TDD or FDD. In
15 instances in which the network 12 is an LTE network configured in accordance with LTE Rel-12 to utilize an SA-NCT, the mobile terminal 10 may also be configured to use the SA-NCT. In some cases, the communication device may include an antenna for transmitting signals to and for receiving signals from a base station via one or more component carriers (CCs), such as a primary cell (Pcell) and, in some cases, one or more secondary cells (Scell). Each of the primary
20 and/or secondary cells may have a TDD or FDD UL/DL subframe configuration that defines a predefined sequence of DL subframes, UL subframes and special subframes to be exchanged between the mobile terminal and the network.

[0023] In some example embodiments, the mobile terminal 10 may be a mobile communication device such as, for example, a mobile telephone, portable digital assistant (PDA),
25 pager, laptop computer, or any of numerous other hand held or portable communication devices, computation devices, content generation devices, content consumption devices, or combinations thereof. As such, the mobile terminal may include one or more processors that may define processing circuitry either alone or in combination with one or more memories. The processing circuitry may utilize instructions stored in the memory to cause the mobile terminal to operate in
30 a particular way or execute specific functionality when the instructions are executed by the one or more processors. The mobile terminal may also include communication circuitry and

corresponding hardware/software to enable communication with other devices and/or the network 12.

[0024] In one example embodiment, for example, the mobile terminal 10 may be embodied as or otherwise include an apparatus 20 as generically represented by the block diagram of FIG.2.

5 According to another example embodiment, the base station 11 may additionally or alternatively be embodied as or otherwise include the apparatus 20. In the context of a mobile terminal or base station, the apparatus may be configured to provide for various ePDCCH configurations. While the apparatus may be employed, for example, by a mobile terminal or a base station, it should be noted that the components, devices or elements described below may not be mandatory and thus
10 some may be omitted in certain embodiments. Additionally, some embodiments may include further or different components, devices or elements beyond those shown and described herein.

[0025] As shown in FIG. 2, the apparatus 20 may include or otherwise be in communication with processing circuitry 22 that is configurable to perform actions in accordance with example embodiments described herein. The processing circuitry may be configured to perform data
15 processing, application execution and/or other processing and management services according to an example embodiment of the present invention. In some embodiments, the apparatus or the processing circuitry may be embodied as a chip or chip set. In other words, the apparatus or the processing circuitry may comprise one or more physical packages (e.g., chips) including materials, components and/or wires on a structural assembly (e.g., a baseboard). The structural
20 assembly may provide physical strength, conservation of size, and/or limitation of electrical interaction for component circuitry included thereon. The apparatus or the processing circuitry may therefore, in some cases, be configured to implement an embodiment of the present invention on a single chip or as a single “system on a chip.” As such, in some cases, a chip or chipset may constitute means for performing one or more operations for providing the
25 functionalities described herein.

[0026] In an example embodiment, the processing circuitry 22 may include a processor 24 and memory 26 that may be in communication with or otherwise control a device interface 28 and, in some cases, a user interface 30. As such, the processing circuitry may be embodied as a circuit chip (e.g., an integrated circuit chip) configured (e.g., with hardware, software or a
30 combination of hardware and software) to perform operations described herein. However, in some embodiments taken in the context of the mobile terminal 10 or base station 11, the

processing circuitry may be embodied as a portion of a mobile or fixed computing device or terminal.

[0027] The user interface 30 (if implemented) may be in communication with the processing circuitry 22 to receive an indication of a user input at the user interface and/or to provide an audible, visual, mechanical or other output to the user. As such, the user interface may include, for example, a keyboard, a mouse, a joystick, a display, a touch screen, a microphone, a speaker, and/or other input/output mechanisms.

[0028] The device interface 28 may include one or more interface mechanisms for enabling communication with other devices and/or networks. In some cases, the device interface may be any means such as a device or circuitry embodied in either hardware, or a combination of hardware and software that is configured to receive and/or transmit data from/to a network 12 and/or any other device or module in communication with the processing circuitry 22. In this regard, the device interface may include, for example, an antenna (or multiple antennas) and supporting hardware and/or software for enabling communications with a wireless communication network and/or a communication modem or other hardware/software for supporting communication via cable, digital subscriber line (DSL), universal serial bus (USB), Ethernet or other methods.

[0029] In an example embodiment, the memory 26 may include one or more non-transitory memory devices such as, for example, volatile and/or non-volatile memory that may be either fixed or removable. The memory may be configured to store information, data, applications, instructions or the like for enabling the apparatus 20 to carry out various functions in accordance with example embodiments of the present invention. For example, the memory could be configured to buffer input data for processing by the processor 24. Additionally or alternatively, the memory could be configured to store instructions for execution by the processor. As yet another alternative, the memory may include one of a plurality of databases that may store a variety of files, contents or data sets. Among the contents of the memory, applications may be stored for execution by the processor in order to carry out the functionality associated with each respective application. In some cases, the memory may be in communication with the processor via a bus for passing information among components of the apparatus.

[0030] The processor 24 may be embodied in a number of different ways. For example, the processor may be embodied as various processing means such as one or more of a

microprocessor or other processing element, a coprocessor, a controller or various other computing or processing devices including integrated circuits such as, for example, an ASIC (application specific integrated circuit), an FPGA (field programmable gate array), or the like. In an example embodiment, the processor may be configured to execute instructions stored in the memory 26 or otherwise accessible to the processor. As such, whether configured by hardware or by a combination of hardware and software, the processor may represent an entity (e.g., physically embodied in circuitry – in the form of processing circuitry 22) capable of performing operations according to embodiments of the present invention while configured accordingly.

Thus, for example, when the processor is embodied as an ASIC, FPGA or the like, the processor may be specifically configured hardware for conducting the operations described herein.

Alternatively, as another example, when the processor is embodied as an executor of software instructions, the instructions may specifically configure the processor to perform the operations described herein.

[0031] As discussed in the background, an SA-NCT has been proposed as a work item in LTE Rel-12 and in this NCT it is likely that legacy signals such as PDCCH and CRS are dropped. Dropping such legacy signals is motivated by a desire to minimize legacy control and reference signals transmissions to achieve the enhancements of the NCT in LTE Rel-12. Thus, following this technical direction, the downlink control may be based on ePDCCH, which uses DMRS for channel estimation and demodulation.

[0032] However, some cases have been identified in which ePDCCH resources may not be sufficient. For example, in TDD special subframes with special subframe configuration #0 or #5, the DwPTS region may be, as shown in Table 1 below, too short to use the current DM RS pattern or the ePDCCH search space, both of which are longer than 3 symbols.

Table 1: TDD special subframe with configuration #0 and #5, length of the fields (in symbols)			
	DwPTS	GP	UwPTS
Special subframe Config. #0	3	10	1
Special subframe Config. #5	3	9	2

[0033] Figure 3 illustrates another example in which ePDCCH resources may not be sufficient. In this regard, Figure 3 depicts an example of a Multicast-Broadcast Single Frequency Network (MBFSN) subframe in which the MBFSN reference signal uses antenna port 4. In this

case, and as can be seen from Figure 3, all of the orthogonal frequency division multiplexing (OFDM) symbols starting from $l=2$ until the end of the subframe are reserved for the MBSFN region and thus are also not useable for the current DM RS pattern or the ePDCCH search space. Other examples where EPDCCH resources may be insufficient include any subframes with too many Channel State Information Reference Signal (CSI-RS) resources and subframes used for a Physical Multicast Channel (PMCH).

[0034] Some solutions for the above problem with ePDCCH resource insufficiency have been proposed. For example, it has been proposed in LTE Rel-11 to not to allow ePDCCH transmissions to a UE in those problematic cases (subframes), and to possibly fallback to cross-carrier scheduling so that the UE can monitor downlink control from another component carrier which has a PDCCH region, or to use a PDCCH region from the same cell (however, this may not always be possible, especially when inter-cell interference is high). These solutions, however, may be unsuitable for use in conjunction with an SA-NCT, as there is no other component carrier to fallback to. Thus, unused resources, e.g., the DwPTS region(s) in one or more TDD special subframes, may be wasted.

[0035] Referring now to FIG. 4, a flowchart illustrating the operations performed by a method, apparatus and computer program product, such as apparatus 20 of FIG. 2, in accordance with one embodiment of the present invention are illustrated. It will be understood that each block of the flowchart, and combinations of blocks in the flowchart, may be implemented by various means, such as hardware, firmware, processor, circuitry and/or other device associated with execution of software including one or more computer program instructions. For example, one or more of the procedures described above may be embodied by computer program instructions. In this regard, the computer program instructions which embody the procedures described above may be stored by a memory device of an apparatus employing an embodiment of the present invention and executed by a processor in the apparatus. As will be appreciated, any such computer program instructions may be loaded onto a computer or other programmable apparatus (e.g., hardware) to produce a machine, such that the resulting computer or other programmable apparatus provides for implementation of the functions specified in the flowchart block(s). These computer program instructions may also be stored in a non-transitory computer-readable storage memory that may direct a computer or other programmable apparatus to function in a particular manner, such that the instructions stored in the computer-readable storage

memory produce an article of manufacture, the execution of which implements the function specified in the flowchart block(s). The computer program instructions may also be loaded onto a computer or other programmable apparatus to cause a series of operations to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions which execute on the computer or other programmable apparatus provide operations for implementing the functions specified in the flowchart block(s). As such, the operations of FIG. 4, when executed, convert a computer or processing circuitry into a particular machine configured to perform an example embodiment of the present invention. Accordingly, the operations of FIG. 4 define an algorithm for configuring a computer or processing circuitry, e.g., processor 24, to perform an example embodiment. In some cases, a general purpose computer may be provided with an instance of the processor which performs the algorithm of FIG. 4 to transform the general purpose computer into a particular machine configured to perform an example embodiment.

[0036] Accordingly, blocks of the flowchart support combinations of means for performing the specified functions and combinations of operations for performing the specified functions. It will also be understood that one or more blocks of the flowchart, and combinations of blocks in the flowchart, can be implemented by special purpose hardware-based computer systems which perform the specified functions, or combinations of special purpose hardware and computer instructions.

[0037] As shown in block 40 of Figure 4, an apparatus 20 according to one embodiment of the present invention includes means, such as the processing circuitry 22, the processor 24, the device interface 28 or the like, for determining whether the UE, e.g., mobile device 10, is configured with a subframe subset in which an ePDCCH is monitored. As shown in block 42 of Figure 4, the apparatus of the illustrated embodiment also includes means, such as the processing circuitry, the processor or the like, for performing, in an instance in which the UE is configured with a subframe subset in which the ePDCCH is not monitored, at least one of: (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored; (ii) defining a control region to be used in at least one subframe of the subframe subset as comprising a number of beginning orthogonal frequency-division multiplexing (OFDM) symbols within one or more subframes of the subframe subset and a demodulation reference signal (DM RS) pattern; or (iii) defining an extended downlink subframe

by causing the plurality of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset. Each of these potential operations will be described hereinafter.

[0038] With reference to FIG. 5, according to existing uplink grant timing relationships 510, the UE monitors subframe 1 for an uplink grant and applies the grant to subframe 7 if one is detected. However, according to an example embodiment in which operation (i) is utilized, because subframe 1 is configured with special subframe configuration #0 or #5 and, therefore, the ePDCCH is not monitored, cross-subframe scheduling 520 may be used. Thus, according to the depicted example embodiment, the apparatus 20 embodied in or otherwise associated with the UE 10 may cause downlink control information corresponding to a previous downlink subframe of the subframe subset 530, e.g., subframe 0, to be monitored. The apparatus 20 may thus cause an uplink grant to be detected in the previous downlink subframe, e.g., subframe 0, and cause the uplink grant to be applied to a subsequent uplink subframe in the subframe subset 530, e.g., subframe 7. According to another example embodiment, the apparatus 20 may cause a similar procedure to be performed with a downlink grant. That is, according to an example embodiment, the apparatus 20 may cause downlink control information corresponding to the previous downlink subframe of the subframe subset 530, e.g., subframe 0, to be monitored; cause a downlink grant to be detected in the previous subframe; and cause the downlink grant to be applied to a subsequent subframe in the subframe subset 530, e.g., subframe 7.

[0039] According to further example embodiments, certain precautions may be taken in order to prevent more than one uplink subframe being associated with the same downlink subframe in terms of uplink grant reception. In this regard, according to one example embodiment, a new uplink subframe indicator field may be inserted in the uplink grant so as to indicate to which uplink subframe the grant is to apply. According to another example embodiment, a plurality of sequences may be used to scramble the cyclic redundancy check (CRC) field of the downlink control channel, such that each sequence is linked to a given uplink subframe.

[0040] Turning to FIG. 6, an example physical resource block (PRB) configured according to an example embodiment utilizing operation (ii) is depicted. According to the depicted example, TDD special subframe configuration #0 is utilized and a new DM RS and control region are defined in the DwPTS 600. According to an example embodiment, the frequency resources of

the control region may be determined based on the PRB sets defined for ePDCCH. Reusing these PRB sets may be beneficial because such PRB sets are ordinarily selected based on their good inter-cell interference handling. According to another example embodiment, the PRB sets may be defined separately for each subframe. As discussed above, for MBSFN subframes only the first two OFDM symbols may be available for the new control region. Accordingly, the control region in such a case may be defined as consisting of two OFDM symbols. According to an example embodiment, operation (ii) may not require any changes to hybrid acknowledgement request (HARQ) timing, as the downlink control may be transmitted in the current subframe.

[0041] According to operation (iii), the UE may use a non-zero number of beginning OFDM symbols within at least one subframe jointly with a previous subframe, such as a previous downlink subframe, as an extended downlink subframe. Thus, returning to FIG. 5 and again assuming that TDD special subframe configuration #0 is being used, three beginning OFDM symbols of (special) subframe 1 may, according to an example embodiment, be used jointly by the UE along with all of the OFDM symbols of subframe 0. The beginning OFDM symbols of subframe 1 along with the OFDM symbols of subframe 0 may thus comprise an extended subframe. The extended subframe may thus, for example, comprise 17 OFDM symbols if a normal cyclic prefix (CP) is being used. According to an example embodiment, the extended subframe may utilize the same physical layer timing as the previous subframe, such as the previous downlink subframe. According to another example embodiment, the extended subframe may be used for both control and data transmissions. According to yet another example embodiment, HARQ timing may remain the same as is defined in existing LTE specifications. According to another example embodiment, a scaling operation may be applied to the transport block size determination due to the increased resources introduced by the extended subframe.

[0042] It will be understood that two or more of operations (i), (ii), and/or (iii) may, according to example embodiments, be used in combination with one another. For example, according to one embodiment, operation (i) may be used jointly with operation (iii), while HARQ timing may follow the example of Figure 5 such that the extended subframe is monitored for an uplink grant.

[0043] Methods, apparatus and computer program products of example embodiments therefore may allow uplink or downlink grants to be sent even when a current subframe does not have the resources for ePDCCH and/or may avoid resource waste. Example embodiments may

thus be beneficial when used in conjunction with an SA-NCT, such as the SA-NCT that has been proposed in LTE Rel-12.

[0044] Many modifications and other embodiments of the inventions set forth herein will come to mind to one skilled in the art to which these inventions pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the inventions are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. For example, while principally described herein in conjunction with LTE, the method and apparatus of example embodiments may be employed in conjunction with other types of systems. Moreover, although the foregoing descriptions and the associated drawings describe example embodiments in the context of certain example combinations of elements and/or functions, it should be appreciated that different combinations of elements and/or functions may be provided by alternative embodiments without departing from the scope of the appended claims. In this regard, for example, different combinations of elements and/or functions than those explicitly described above are also contemplated as may be set forth in some of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

WHAT IS CLAIMED IS:

1. A method comprising:

determining whether a user equipment (UE) is configured with a subframe subset in which an enhanced Physical Downlink Control Channel (ePDCCH) is not monitored; and performing, in an instance in which the UE is configured with the subframe subset in which the ePDCCH is not monitored, at least one of:

- (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored;
- (ii) defining a control region to be used in at least one subframe of the subframe subset, the control region comprising a non-zero number of beginning orthogonal frequency-division multiplexing (OFDM) symbols, the beginning OFDM symbols comprising a number of demodulation reference signal (DM RS) symbols, the number of DM RS symbols being determined based on a DM RS pattern; or
- (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset.

2. The method of Claim 1, wherein causing the downlink control information corresponding to the previous downlink subframe of the subframe subset to be monitored comprises:

causing an uplink or downlink grant to be detected in the previous downlink subframe, and

causing the uplink or downlink grant to be applied in a subsequent uplink subframe.

3. The method of either of Claims 1 or 2, wherein the previous downlink subframe is predefined.

4. The method of either of Claims 1 or 2, wherein the previous downlink subframe is nearest to a current subframe.

5. The method of Claim 4, wherein the current subframe comprises a time division duplex (TDD) special subframe being configured according to special subframe configuration #0 or #5.

5 6. The method of any of Claims 2 to 5, wherein the uplink or downlink grant comprises a subframe indicator field.

7. The method of any of Claims 1 to 6, wherein a Cyclic Redundancy Check (CRC) field of a downlink control channel is scrambled using two or more different sequences, each of the
10 sequences being linked to a respective uplink subframe.

8. The method of any of Claims 1 to 7, wherein the non-zero number of beginning OFDM symbols and the DM RS pattern are determined based on a condition of the subframes of the subframe subset.

15 9. The method of any of Claims 1 to 8, wherein the non-zero number of beginning OFDM symbols is three.

10. The method of any of Claims 1 to 8, wherein at least one subframe comprises a
20 Multicast-Broadcast Single Frequency Network (MBFSN) subframe, and further wherein the non-zero number of beginning OFDM symbols is two.

11. The method of any of Claims 1 to 10, wherein one or more frequency resources of the control region comprise one or more Physical Resource Block (PRB) sets defined for the
25 ePDCCH.

12. The method of any of Claims 1 to 10, wherein one or more frequency resources of the control region comprise one or more Physical Resource Block (PRB) sets defined separately for each of one or more subframes.

30 13. The method of any of Claims 1 to 12, wherein the beginning OFDM symbols comprise a downlink pilot time slot (DwPTS).

14. The method of any of Claims 1 to 13, wherein the extended downlink subframe is used for both control and data transmissions.

15. The method of any of Claims 1 to 14, wherein the extended downlink subframe uses the same physical layer timing as the previous downlink subframe.

16. The method of any of Claims 1 to 15, wherein the method is used in an LTE wireless communication network configured to utilize a standalone new carrier type (SA-NCT).

17. An apparatus comprising at least one processor and at least one memory including program code, the at least one memory and the program code being configured to, with the at least one processor, cause the apparatus to at least:

determine whether a user equipment (UE) is configured with a subframe subset in which an enhanced Physical Downlink Control Channel (ePDCCH) is not monitored; and

perform, in an instance in which the UE is configured with the subframe subset in which the ePDCCH is not monitored, at least one of:

- (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored;
- (ii) defining a control region to be used in at least one subframe of the subframe subset, the control region comprising a non-zero number of beginning orthogonal frequency-division multiplexing (OFDM) symbols, the beginning OFDM symbols comprising a number of demodulation reference signal (DM RS) symbols, the number of DM RS symbols being determined based on a DM RS pattern; or
- (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset.

18. The apparatus of Claim 17, wherein causing the downlink control information corresponding to the previous downlink subframe of the subframe subset to be monitored comprises:

causing an uplink or downlink grant to be detected in the previous downlink subframe,
and

causing the uplink or downlink grant to be applied in a subsequent uplink subframe.

5 19. The apparatus of either of Claims 17 or 18, wherein the previous downlink subframe is predefined.

20. The apparatus of either of Claims 17 or 18, wherein the previous downlink subframe is nearest to a current subframe.

10

21. The apparatus of Claim 20, wherein the current subframe comprises a time division duplex (TDD) special subframe being configured according to special subframe configuration #0 or #5.

15 22. The apparatus of any of Claims 18 to 21, wherein the uplink or downlink grant comprises a subframe indicator field.

23. The apparatus of any of Claims 17 to 22, wherein a Cyclic Redundancy Check (CRC) field of a downlink control channel is scrambled using two or more different sequences, each of
20 the sequences being linked to a respective uplink subframe.

24. The apparatus of any of Claims 17 to 23, wherein the non-zero number of beginning OFDM symbols and the DM RS pattern are determined based on a condition of the subframes of the subframe subset.

25

25. The apparatus of any of Claims 17 to 24, wherein the non-zero number of beginning OFDM symbols is three.

26. The apparatus of any of Claims 17 to 24, wherein at least one subframe comprises a
30 Multicast-Broadcast Single Frequency Network (MBFSN) subframe, and further wherein the non-zero number of beginning OFDM symbols is two.

27. The apparatus of any of Claims 17 to 26, wherein one or more frequency resources of the control region comprise one or more Physical Resource Block (PRB) sets defined for the ePDCCH.

5 28. The apparatus of any of Claims 17 to 26, wherein one or more frequency resources of the control region comprise one or more Physical Resource Block (PRB) sets defined separately for each of one or more subframes.

10 29. The apparatus of any of Claims 17 to 28, wherein the beginning OFDM symbols comprise a downlink pilot time slot (DwPTS).

30. The apparatus of any of Claims 17 to 29, wherein the extended downlink subframe is used for both control and data transmissions.

15 31. The apparatus of any of Claims 17 to 30, wherein the extended downlink subframe uses the same physical layer timing as the previous downlink subframe.

20 32. The apparatus of any of Claims 17 to 31, wherein the method is used in an LTE wireless communication network configured to utilize a standalone new carrier type (SA-NCT).

33. An computer program product comprising at least one computer-readable storage medium having computer-executable program code instructions stored therein, the computer-executable program code instructions being configured to, upon execution, cause an apparatus to at least:

25 determine whether a user equipment (UE) is configured with a subframe subset in which an enhanced Physical Downlink Control Channel (ePDCCH) is not monitored; and

perform, in an instance in which the UE is configured with the subframe subset in which the ePDCCH is not monitored, at least one of:

- 30 (i) causing downlink control information corresponding to a previous downlink subframe of the subframe subset to be monitored;
- (ii) defining a control region to be used in at least one subframe of the subframe subset, the control region comprising a non-zero number of

beginning orthogonal frequency-division multiplexing (OFDM) symbols, the beginning OFDM symbols comprising a number of demodulation reference signal (DM RS) symbols, the number of DM RS symbols being determined based on a DM RS pattern; or

- 5 (iii) defining an extended downlink subframe by causing the non-zero number of beginning OFDM symbols of the at least one subframe of the subframe subset to be used jointly with a previous downlink subframe of the subframe subset.

10 34. The computer program product of Claim 33, wherein causing the downlink control information corresponding to the previous downlink subframe of the subframe subset to be monitored comprises:

causing an uplink or downlink grant to be detected in the previous downlink subframe,
and

15 causing the uplink or downlink grant to be applied in a subsequent uplink subframe.

35. The computer program product of either of Claims 33 or 34, wherein the previous downlink subframe is predefined.

20 36. The computer program product of either of Claims 33 or 34, wherein the previous downlink subframe is nearest to a current subframe.

37. The computer program product of Claim 36, wherein the current subframe comprises a time division duplex (TDD) special subframe being configured according to special subframe
25 configuration #0 or #5.

38. The computer program product of any of Claims 33 to 37, wherein the uplink or downlink grant comprises a subframe indicator field.

30 39. The computer program product of any of Claims 33 to 38, wherein a Cyclic Redundancy Check (CRC) field of a downlink control channel is scrambled using two or more different sequences, each of the sequences being linked to a respective uplink subframe.

40. The computer program product of any of Claims 33 to 39, wherein the non-zero number of beginning OFDM symbols and the DM RS pattern are determined based on a condition of the subframes of the subframe subset.

5

41. The computer program product of any of Claims 33 to 40, wherein the non-zero number of beginning OFDM symbols is three.

42. The computer program product of any of Claims 33 to 40, wherein at least one subframe comprises a Multicast-Broadcast Single Frequency Network (MBFSN) subframe, and further wherein the non-zero number of beginning OFDM symbols is two.

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43. The computer program product of any of Claims 33 to 42, wherein one or more frequency resources of the control region comprise one or more Physical Resource Block (PRB) sets defined for the ePDCCH.

15

44. The computer program product of any of Claims 33 to 42, wherein one or more frequency resources of the control region comprise one or more Physical Resource Block (PRB) sets defined separately for each of one or more subframes.

20

45. The computer program product of any of Claims 33 to 44, wherein the beginning OFDM symbols comprise a downlink pilot time slot (DwPTS).

46. The computer program product of any of Claims 33 to 45, wherein the extended downlink subframe is used for both control and data transmissions.

25

47. The computer program product of any of Claims 33 to 46, wherein the extended downlink subframe uses the same physical layer timing as the previous downlink subframe.

30

48. The computer program product of any of Claims 33 to 47, wherein the method is used in an LTE wireless communication network configured to utilize a standalone new carrier type (SA-NCT).

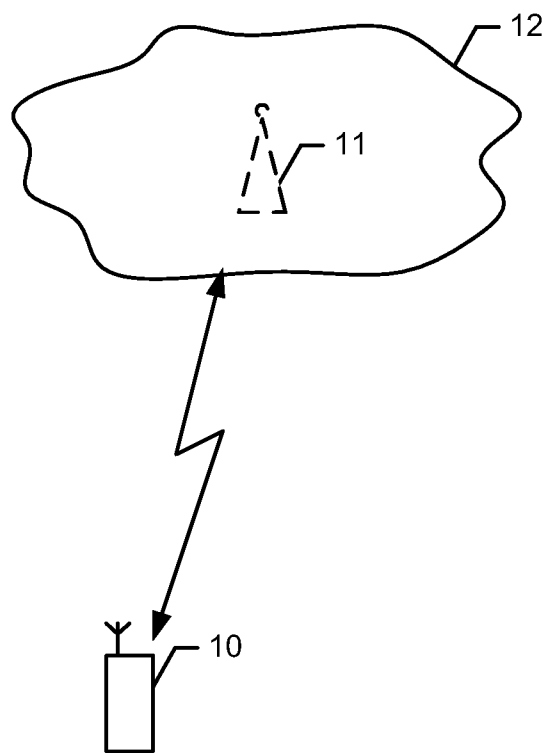


FIG. 1

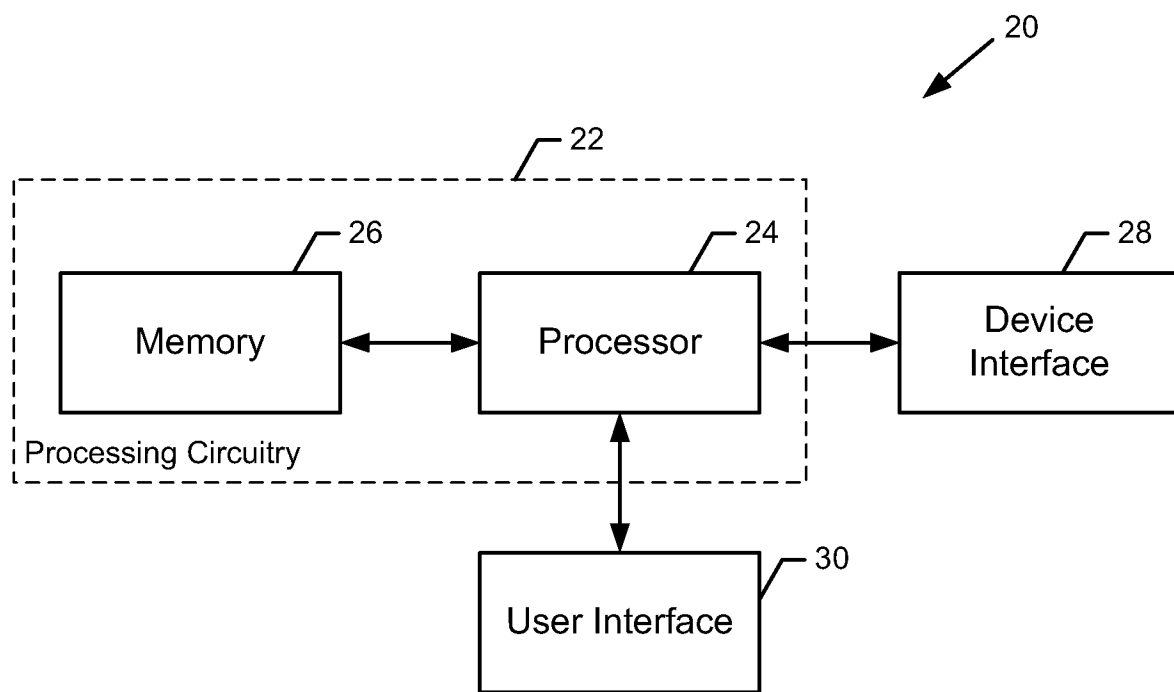


FIG. 2

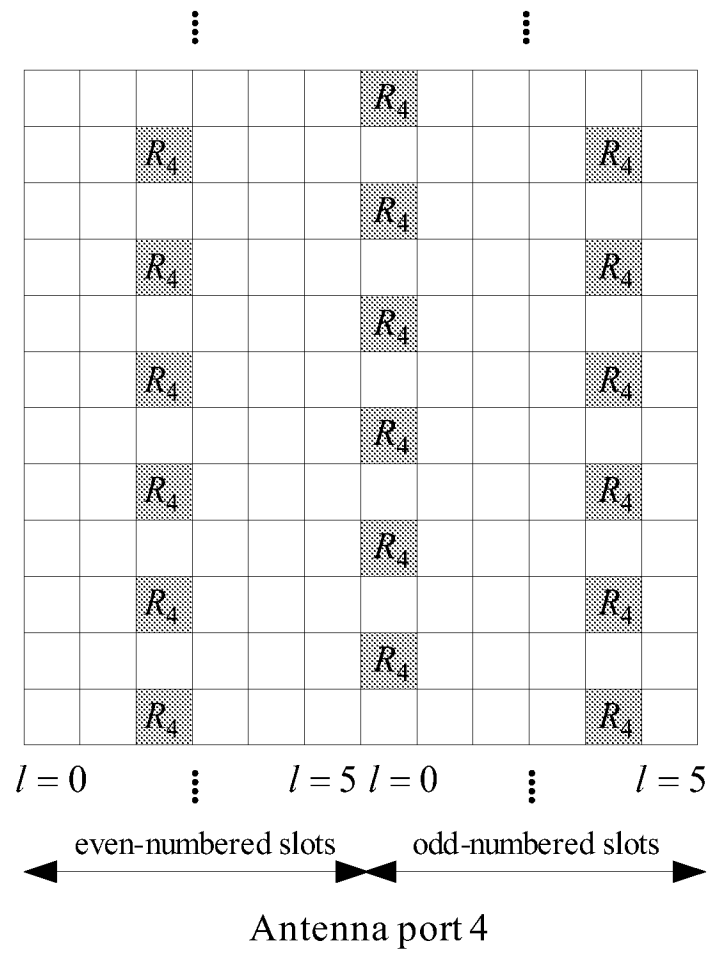


FIG. 3

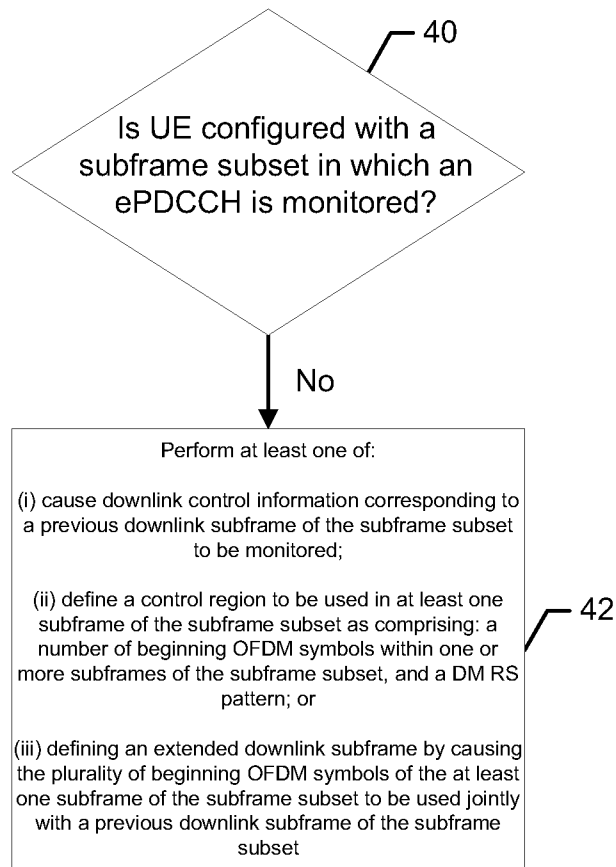


FIG. 4

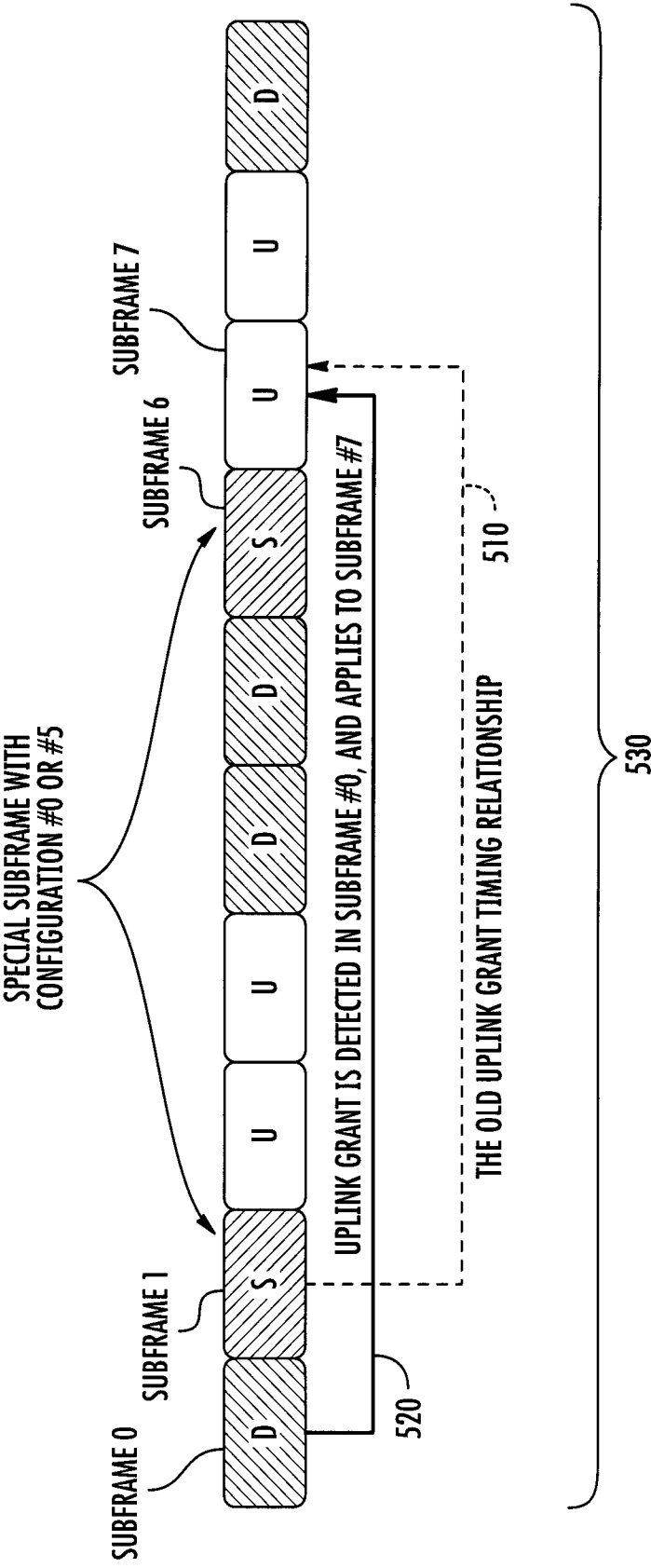


FIG. 5

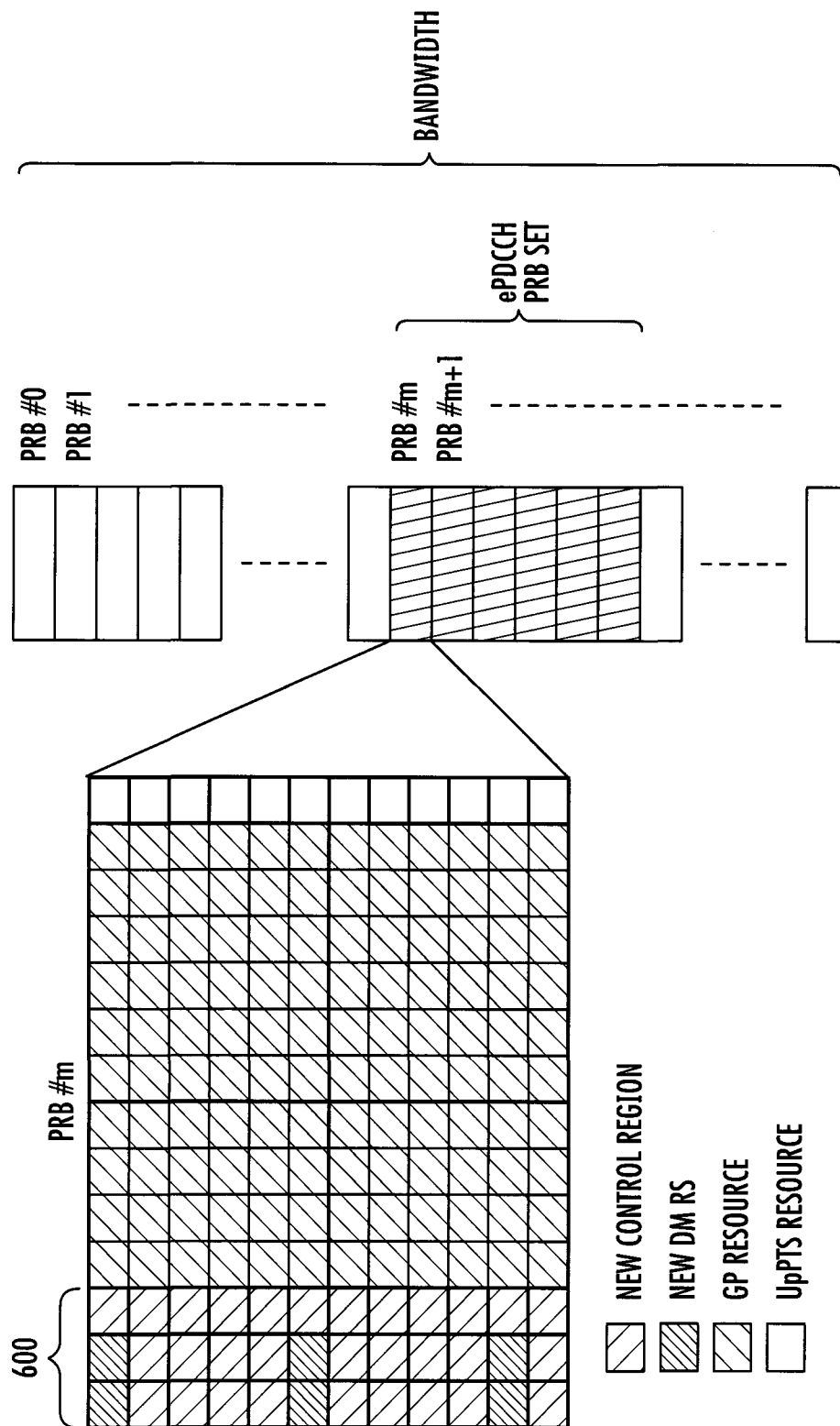


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2013/070689

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/04 (2009.01) i

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 72/-

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

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

Database: WPI, EPODOC, CNPAT, CNKI

Keyword: PDCCH, OFDM, frame, physical downlink control channel, orthogonal frequency division multiplex, control, monitor

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2011093644 A2 (LG ELECTRONICS INC.) 04 August 2011 (04.08.2011) Claims 1 to 38	1-48
A	CN 102594513 A (CHINA ACADEMY OF TELECOMMUNICATIONS TECHNOLOGY) 18 July 2012 (18.07.2012) the whole document	1-48
A	CN 102625457 A (ZTE CORPORATION) 01 August 2012 (01.08.2012) the whole document	1-48

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	“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
“A” document defining the general state of the art which is not considered to be of particular relevance	“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
“E” earlier application or patent but published on or after the international filing date	“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
“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)	“&” document member of the same patent family
“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	

Date of the actual completion of the international search
14 October 2013 (14.10.2013)Date of mailing of the international search report
24 Oct. 2013 (24.10.2013)Name and mailing address of the ISA/CN
The State Intellectual Property Office, the P.R.China
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2013/070689

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2011093644 A2	04.08.2011	EP 2529588 A2	05.12.2012
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CN 102625457 A	01.08.2012	None	