(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
13 February 2025 (13.02.2025)

(10) International Publication Number
WO 2025/035003 A1

(51) International Patent Classification:
H04W 72/23 (2023.01) *H04L 5/00* (2006.01)

(21) International Application Number:
PCT/US2024/041527

(22) International Filing Date:
08 August 2024 (08.08.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/518,526 09 August 2023 (09.08.2023) US

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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, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(54) Title: LIMITATIONS ON UNICAST DCI PROCESSING WITH MULTI-CELL AND SINGLE-CELL SCHEDULING

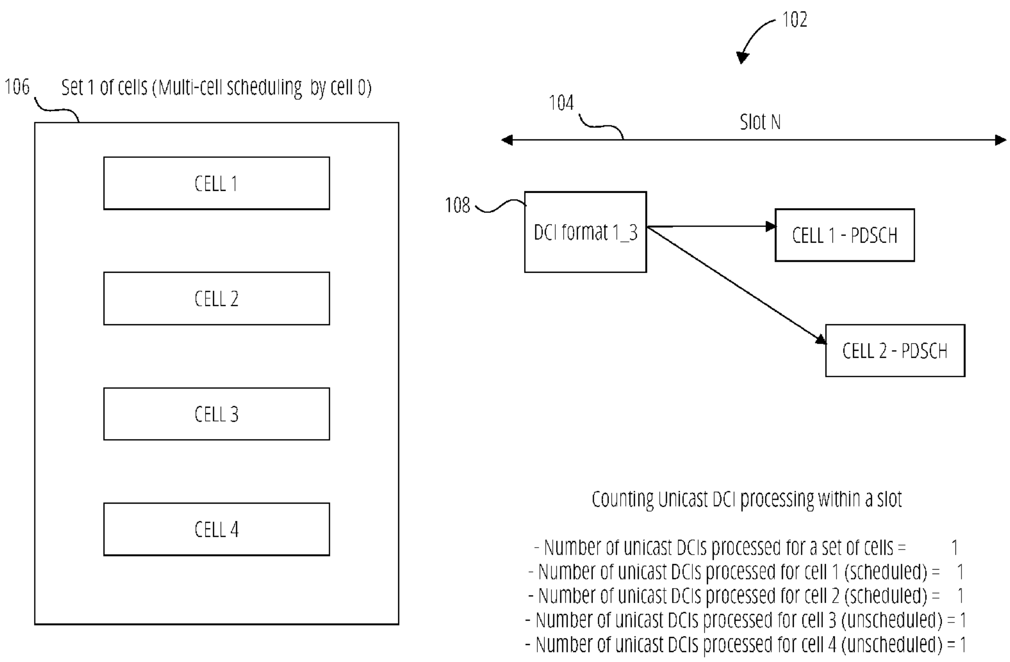

FIG. 1

(57) Abstract: Described herein are embodiments for processing and counting unicast downlink control information (DCI) when both single-cell scheduling and multi-cell scheduling is configured to a UE. In some embodiments, wireless communication systems determine available processing capability of the UE associated for both unscheduled cells and the scheduled cells of the set of cells during the slot for additional unicast DCI formats based on the use of the multi-cell scheduling unicast DCI format.

WO 2025/035003 A1

[Continued on next page]

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, 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, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

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

LIMITATIONS ON UNICAST DCI PROCESSING WITH MULTI-CELL AND SINGLE-CELL SCHEDULING

TECHNICAL FIELD

[0001] This application relates generally to wireless communication systems, including processing and counting of unicast downlink control information when both single-cell scheduling and multi-cell scheduling is configured for a UE.

BACKGROUND

[0002] Wireless mobile communication technology uses various standards and protocols to transmit data between a base station and a wireless communication device. Wireless communication system standards and protocols can include, for example, 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) (e.g., 4G), 3GPP New Radio (NR) (e.g., 5G), and Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard for Wireless Local Area Networks (WLAN) (commonly known to industry groups as Wi-Fi®).

[0003] As contemplated by the 3GPP, different wireless communication systems' standards and protocols can use various radio access networks (RANs) for communicating between a base station of the RAN (which may also sometimes be referred to generally as a RAN node, a network node, or simply a node) and a wireless communication device known as a user equipment (UE). 3GPP RANs can include, for example, Global System for Mobile communications (GSM), Enhanced Data Rates for GSM Evolution (EDGE) RAN (GERAN), Universal Terrestrial Radio Access Network (UTRAN), Evolved Universal Terrestrial Radio Access Network (E-UTRAN), and/or Next-Generation Radio Access Network (NG-RAN).

[0004] Each RAN may use one or more radio access technologies (RATs) to perform communication between the base station and the UE. For example, the GERAN implements GSM and/or EDGE RAT, the UTRAN implements Universal Mobile Telecommunication System (UMTS) RAT or other 3GPP RAT, the E-UTRAN implements LTE RAT (sometimes simply referred to as LTE), and NG-RAN implements NR RAT (sometimes referred to herein as 5G RAT, 5G NR RAT, or simply NR). In certain deployments, the E-UTRAN may also implement NR RAT. In certain deployments, NG-RAN may also implement LTE RAT.

[0005] A base station used by a RAN may correspond to that RAN. One example of an E-UTRAN base station is an Evolved Universal Terrestrial Radio Access Network (E-UTRAN) Node B (also commonly denoted as evolved Node B, enhanced Node B, eNodeB, or eNB). One example of an NG-RAN base station is a next generation Node B (also sometimes referred to as a g Node B or gNB).

[0006] A RAN provides its communication services with external entities through its connection to a core network (CN). For example, E-UTRAN may utilize an Evolved Packet Core (EPC) while NG-RAN may utilize a 5G Core Network (5GC).

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0007] To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number refer to the figure number in which that element is first introduced.

[0008] FIG. 1 illustrates counting for a DCI transmission during a slot, according to some embodiments.

[0009] FIG. 2 illustrates counting for a DCI transmission during a slot using a second approach, according to some embodiments.

[0010] FIG. 3 illustrates a set of cells where cell 1 is the scheduling cell and is also part of the set of cells in accordance with some embodiments.

[0011] FIG. 4 illustrates a method of operation for a network node in accordance with some embodiments.

[0012] FIG. 5 illustrates a method for operating a UE in accordance with some embodiments.

[0013] FIG. 6 illustrates an example architecture of a wireless communication system, according to embodiments disclosed herein.

[0014] FIG. 7 illustrates a system for performing signaling between a wireless device and a network device, according to embodiments disclosed herein.

DETAILED DESCRIPTION

[0015] Various embodiments are described with regard to a user equipment (UE). However, reference to a UE is merely provided for illustrative purposes. The example embodiments may be utilized with any electronic component that may establish a connection to a network and is configured with the hardware, software, and/or firmware to exchange information and data with the network. Therefore, the UE as described herein is used to represent any appropriate electronic component.

[0016] In new radio (NR), UE features are specified to limit the number of unicast Downlink Control information (DCI) that the UE can process per slot of scheduling cell. For slot-based monitoring, processing one unicast DCI scheduling downlink (DL) and one unicast DCI scheduling uplink (UL) per slot per scheduled component carrier (CC) for Frequency Division Duplexing (FDD) is supported. Additionally, for slot-based monitoring, processing one unicast DCI scheduling DL and two unicast DCI scheduling UL per slot per scheduled CC for Time Division Duplexing (TDD) is supported. This is valid for both self-scheduling and cross-carrier scheduling in case of same Subcarrier Spacing (SCS) between the scheduling cell and a scheduled cell.

[0017] For cross-carrier scheduling with different SCS combination, lower-to-higher SCS for scheduling-to-scheduled cell may be supported. In other words, the scheduling cell can have a lower SCS and the corresponding scheduled cell can have a higher SCS. The Baseline capability may be the same as for same SCS cases as discussed above. Further, advanced capabilities are also specified for DL and UL.

[0018] For cross-carrier scheduling with different SCS combination, processing up to X unicast DCI scheduling for DL per scheduled CC may be supported, where X is based on a pair of scheduling CC SCS and scheduled CC SCS (scheduling CC SCS, scheduled CC SCS). Example candidate value(s) of X for DL may be: X ={1,2,4} for pairs of scheduling CC SCS, scheduled CC SCS set to (15kHz, 120kHz), (15kHz, 60kHz), (30kHz, 120kHz), and X={2} for pairs of scheduling CC SCS, scheduled CC SCS set to (15kHz, 30kHz), (30kHz, 60kHz), (60kHz, 120kHz). Similarly, processing up to X unicast DCI scheduling for UL per scheduled CC may be supported, where X is based on a pair of (scheduling CC SCS, scheduled CC SCS). Example candidate value(s) of X for UL may be: X ={1,2,4} for pairs of scheduling CC SCS, scheduled CC SCS set to (15kHz, 120kHz), (15kHz, 60kHz), (30kHz, 120kHz), and X={2} for pairs of scheduling CC SCS, scheduled CC SCS set to (15kHz, 30kHz), (30kHz, 60kHz), (60kHz, 120kHz).

[0019] Further, for cross-carrier scheduling with different SCS combination higher-to-lower SCS for scheduling-to-scheduled cell may be supported. For DL scheduling, the following components are applicable to CCS from higher SCS to lower SCS. The UE may support processing one unicast DCI scheduling DL per N consecutive scheduling CC slot per scheduled CC for FDD scheduling CC. The UE may support processing one unicast DCI scheduling DL per N consecutive scheduling CC slot per scheduled CC for TDD scheduling CC. N is based on pair of (scheduling CC SCS, scheduled CC SCS). Example candidate value(s) of N may be: N=2 for pairs of scheduling CC SCS, scheduled CC SCS set to (30kHz, 15kHz), (60kHz, 30kHz), (120kHz, 60kHz), N=4 for pairs of scheduling CC SCS, scheduled CC SCS set to (60kHz, 15kHz), (120kHz, 30kHz), and N = 8 for pairs of scheduling CC SCS, scheduled CC SCS set to (120kHz, 15kHz).

[0020] Similarly, for UL scheduling the following components are applicable to CCS from higher SCS to lower SCS. The UE may support processing one unicast DCI scheduling UL per N consecutive scheduling CC slot per scheduled CC for FDD scheduling CC. The UE may support processing two unicast DCI scheduling UL per N consecutive scheduling CC slot per scheduled CC for TDD scheduling CC. N is based on pair of (scheduling CC SCS, scheduled CC SCS). Example candidate value(s) of N may be: N=2 for pairs of scheduling CC SCS, scheduled CC SCS set to (30kHz, 15kHz), (60kHz, 30kHz), (120kHz, 60kHz), N=4 for pairs of scheduling CC SCS, scheduled CC SCS set to (60kHz, 15kHz), (120kHz, 30kHz), and N = 8 for pairs of scheduling CC SCS, scheduled CC SCS set to (120kHz, 15kHz).

[0021] Some wireless communication systems may include features for a UE to support multiple-cell physical downlink shared channel (PDSCH) scheduling. The number of unicast DL DCI to process (e.g., for a set of cells) configured for multi-cell PDSCH scheduling by a DCI format 1_3 may be one unicast DCI per slot of scheduling cell (for the set of cells) for FDD/TDD scheduling cell. It is undefined of whether to count DCI format 1_3 only or both legacy DCI formats (1_1, 1_2, 1_0, etc.) and DCI format 1_3. Additionally, advanced UE capability may be introduced for larger number of unicast DL DCI.

[0022] Similarly, for uplink, the number of unicast UL DCI to process (for a set of cells) configured for multi-cell PUSCH scheduling by a DCI format 0_3 may be one unicast DCI per slot of scheduling cell (for the set of cells) for FDD scheduling cell, and two unicast DCI per slot of scheduling cell (for the set of cells) for TDD scheduling cell. It is undefined whether to count DCI format 0_3 only or both legacy DCI formats and DCI format 0_3. Additionally, advanced UE capability may be introduced for larger number of unicast UL DCI.

[0023] Some embodiments herein provide different options in terms of how the unicast DCI is processed and counted in case when both single-cell scheduling and multi-cell scheduling is configured to a UE. In some embodiments, UE complexity may not be increased in comparison to legacy UEs for single cell scheduling, at least as a baseline UE capability. Some embodiments describe how the counting is done for unicast DCI processing for a set of cells. Some embodiments describe how the counting is handled for UE configured with both legacy unicast DCI formats as well new multi-cell scheduling DCI format. Some embodiments describe how baseline and advanced UE capabilities are defined for unicast DCI processing. Some embodiments consider both the cases of same SCS and different SCS between scheduling cell and scheduled cells.

[0024] FIG. 1 illustrates counting for a DCI transmission 102 during a slot 104 according to some embodiments. In the illustrated embodiment, if a UE is capable and configured with both multi-cell scheduling and single cell scheduling for DL, and also configured with same subcarrier spacing between scheduling cells and the co-scheduled cells within the set, then the number of unicast DCIs (e.g., DCI format 1_3 108) for a UE to process for the set of cells (set of cells 106) and for each cell (e.g., cell 1, cell 2, cell 3, and cell 4) within the set of cells is equal to one per slot of scheduling cell for DL scheduling for FDD/TDD.

[0025] In the illustrated embodiment, the number of unicast DCIs include both single-cell scheduling legacy unicast DCI formats such as format 1_0, 1_1, 1_2 as well as the new multi-cell scheduling unicast DCI format 1_3. In some embodiments, for DCI format 1_3, if it is processed by UE in a slot 104 of scheduling cell, it is counted for all cells within the set of cells regardless of whether all cells within a set are scheduled or not. For instance, in some embodiments, the set of cells 106 may be configured with up to four cells, but the network may schedule less than the number of cells in the set of cells 106. However, even if a cell is not scheduled, the DCI format 1_3 will be counted thereby exhausting the DCI count for all cells in the set of cells 106. This can limit the number of DCIs for a UE to process, thereby ensuring that the complexity for the UE processing is not increased.

[0026] The following possibilities can be supported based on limitation of one unicast DCI processing per slot of scheduling cell using the illustrated DCI counting technique. A DCI format 1_3 can be processed by the UE once for set of cells 106. If no DCI format 1_3 is processed for the set of cells 106, then legacy DCI formats 1_0, 1_1, 1_2 can be processed by the UE once per scheduled cell within a set.

[0027] For example, in the illustrated embodiment, for DL where the same subcarrier spacing is used between scheduling cells and the co-scheduled cells within the set of cells 106, the following is an example of a DCI count. The set of cells 106 includes cell 1, cell 2, cell 3, and cell 4. During the slot 104 cell 1 and cell 2 are scheduled, and cell 3 and cell 4 are unscheduled. Further, during the slot 104 DCI format 1_3 108 is sent to the UE over PDSCH for cell 1 and cell 2. The UE and network node may count the number of unicast DCI processing within a slot for each cell to determine whether additional DCI may be processed. In the illustrated embodiment, each of the cells have a count of one and the slot cannot be used for additional DCI processing for any of the cells in the set of cells 106 even though cell 3 and cell 4 are unscheduled and DCI format 1_3 was not received for cell 3 and cell 4.

[0028] A similar DCI counting method may be used for UL where the same subcarrier spacing is used between scheduling cells and the co-scheduled cells within the set. If a UE is capable and configured with both multi-cell scheduling and single cell scheduling for UL, and also configured with same subcarrier spacing between scheduling cells and the co-scheduled cells within the set, then the number of unicast DCIs for a UE to process for the set of cells and for each cell within the set of cells may be equal to 1 and 2 per slot of scheduling cell for UL scheduling for FDD and TDD, respectively. The number of unicast DCIs may include both single-cell scheduling legacy unicast DCI formats such as format 0_0, 0_1, 0_2 as well as the new multi-cell scheduling unicast DCI format 0_3.

[0029] In some embodiments, for DCI format 0_3 for the FDD case, if it is processed by UE in a slot of scheduling cell, it may be counted for all cells within the set of cells regardless of whether all cells within a set are scheduled or not. For the TDD case, the following possibilities can be allowed based on limitation of two unicast DCIs processing per slot of scheduling cell. A first possibility may be that the UE ma process DCI format 0_3 twice for the set of cells 106 during a slot. A second possibility is that if DCI format 0_3 is processed once per set of cells, then legacy DCI formats 0_0, 0_1, 0_2 can be processed once per scheduled cell within a set during a slot. A third possibility is that if no DCI format 0_3 processed for set of cells, then legacy DCI formats 0_0, 0_1, 0_2 can be processed twice per scheduled cell within a set during a slot.

[0030] FIG. 2 illustrates counting for a DCI transmission 202 during a slot 204 using a second approach according to some embodiments. In the illustrated embodiment, if a UE is capable and configured with both multi-cell scheduling and single cell scheduling for DL, and also configured with same subcarrier spacing between scheduling cells and the co-scheduled cells within the set, then the number of unicast DCIs (e.g., DCI format 1_3 206) for a UE to process for the set of cells (set of cells 208) and for each cell (e.g., cell 1, cell 2, cell 3, and cell 4) within the set of cells is equal to one per slot of scheduling cell for DL scheduling for FDD/TDD.

[0031] In the illustrated embodiment, the number of unicast DCIs include both single-cell scheduling legacy unicast DCI formats such as format 1_0, 1_1, 1_2 as well as the new multi-cell scheduling unicast DCI format 1_3. In some embodiments, for DCI format 1_3, if it is processed by UE in a slot 204 of scheduling cell, it is counted for cells within the set of cells that are actually scheduled by the processed DCI format 1_3.

[0032] For instance, in some embodiments, the set of cells 208 may be configured with up to four cells, but the network may schedule less than the number of cells in the set of cells 208. If a cell is scheduled for DCI format 1_3 206, then the DCI count may be set to one and then no more DCIs may be processed for that cell during the slot 204. If a cell is not scheduled for a cell, the DCI format 1_3 may not be counted for that cell, allowing those unscheduled cells to process a legacy unicast DCI format during the slot 204.

[0033] The following possibilities can be supported based on the limitation of one unicast DCI processing per slot of scheduling cell using the illustrated DCI counting technique. In the illustrated embodiment, if DCI format 1_3 206 is processed once for the set of cells 208 and schedule at least a given cell within the set, then the UE is not expected to process legacy DCI format 1_0, 1_1, 1_2 for that given scheduled cell. Further, if DCI format 1_3 206 is processed once for the set of cells and did not schedule at least a given cell within the set, then legacy DCI format 1_0, 1_1, 1_2 can be processed once for that given cell not scheduled for DCI format 1_3. If no DCI format 1_3 206 is processed for the set of cells, then legacy DCI formats 1_0, 1_1, 1_2 can be processed once per scheduled cell within a set of cells 208.

[0034] For example, in the illustrated embodiment, for DL where the same subcarrier spacing is used between scheduling cells and the co-scheduled cells within the set of cells 208, the following is an example of a DCI count. The set of cells 208 includes cell 1, cell 2, cell 3, and cell 4. During the slot 204, cell 1 and cell 2 are scheduled, and cell 3 and cell 4 are unscheduled. Further, during the slot 204, DCI format 1_3 206 is sent to the UE over PDSCH for cell 1 and cell 2. The UE and network node may count the number of unicast DCI processing within a slot for each cell to determine whether additional DCI may be processed. In the illustrated embodiment, cell 1 and cell 2 have a DCI count of one. Therefore, the UE is not expected to process an additional DCI during the slot 204. In contrast, cell 3 and cell 4 are unscheduled and the count is still zero. Thus, the UE may still process a legacy DCI format for cell 3 and cell 4 during the slot 204.

[0035] A similar DCI counting method may be used for UL where the same subcarrier spacing is used between scheduling cells and the co-scheduled cells within the set. If a UE is capable and configured with both multi-cell scheduling and single cell scheduling for UL, and also configured with same subcarrier spacing between scheduling cells and the co-scheduled cells within the set, then the number of unicast DCIs for a UE to process for the set of cells and for each cell within the set of cells may be equal to 1 and 2 per slot of scheduling cell for UL scheduling for FDD and TDD, respectively. The number of unicast DCIs may include both single-cell scheduling legacy unicast DCI formats such as format 0_0, 0_1, 0_2 as well as the new multi-cell scheduling unicast DCI format 0_3.

[0036] In some embodiments, for DCI format 0_3 for the FDD case, if it is processed by UE in a slot of scheduling cell, it may be counted for cells within the set of cells that are actually scheduled by the processed DCI format 0_3.

[0037] For the TDD case, the following possibilities can be allowed based on the limitation of two unicast DCIs processing per slot of scheduling cell. If DCI format 0_3 is processed twice for a set of cells and at least a given cell twice within the set is scheduled, then the UE may not be expected to process any legacy DCI format 0_0, 0_1, 0_2 for that given cell. If DCI format 0_3 is processed twice for a set of cells, and a given cell is scheduled only once within the set, then legacy DCI format 0_0, 0_1, 0_2 can be processed once for that given cell. If DCI format 0_3 is processed twice for a set of cells and at least a given cell was not scheduled even once within the set, then legacy DCI format 0_0, 0_1, 0_2 can be processed twice for that given cell. If DCI format 0_3 is processed once for a set of cells and at least a given cell is scheduled once within the set, then legacy DCI format 0_0, 0_1, 0_2 can be processed once for that given cell. If DCI format 0_3 is processed once for a set of cells and at least a given cell is not scheduled even once within the set, then legacy DCI format 0_0, 0_1, 0_2 can be processed twice for that given cell. If no DCI format 0_3 is processed for a set of cells, then legacy DCI format 0_0, 0_1, 0_2 can be processed twice for each of the scheduled cells within the set.

[0038] In some embodiments, if a UE is capable and configured with both multi-cell scheduling and single cell scheduling for DL, and also configured with same subcarrier spacing between scheduling cells and the co-scheduled cells within the set, then the following limitations may be used for DL scheduling for FDD/TDD. The number of new DCI format 1_3 for a UE to process for the set of cells may be equal to one per slot of scheduling cell. The number of legacy unicast DCI formats 1_0, 1_1, 1_2 to process for each cell within the set of cells may be equal to one per slot of scheduling. The total number of new and legacy DCI formats for a UE to process for the set of cells may not be more than the number of cells within the set.

[0039] For example, in some embodiments, if there are four cells within a set, then within a slot of the scheduling cell the total number of DCI formats that can be processed by the UE may be no more than four. For instance, DCI format 1_3 can be processed once by UE, and the legacy DCI format 1_0, 1_1, 1_2 can be processed once by UE, but the total number of DCI formats that can be processed by UE may be no more than four for a set with four cells. For example, the network node may send the new DCI format 1_3 and three unicast DCIs with legacy formats 1_0, 1_1, and/or 1_2.

[0040] In some embodiments, a similar procedure may be used for DCI counting for UL. If a UE is capable and configured with both multi-cell scheduling and single cell scheduling for UL, and also configured with the same subcarrier spacing between scheduling cells and the co-scheduled cells within the set, then the following limitations may be used for UL scheduling for FDD. The number of new DCI format 0_3 for a UE to process for the set of cells may be equal to one per slot of scheduling cell. The number of legacy unicast DCI formats 0_0, 0_1, 0_2 to process for each cell within the set of cells may be equal to one per slot of scheduling. The total number of new and legacy DCI formats for a UE to process for the set of cells may be not more than the number of cells within the set.

[0041] Further, the following limitations may be used for UL scheduling for TDD. The number of new DCI format 0_3 for a UE to process for the set of cells may be equal to two per slot of a scheduling cell. The number of legacy unicast DCI formats 0_0, 0_1, 0_2 to process for each cell within the set of cells may be equal to two per slot of scheduling. The total number of new and legacy DCI formats for a UE to process for the set of cells may not be more than two times the number of cells within the set.

[0042] For example, if there are four cells within a set, then within a slot of the scheduling cell for TDD, the DCI format 0_3 can potentially be processed twice for each cell by the UE. Further, the legacy DCI format 0_0, 0_1, 0_2 can potentially be processed twice for each cell by the UE. However, the total number of DCI formats that can be processed by UE may be no more than 8 (e.g., twice the number of cells within the set).

[0043] FIG. 3 illustrates a set of cells 302 where cell 1 is the scheduling cell and is also part of the set of cells 302. In some embodiments, if a UE is capable and configured with both multi-cell scheduling and single cell scheduling for DL and/or UL, and if the same subcarrier spacing between scheduling cells and the co-scheduled cells within the set is configured, and if the scheduling cell (e.g., cell 1) is included within the set of cells 302, then the number of total unicast DCIs that can be processed for self-scheduling of the scheduling cell within the set can be different than the other cells within the set.

[0044] For example, in some embodiments, if DCI format 0_3 or 1_3 is processed once (maximum allowed number) by a UE for a set of cells, then legacy DCI format can be processed once for the scheduling cell (e.g., cell 1), but not for any other cell within the set of cells 106. For instance, in the illustrated embodiment, a higher budget may be provided for cell 1 than for cells 2-4. The higher budget may allow the UE to process both the DCI format 0_3 or 1_3 and a legacy DCI format for cell 1.

[0045] In some embodiments, for the scenario involving different SCS between scheduling cell and the co-scheduled cells within the set of cells, scaling may be used to determine the number of unicast DCI's that can be processed by the UE. Scaling of the number of DCIs for the different SCS scenario may be combined with any of the other embodiments described herein with the same SCS between scheduling cell and the co-scheduled cells within the set of cells. For instance, instead of being limited to one unicast DCI processing (e.g., embodiments discussed with reference to FIG. 1 and FIG. 2) the UE may have a scaled number of DCI's that it can process.

[0046] In one example, in case of lower-to-higher SCS between scheduling cell and scheduled cells, for a SCS combination (15kHz,60kHz), the number of DCI's that can be processed can be scaled by four times and the DCI counting procedures described with respect to other embodiments can be applied directly. In another example, in case of higher-to-lower SCS between scheduling cell and scheduled cells, for a SCS combination (30kHz, 15kHz), the limitation of number of unicast DCI processing can be scaled for N = 2 slots (i.e., one unicast DCI processing by UE in two consecutive slots).

[0047] FIG. 4 illustrates a method 400 of operation for a network node in accordance with some embodiments. The method 400 includes scheduling 402 a PDSCH during a slot for one or more cells within a set of cells of a scheduling cell. The method 400 includes determining 404 a DCI count for the slot for user equipment devices. The method 400 includes determining 406, based on the DCI count, available processing capability for unicast DCI formats during the slot for multi-cell scheduling and single-cell scheduling, wherein the available processing capability is determined for the set of cells and each cell within the set of cells. Based on a determination of the available processing capability of the user equipment devices, encoding 408 one or more unicast DCI format for transmission during the slot, via a physical downlink control channel (PDCCH). The method 400 includes transmitting 410 the PDCCH to the user equipment devices associated with the one or more scheduled cells.

[0048] In some embodiments, the unicast DCI formats includes single-cell scheduling legacy unicast DCI formats 0_0 or 0_1 or 0_2 for Physical Downlink Shared Channel (PDSCH) scheduling and unicast DCI formats 1_0 or 1_1 or 1_2 for Physical Uplink Shared Channel (PUSCH) scheduling.

[0049] In some embodiments, the multi-cell scheduling unicast DCI format is DCI format 1_3 for PDSCH scheduling and DCI format 0_3 for PUSCH scheduling.

[0050] In some embodiments, if a same subcarrier spacing is used for the scheduling cell and the scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one unicast DCI per slot of the scheduling cell for downlink scheduling for FDD and TDD. In some embodiments when determining the available processing capability, if the DCI format 1_3 is processed by the user equipment devices, the DCI format 1_3 is counted against the available processing capability for both the scheduled cells and the unscheduled cells within the set of cells.

[0051] In some embodiments, if a same subcarrier spacing is used for the scheduling cell and the scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one per slot of the scheduling cell for uplink scheduling for frequency division duplexing (FDD), and two per slot of the scheduling cell for the uplink scheduling for time division duplexing (TDD). In some embodiments, when determining the available processing, if the DCI format 0_3 is processed by the user equipment devices, the DCI format 0_3 is counted against the available processing capability for both the scheduled cells and the unscheduled cells within the set of cells.

[0052] In some embodiments, if the DCI format 1_3 is processed by the user equipment devices, the DCI format 1_3 is counted against the available processing capability for only the scheduled cells and not the unscheduled cells within the set of cells.

[0053] In some embodiments, the DCI format 0_3 is processed by the user equipment devices, the DCI format 0_3 is counted against the available processing capability for only the scheduled cells and not the unscheduled cells within the set of cells.

[0054] In some embodiments, the multi-cell scheduling unicast DCI format is DCI format 1_3, and wherein if a total number of DCI formats for the user equipment devices to process for the set of cells is not more than a number of cells within the set of cells.

[0055] In some embodiments, the multi-cell scheduling unicast DCI format is DCI format 0_3, and wherein if a total number of DCI formats for the user equipment devices to process for the set of cells is not more than two times a number of cells within the set of cells.

[0056] In some embodiments, if the scheduling cell is included within the set of cells, then a number of total unicast DCIs that can be processed for self-scheduling of the scheduling cell within the set of cells is different than other cells within the set of cells.

[0057] In some embodiments, a number of unicast DCIs that can be processed by the user equipment devices is scaled when a different subcarrier spacing is used for the scheduling cell and the scheduled cells within the set of cells.

[0058] Embodiments contemplated herein include an apparatus comprising means to perform one or more elements of the method 400. This apparatus may be, for example, an apparatus of a base station (such as a network device 718 that is a base station, as described herein).

[0059] Embodiments contemplated herein include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of the method 400. This non-transitory computer-readable media may be, for example, a memory of a base station (such as a memory 722 of a network device 718 that is a base station, as described herein).

[0060] Embodiments contemplated herein include an apparatus comprising logic, modules, or circuitry to perform one or more elements of the method 400. This apparatus may be, for example, an apparatus of a base station (such as a network device 718 that is a base station, as described herein).

[0061] Embodiments contemplated herein include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform one or more elements of the method 400. This apparatus may be, for example, an apparatus of a base station (such as a network device 718 that is a base station, as described herein).

[0062] Embodiments contemplated herein include a signal as described in or related to one or more elements of the method 400.

[0063] Embodiments contemplated herein include a computer program or computer program product comprising instructions, wherein execution of the program by a processing element is to cause the processing element to carry out one or more elements of the method 400. The processor may be a processor of a base station (such as a processor(s) 720 of a network device 718 that is a base station, as described herein). These instructions may be, for example, located in the processor and/or on a memory of the base station (such as a memory 722 of a network device 718 that is a base station, as described herein).

[0064] FIG. 5 illustrates a method for operating a UE in accordance with some embodiments. The method 500 includes determining 502 a DCI count for a slot. The method 500 includes determining 504 based on the DCI count, available processing capability for unicast DCI formats during the slot for multi-cell scheduling and single-cell scheduling, wherein the available processing capability is determined for a set of cells and each cell within the set of cells. The method 500 includes, based on a determination of the available processing capability, preparing 506 to receive and process a unicast DCI format from a network node during the slot, via a physical downlink control channel (PDCCH).

[0065] In some embodiments, the unicast DCI formats includes single-cell scheduling legacy unicast DCI formats 0_0 or 0_1 or 0_2 for Physical Downlink Shared Channel (PDSCH) scheduling and unicast DCI formats 1_0 or 1_1 or 1_2 for Physical Uplink Shared Channel (PUSCH) scheduling.

[0066] In some embodiments, the multi-cell scheduling unicast DCI format is DCI format 1_3 for PDSCH scheduling and DCI format 0_3 for PUSCH scheduling.

[0067] In some embodiments, if a same subcarrier spacing is used for the scheduling cell and the scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one unicast DCI per slot of the scheduling cell for downlink scheduling for FDD and TDD. In some embodiments when determining the available processing capability, if the DCI format 1_3 is processed by the user equipment devices, the DCI format 1_3 is counted against the available processing capability for both the scheduled cells and the unscheduled cells within the set of cells.

[0068] In some embodiments, if a same subcarrier spacing is used for the scheduling cell and the scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one per slot of the scheduling cell for uplink scheduling for frequency division duplexing (FDD), and two per slot of the scheduling cell for the uplink scheduling for time division duplexing (TDD). In some embodiments, when determining the available processing, if the DCI format 0_3 is processed by the user equipment devices, the DCI format 0_3 is counted against the available processing capability for both the scheduled cells and the unscheduled cells within the set of cells.

[0069] In some embodiments, if the DCI format 1_3 is processed by the user equipment devices, the DCI format 1_3 is counted against the available processing capability for the scheduled cells and not the unscheduled cells within the set of cells.

[0070] In some embodiments, the DCI format 0_3 is processed by the user equipment devices, the DCI format 0_3 is counted against the available processing capability for the scheduled cells and not the unscheduled cells within the set of cells.

[0071] In some embodiments, the multi-cell scheduling unicast DCI format is DCI format 1_3, and wherein if a total number of DCI formats for the user equipment devices to process for the set of cells is not more than a number of cells within the set of cells.

[0072] In some embodiments, the multi-cell scheduling unicast DCI format is DCI format 0_3, and wherein if a total number of DCI formats for the user equipment devices to process for the set of cells is not more than two times a number of cells within the set of cells.

[0073] In some embodiments, if the scheduling cell is included within the set of cells, then a number of total unicast DCIs that can be processed for self-scheduling of the scheduling cell within the set of cells is different than other cells within the set of cells.

[0074] In some embodiments, a number of unicast DCIs that can be processed by the user equipment devices is scaled when a different subcarrier spacing is used for the scheduling cell and the scheduled cells within the set of cells.

[0075] Embodiments contemplated herein include an apparatus comprising means to perform one or more elements of the method 500. This apparatus may be, for example, an apparatus of a UE (such as a wireless device 702 that is a UE, as described herein).

[0076] Embodiments contemplated herein include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of the method 500. This non-transitory computer-readable media may be, for example, a memory of a UE (such as a memory 706 of a wireless device 702 that is a UE, as described herein).

[0077] Embodiments contemplated herein include an apparatus comprising logic, modules, or circuitry to perform one or more elements of the method 500. This apparatus may be, for example, an apparatus of a UE (such as a wireless device 702 that is a UE, as described herein).

[0078] Embodiments contemplated herein include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform one or more elements of the method 500. This apparatus may be, for example, an apparatus of a UE (such as a wireless device 702 that is a UE, as described herein).

[0079] Embodiments contemplated herein include a signal as described in or related to one or more elements of the method 500.

[0080] Embodiments contemplated herein include a computer program or computer program product comprising instructions, wherein execution of the program by a processor is to cause the processor to carry out one or more elements of the method 500. The processor may be a processor of a UE (such as a processor(s) 704 of a wireless device 702 that is a UE, as described herein). These instructions may be, for example, located in the processor and/or on a memory of the UE (such as a memory 706 of a wireless device 702 that is a UE, as described herein).

[0081] FIG. 6 illustrates an example architecture of a wireless communication system 600, according to embodiments disclosed herein. The following description is provided for an example wireless communication system 600 that operates in conjunction with the LTE system standards and/or 5G or NR system standards as provided by 3GPP technical specifications.

[0082] As shown by FIG. 6, the wireless communication system 600 includes UE 602 and UE 604 (although any number of UEs may be used). In this example, the UE 602 and the UE 604 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device configured for wireless communication.

[0083] The UE 602 and UE 604 may be configured to communicatively couple with a RAN 606. In embodiments, the RAN 606 may be NG-RAN, E-UTRAN, etc. The UE 602 and UE 604 utilize connections (or channels) (shown as connection 608 and connection 610, respectively) with the RAN 606, each of which comprises a physical communications interface. The RAN 606 can include one or more base stations (such as base station 612 and base station 614) that enable the connection 608 and connection 610.

[0084] In this example, the connection 608 and connection 610 are air interfaces to enable such communicative coupling, and may be consistent with RAT(s) used by the RAN 606, such as, for example, an LTE and/or NR.

[0085] In some embodiments, the UE 602 and UE 604 may also directly exchange communication data via a sidelink interface 616. The UE 604 is shown to be configured to access an access point (shown as AP 618) via connection 620. By way of example, the connection 620 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 618 may comprise a Wi-Fi® router. In this example, the AP 618 may be connected to another network (for example, the Internet) without going through a CN 624.

[0086] In embodiments, the UE 602 and UE 604 can be configured to communicate using orthogonal frequency division multiplexing (OFDM) communication signals with each other or with the base station 612 and/or the base station 614 over a multicarrier communication channel in accordance with various communication techniques, such as, but not limited to, an orthogonal frequency division multiple access (OFDMA) communication technique (e.g., for downlink communications) or a single carrier frequency division multiple access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[0087] In some embodiments, all or parts of the base station 612 or base station 614 may be implemented as one or more software entities running on server computers as part of a virtual network. In addition, or in other embodiments, the base station 612 or base station 614 may be configured to communicate with one another via interface 622. In embodiments where the wireless communication system 600 is an LTE system (e.g., when the CN 624 is an EPC), the interface 622 may be an X2 interface. The X2 interface may be defined between two or more base stations (e.g., two or more eNBs and the like) that connect to an EPC, and/or between two eNBs connecting to the EPC. In embodiments where the wireless communication system 600 is an NR system (e.g., when CN 624 is a 5GC), the interface 622 may be an Xn interface. The Xn interface is defined between two or more base stations (e.g., two or more gNBs and the like) that connect to 5GC, between a base station 612 (e.g., a gNB) connecting to 5GC and an eNB, and/or between two eNBs connecting to 5GC (e.g., CN 624).

[0088] The RAN 606 is shown to be communicatively coupled to the CN 624. The CN 624 may comprise one or more network elements 626, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UE 602 and UE 604) who are connected to the CN 624 via the RAN 606. The components of the CN 624 may be implemented in one physical device or separate physical devices including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium).

[0089] In embodiments, the CN 624 may be an EPC, and the RAN 606 may be connected with the CN 624 via an S1 interface 628. In embodiments, the S1 interface 628 may be split into two parts, an S1 user plane (S1-U) interface, which carries traffic data between the base station 612 or base station 614 and a serving gateway (S-GW), and the S1-MME interface, which is a signaling interface between the base station 612 or base station 614 and mobility management entities (MMEs).

[0090] In embodiments, the CN 624 may be a 5GC, and the RAN 606 may be connected with the CN 624 via an NG interface 628. In embodiments, the NG interface 628 may be split into two parts, an NG user plane (NG-U) interface, which carries traffic data between the base station 612 or base station 614 and a user plane function (UPF), and the S1 control plane (NG-C) interface, which is a signaling interface between the base station 612 or base station 614 and access and mobility management functions (AMFs).

[0091] Generally, an application server 630 may be an element offering applications that use internet protocol (IP) bearer resources with the CN 624 (e.g., packet switched data services). The application server 630 can also be configured to support one or more communication services (e.g., VoIP sessions, group communication sessions, etc.) for the UE 602 and UE 604 via the CN 624. The application server 630 may communicate with the CN 624 through an IP communications interface 632.

[0092] FIG. 7 illustrates a system 700 for performing signaling 734 between a wireless device 702 and a network device 718, according to embodiments disclosed herein. The system 700 may be a portion of a wireless communications system as herein described. The wireless device 702 may be, for example, a UE of a wireless communication system. The network device 718 may be, for example, a base station (e.g., an eNB or a gNB) of a wireless communication system.

[0093] The wireless device 702 may include one or more processor(s) 704. The processor(s) 704 may execute instructions such that various operations of the wireless device 702 are performed, as described herein. The processor(s) 704 may include one or more baseband processors implemented using, for example, a central processing unit (CPU), a digital signal processor (DSP), an application specific integrated circuit (ASIC), a controller, a field programmable gate array (FPGA) device, another hardware device, a firmware device, or any combination thereof configured to perform the operations described herein.

[0094] The wireless device 702 may include a memory 706. The memory 706 may be a non-transitory computer-readable storage medium that stores instructions 708 (which may include, for example, the instructions being executed by the processor(s) 704). The instructions 708 may also be referred to as program code or a computer program. The memory 706 may also store data used by, and results computed by, the processor(s) 704.

[0095] The wireless device 702 may include one or more transceiver(s) 710 that may include radio frequency (RF) transmitter circuitry and/or receiver circuitry that use the antenna(s) 712 of the wireless device 702 to facilitate signaling (e.g., the signaling 734) to and/or from the wireless device 702 with other devices (e.g., the network device 718) according to corresponding RATs.

[0096] The wireless device 702 may include one or more antenna(s) 712 (e.g., one, two, four, or more). For embodiments with multiple antenna(s) 712, the wireless device 702 may leverage the spatial diversity of such multiple antenna(s) 712 to send and/or receive multiple different data streams on the same time and frequency resources. This behavior may be referred to as, for example, multiple input multiple output (MIMO) behavior (referring to the multiple antennas used at each of a transmitting device and a receiving device that enable this aspect). MIMO transmissions by the wireless device 702 may be accomplished according to precoding (or digital beamforming) that is applied at the wireless device 702 that multiplexes the data streams across the antenna(s) 712 according to known or assumed channel characteristics such that each data stream is received with an appropriate signal strength relative to other streams and at a desired location in the spatial domain (e.g., the location of a receiver associated with that data stream). Certain embodiments may use single user MIMO (SU-MIMO) methods (where the data streams are all directed to a single receiver) and/or multi user MIMO (MU-MIMO) methods (where individual data streams may be directed to individual (different) receivers in different locations in the spatial domain).

[0097] In certain embodiments having multiple antennas, the wireless device 702 may implement analog beamforming techniques, whereby phases of the signals sent by the antenna(s) 712 are relatively adjusted such that the (joint) transmission of the antenna(s) 712 can be directed (this is sometimes referred to as beam steering).

[0098] The wireless device 702 may include one or more interface(s) 714. The interface(s) 714 may be used to provide input to or output from the wireless device 702. For example, a wireless device 702 that is a UE may include interface(s) 714 such as microphones, speakers, a touchscreen, buttons, and the like in order to allow for input and/or output to the UE by a user of the UE. Other interfaces of such a UE may be made up of transmitters, receivers, and other circuitry (e.g., other than the transceiver(s) 710/antenna(s) 712 already described) that allow for communication between the UE and other devices and may operate according to known protocols (e.g., Wi-Fi®, Bluetooth®, and the like).

[0099] The wireless device 702 may include a DCI module 716. The DCI module 716 may be implemented via hardware, software, or combinations thereof. For example, the DCI module 716 may be implemented as a processor, circuit, and/or instructions 708 stored in the memory 706 and executed by the processor(s) 704. In some examples, the DCI module 716 may be integrated within the processor(s) 704 and/or the transceiver(s) 710. For example, the DCI module 716 may be implemented by a combination of software components (e.g., executed by a DSP or a general processor) and hardware components (e.g., logic gates and circuitry) within the processor(s) 704 or the transceiver(s) 710.

[0100] The DCI module 716 may be used for various aspects of the present disclosure, for example, aspects of FIGS. 1-6. The DCI module 716 is configured to receive, process, and count DCI.

[0101] The network device 718 may include one or more processor(s) 720. The processor(s) 720 may execute instructions such that various operations of the network device 718 are performed, as described herein. The processor(s) 720 may include one or more baseband processors implemented using, for example, a CPU, a DSP, an ASIC, a controller, an FPGA device, another hardware device, a firmware device, or any combination thereof configured to perform the operations described herein.

[0102] The network device 718 may include a memory 722. The memory 722 may be a non-transitory computer-readable storage medium that stores instructions 724 (which may include, for example, the instructions being executed by the processor(s) 720). The instructions 724 may also be referred to as program code or a computer program. The memory 722 may also store data used by, and results computed by, the processor(s) 720.

[0103] The network device 718 may include one or more transceiver(s) 726 that may include RF transmitter circuitry and/or receiver circuitry that use the antenna(s) 728 of the network device 718 to facilitate signaling (e.g., the signaling 734) to and/or from the network device 718 with other devices (e.g., the wireless device 702) according to corresponding RATs.

[0104] The network device 718 may include one or more antenna(s) 728 (e.g., one, two, four, or more). In embodiments having multiple antenna(s) 728, the network device 718 may perform MIMO, digital beamforming, analog beamforming, beam steering, etc., as has been described.

[0105] The network device 718 may include one or more interface(s) 730. The interface(s) 730 may be used to provide input to or output from the network device 718. For example, a network device 718 that is a base station may include interface(s) 730 made up of transmitters, receivers, and other circuitry (e.g., other than the transceiver(s) 726/antenna(s) 728 already described) that enables the base station to communicate with other equipment in a core network, and/or that enables the base station to communicate with external networks, computers, databases, and the like for purposes of operations, administration, and maintenance of the base station or other equipment operably connected thereto.

[0106] The network device 718 may include a DCI module 732. The DCI module 732 may be implemented via hardware, software, or combinations thereof. For example, the DCI module 732 may be implemented as a processor, circuit, and/or instructions 724 stored in the memory 722 and executed by the processor(s) 720. In some examples, the DCI module 732 may be integrated within the processor(s) 720 and/or the transceiver(s) 726. For example, the DCI module 732 may be implemented by a combination of software components (e.g., executed by a DSP or a general processor) and hardware components (e.g., logic gates and circuitry) within the processor(s) 720 or the transceiver(s) 726.

[0107] The DCI module 732 may be used for various aspects of the present disclosure, for example, aspects of FIGS. 1-6. The DCI module 732 is configured to determine limitations on unicast DCI processing with multi-cell and single-cell scheduling, and transmit DCI according to those limitations.

[0108] For one or more embodiments, at least one of the components set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques, processes, and/or methods as set forth herein. For example, a baseband processor as described herein in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth herein. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth herein.

[0109] Any of the above described embodiments may be combined with any other embodiment (or combination of embodiments), unless explicitly stated otherwise. The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

[0110] Embodiments and implementations of the systems and methods described herein may include various operations, which may be embodied in machine-executable instructions to be executed by a computer system. A computer system may include one or more general-purpose or special-purpose computers (or other electronic devices). The computer system may include hardware components that include specific logic for performing the operations or may include a combination of hardware, software, and/or firmware.

[0111] It should be recognized that the systems described herein include descriptions of specific embodiments. These embodiments can be combined into single systems, partially combined into other systems, split into multiple systems or divided or combined in other ways. In addition, it is contemplated that parameters, attributes, aspects, etc. of one embodiment can be used in another embodiment. The parameters, attributes, aspects, etc. are merely described in one or more embodiments for clarity, and it is recognized that the parameters, attributes, aspects, etc. can be combined with or substituted for parameters, attributes, aspects, etc. of another embodiment unless specifically disclaimed herein.

[0112] It is well understood that the use of personally identifiable information should follow privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining the privacy of users. In particular, personally identifiable information data should be managed and handled so as to minimize risks of unintentional or unauthorized access or use, and the nature of authorized use should be clearly indicated to users.

[0113] Although the foregoing has been described in some detail for purposes of clarity, it will be apparent that certain changes and modifications may be made without departing from the principles thereof. It should be noted that there are many alternative ways of implementing both the processes and apparatuses described herein. Accordingly, the present embodiments are to be considered illustrative and not restrictive, and the description is not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

CLAIMS

1. A method of operation for a user equipment (UE), the method comprising:

determining a Downlink Control information (DCI) count for a slot;

determining, based on the DCI count, available processing capability for unicast DCI formats during the slot for multi-cell scheduling and single-cell scheduling, wherein the available processing capability is determined for a set of cells and each cell within the set of cells; and

based on a determination of the available processing capability, preparing to receive and process a unicast DCI format from a network node during the slot, via a physical downlink control channel (PDCCH).

2. The method of claim 1, wherein the unicast DCI formats includes single-cell scheduling legacy unicast DCI formats 0_0 or 0_1 or 0_2 for Physical Downlink Shared Channel (PDSCH) scheduling and unicast DCI formats 1_0 or 1_1 or 1_2 for Physical Uplink Shared Channel (PUSCH) scheduling.

3. The method of claim 1, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3 for Physical Downlink Shared Channel (PDSCH) scheduling or DCI format 0_3 for Physical Uplink Shared Channel (PUSCH) scheduling.

4. The method of claim 1, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3;

wherein if a same subcarrier spacing is used for a scheduling cell and scheduled cells within the set of cells, then the available processing capability for the UE is equal to one unicast DCI per slot of the scheduling cell for downlink scheduling for frequency division duplexing (FDD) and time division duplexing (TDD); and

wherein when determining the available processing capability, if the DCI format 1_3 is processed by the UE, the DCI format 1_3 is counted against the available processing capability for both the scheduled cells and unscheduled cells within the set of cells.

5. The method of claim 1, wherein the multi-cell scheduling unicast DCI format is DCI format 0_3;

wherein if a same subcarrier spacing is used for a scheduling cell and scheduled cells within the set of cells, then the available processing capability for the UE is equal to one per slot of the scheduling cell for uplink scheduling for frequency division duplexing (FDD), and two per slot of the scheduling cell for the uplink scheduling for time division duplexing (TDD); and

wherein when determining the available processing capability, if the DCI format 0_3 is processed by the UE, the DCI format 0_3 is counted against the available processing capability for both the scheduled cells and unscheduled cells within the set of cells.

6. The method of claim 1, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3;

wherein if a same subcarrier spacing is used for a scheduling cell and scheduled cells within the set of cells, then the available processing capability for the UE is equal to one unicast DCI per slot of the scheduling cell for downlink scheduling for frequency division duplexing (FDD) and time division duplexing (TDD); and

wherein when determining the available processing, if the DCI format 1_3 is processed by the UE, the DCI format 1_3 is counted against the available processing capability for the scheduled cells and not unscheduled cells within the set of cells.

7. The method of claim 1, wherein the multi-cell scheduling unicast DCI format is DCI format 0_3;

wherein if a same subcarrier spacing is used for a scheduling cell and scheduled cells within the set of cells, then the available processing capability for the UE is equal to one per slot of the scheduling cell for uplink scheduling for frequency division duplexing (FDD), and two per slot of the scheduling cell for the uplink scheduling for time division duplexing (TDD); and

wherein when determining the available processing, if the DCI format 0_3 is processed by the UE, the DCI format 0_3 is counted against the available processing capability for the scheduled cells and not unscheduled cells within the set of cells.

8. The method of claim 1, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3, and wherein if a total number of DCI formats for the UE to process for the set of cells is not more than a number of cells within the set of cells.

9. The method of claim 1, wherein the multi-cell scheduling unicast DCI format is DCI format 0_3, and wherein if a total number of DCI formats for the UE to process for the set of cells is not more than two times a number of cells within the set of cells.

10. The method of claim 1, wherein if a scheduling cell is included within the set of cells, then a number of total unicast DCIs that can be processed for self-scheduling of the scheduling cell within the set of cells is different than other cells within the set of cells.

11. The method of claim 1, wherein a number of unicast DCIs that can be processed by the UE is scaled when a different subcarrier spacing is used for a scheduling cell and scheduled cells within the set of cells.

12. A method of operation for a network node, the method comprising:

scheduling a physical downlink shared channel (PDSCH) during a slot for one or more cells within a set of cells of a scheduling cell;

determining a Downlink Control information (DCI) count for the slot for user equipment devices;

determining, based on the DCI count, available processing capability for unicast DCI formats during the slot for multi-cell scheduling and single-cell scheduling, wherein the available processing capability is determined for the set of cells and each cell within the set of cells; and

based on a determination of the available processing capability of the user equipment devices, encoding one or more unicast DCI format for transmission during the slot, via a physical downlink control channel (PDCCH).

13. The method of claim 12, wherein the additional unicast DCI formats includes single-cell scheduling legacy unicast DCI formats 0_0 or 0_1 or 0_2 for Physical Downlink Shared Channel (PDSCH) scheduling and unicast DCI formats 1_0 or 1_1 or 1_2 for Physical Uplink Shared Channel (PUSCH) scheduling.

14. The method of claim 12, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3 for Physical Downlink Shared Channel (PDSCH) scheduling or DCI format 0_3 for Physical Uplink Shared Channel (PUSCH) scheduling.

15. The method of claim 12, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3;

wherein if a same subcarrier spacing is used for the scheduling cell and scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one unicast DCI per slot of the scheduling cell for downlink scheduling for frequency division duplexing (FDD) and time division duplexing (TDD); and

wherein when determining the available processing capability, if the DCI format 1_3 is processed by the user equipment devices, the DCI format 1_3 is counted against the available processing capability for both the scheduled cells and unscheduled cells within the set of cells.

16. The method of claim 12, wherein the multi-cell scheduling unicast DCI format is DCI format 0_3;

wherein if a same subcarrier spacing is used for the scheduling cell and scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one per slot of the scheduling cell for uplink scheduling for frequency division duplexing (FDD), and two per slot of the scheduling cell for the uplink scheduling for time division duplexing (TDD); and

wherein when determining the available processing capability, if the DCI format 0_3 is processed by the user equipment devices, the DCI format 0_3 is counted against the available processing capability for both the scheduled cells and unscheduled cells within the set of cells.

17. The method of claim 12, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3;

wherein if a same subcarrier spacing is used for the scheduling cell and scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one unicast DCI per slot of the scheduling cell for downlink scheduling for frequency division duplexing (FDD) and time division duplexing (TDD); and

wherein when determining the available processing capability, if the DCI format 1_3 is processed by the user equipment devices, the DCI format 1_3 is counted against the available processing capability for the scheduled cells and not unscheduled cells within the set of cells.

18. The method of claim 12, wherein the multi-cell scheduling unicast DCI format is DCI format 0_3;

wherein if a same subcarrier spacing is used for the scheduling cell and scheduled cells within the set of cells, then the available processing capability for the user equipment devices is equal to one per slot of the scheduling cell for uplink scheduling for frequency division duplexing (FDD), and two per slot of the scheduling cell for the uplink scheduling for time division duplexing (TDD); and

wherein when determining the available processing, if the DCI format 0_3 is processed by the user equipment devices, the DCI format 0_3 is counted against the available processing capability for the scheduled cells and not unscheduled cells within the set of cells.

19. The method of claim 12, wherein the multi-cell scheduling unicast DCI format is DCI format 1_3, and wherein if a total number of DCI formats for the user equipment devices to process for the set of cells is not more than a number of cells within the set of cells.

20. The method of claim 12, wherein the multi-cell scheduling unicast DCI format is DCI format 0_3, and wherein if a total number of DCI formats for the user equipment devices to process for the set of cells is not more than two times a number of cells within the set of cells.

21. The method of claim 12, wherein if the scheduling cell is included within the set of cells, then a number of total unicast DCIs that can be processed for self-scheduling of the scheduling cell within the set of cells is different than other cells within the set of cells.

22. The method of claim 12, wherein a number of unicast DCIs that can be processed by the user equipment devices is scaled when a different subcarrier spacing is used for the scheduling cell and scheduled cells within the set of cells.

23. An apparatus comprising means to perform the method of any of claim 1 to claim 22.

24. A computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform the method of any of claim 1 to claim 22.

25. An apparatus comprising logic, modules, or circuitry to perform the method of any of claim 1 to claim 22.

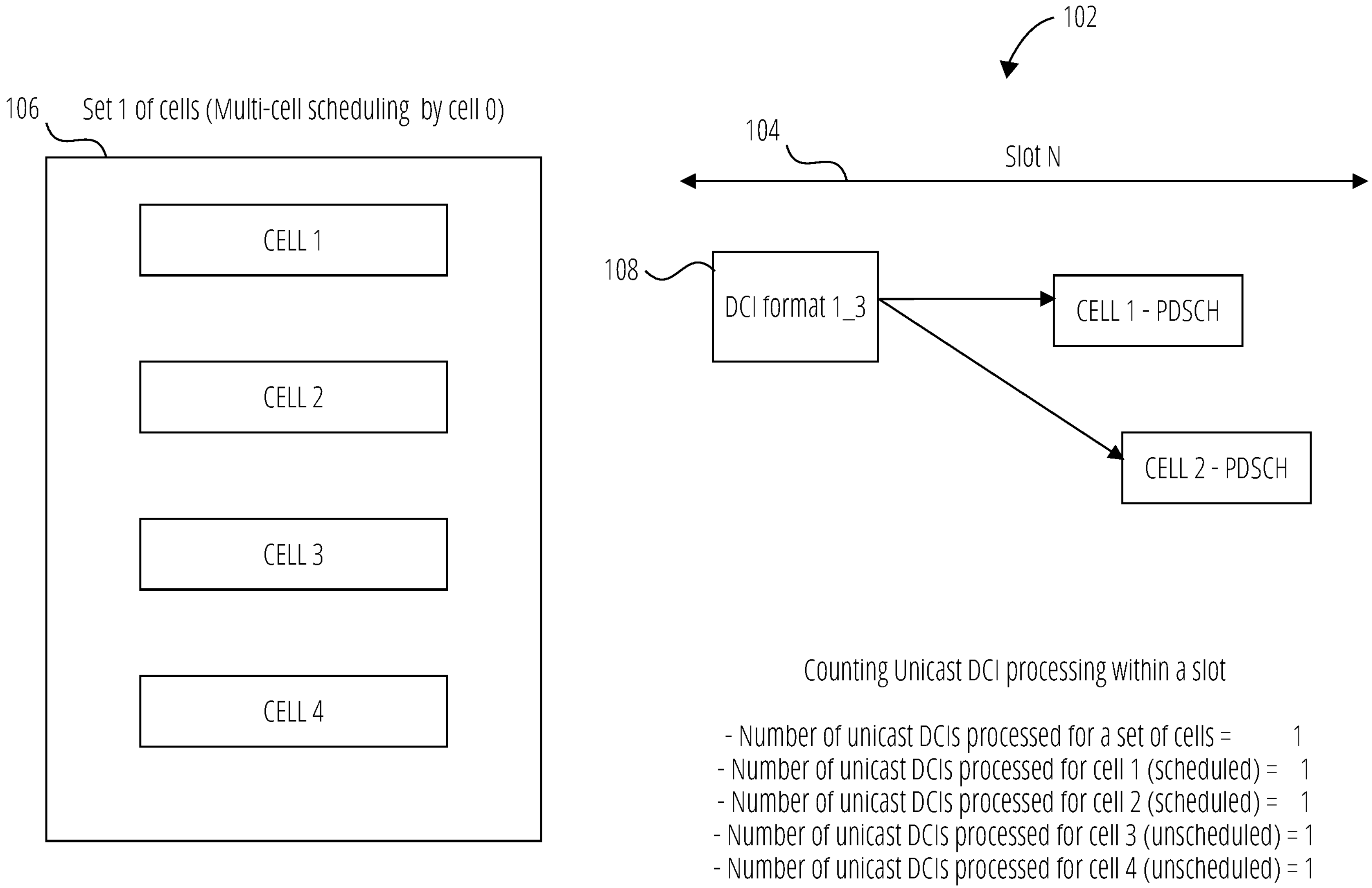
102
106
Set 1 of cells (Multi-cell scheduling by cell 0)
CELL 1
CELL 2
CELL 3
CELL 4
104
Slot N
108
DCI format 1_3
CELL 1 - PDSCH
CELL 2 - PDSCH
Counting Unicast DCI processing within a slot
- Number of unicast DCIs processed for a set of cells = 1
- Number of unicast DCIs processed for cell 1 (scheduled) = 1
- Number of unicast DCIs processed for cell 2 (scheduled) = 1
- Number of unicast DCIs processed for cell 3 (unscheduled) = 1
- Number of unicast DCIs processed for cell 4 (unscheduled) = 1

FIG. 1

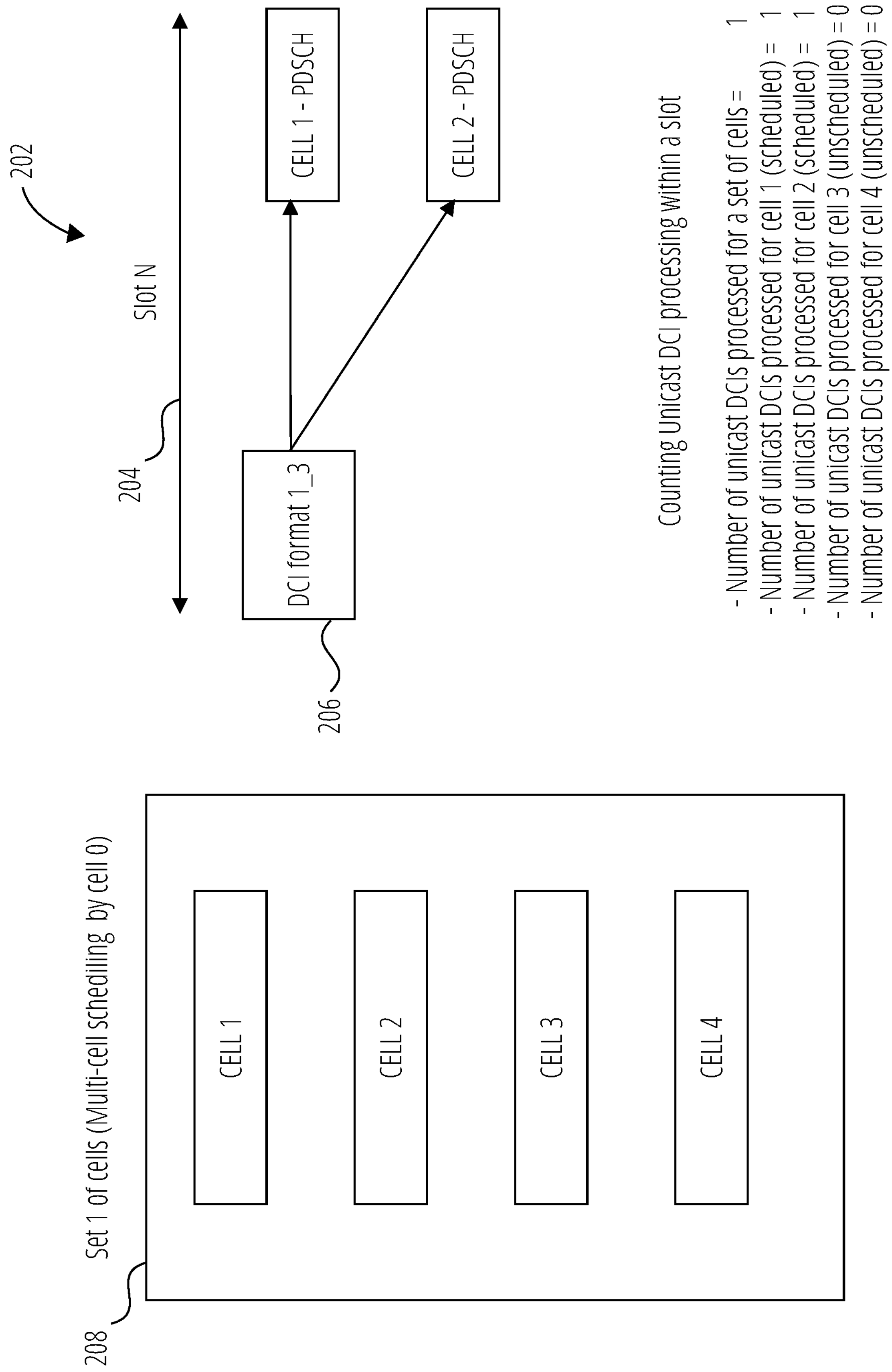
202
Slot N
204
CELL 1 - PDSCH
CELL 2 - PDSCH
DCI format 1_3
206
Counting Unicast DCI processing within a Slot
- Number of unicast DCIs processed for a set of cells = 1
- Number of unicast DCIs processed for cell 1 (scheduled) = 1
- Number of unicast DCIs processed for cell 2 (scheduled) = 1
- Number of unicast DCIs processed for cell 3 (unscheduled) = 0
- Number of unicast DCIs processed for cell 4 (unscheduled) = 0
208
Set 1 of cells (Multi-cell schediling by cell 0)
CELL 1
CELL 2
CELL 3
CELL 4

FIG. 2

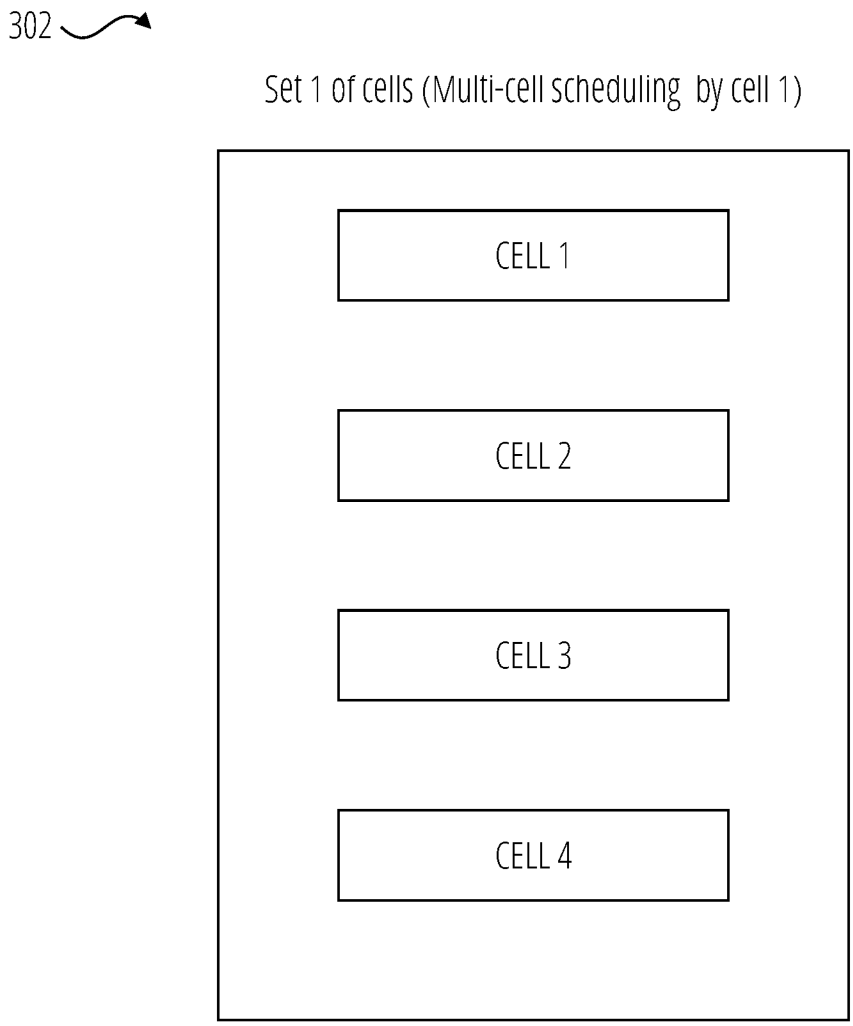
302
Set 1 of cells (Multi-cell scheduling by cell 1)
CELL 1
CELL 2
CELL 3
CELL 4

FIG. 3

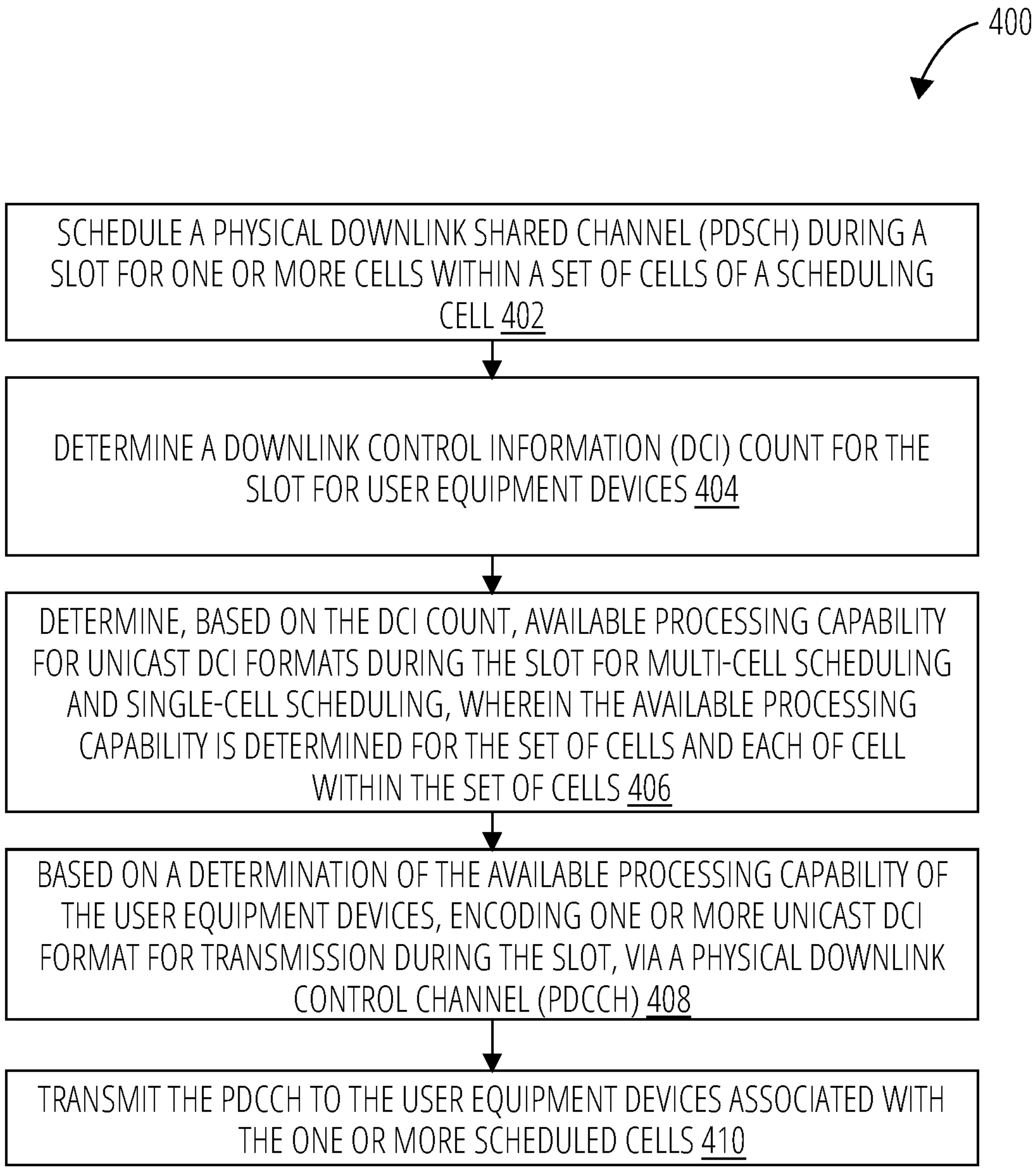
400
SCHEDULE A PHYSICAL DOWNLINK SHARED CHANNEL (PDSCH) DURING A SLOT FOR ONE OR MORE CELLS WITHIN A SET OF CELLS OF A SCHEDULING CELL 402
DETERMINE A DOWNLINK CONTROL INFORMATION (DCI) COUNT FOR THE SLOT FOR USER EQUIPMENT DEVICES 404
DETERMINE, BASED ON THE DCI COUNT, AVAILABLE PROCESSING CAPABILITY FOR UNICAST DCI FORMATS DURING THE SLOT FOR MULTI-CELL SCHEDULING AND SINGLE-CELL SCHEDULING, WHEREIN THE AVAILABLE PROCESSING CAPABILITY IS DETERMINED FOR THE SET OF CELLS AND EACH OF CELL WITHIN THE SET OF CELLS 406
BASED ON A DETERMINATION OF THE AVAILABLE PROCESSING CAPABILITY OF THE USER EQUIPMENT DEVICES, ENCODING ONE OR MORE UNICAST DCI FORMAT FOR TRANSMISSION DURING THE SLOT, VIA A PHYSICAL DOWNLINK CONTROL CHANNEL (PDCCH) 408
TRANSMIT THE PDCCH TO THE USER EQUIPMENT DEVICES ASSOCIATED WITH THE ONE OR MORE SCHEDULED CELLS 410

FIG. 4

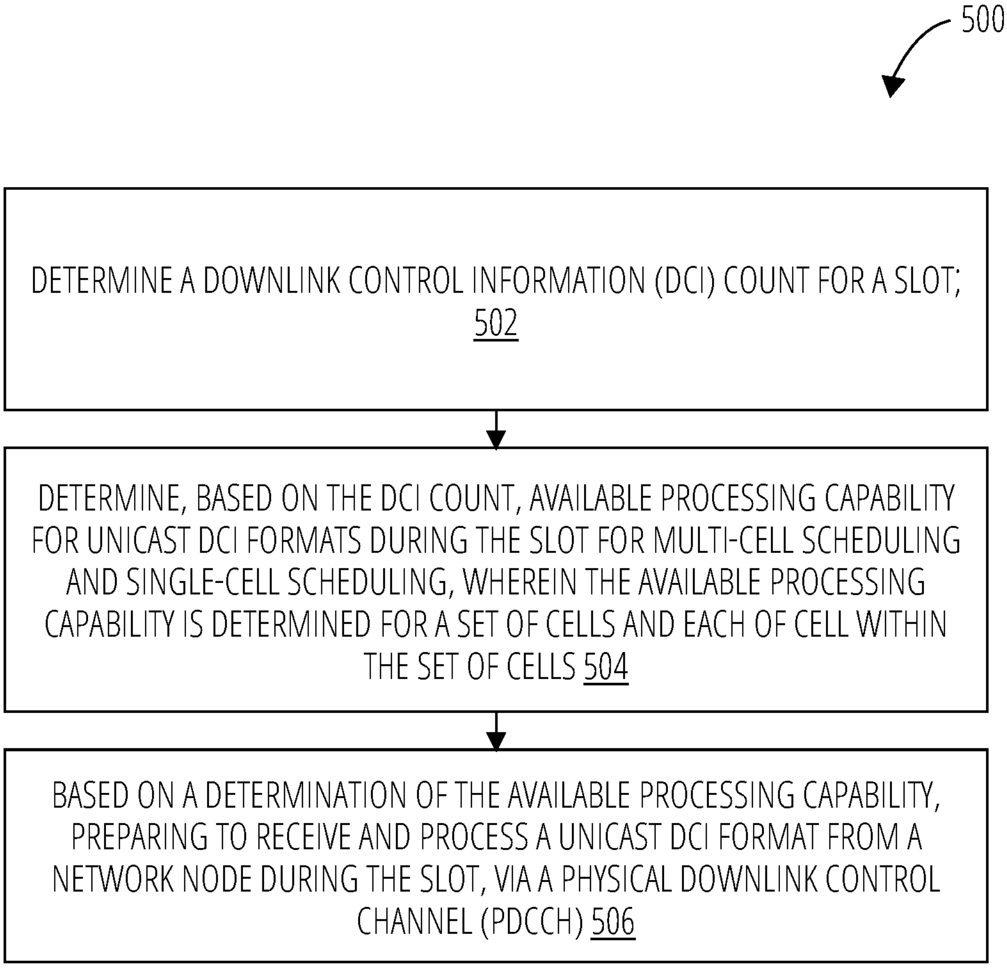
500
DETERMINE A DOWNLINK CONTROL INFORMATION (DCI) COUNT FOR A SLOT; 502
DETERMINE, BASED ON THE DCI COUNT, AVAILABLE PROCESSING CAPABILITY FOR UNICAST DCI FORMATS DURING THE SLOT FOR MULTI-CELL SCHEDULING AND SINGLE-CELL SCHEDULING, WHEREIN THE AVAILABLE PROCESSING CAPABILITY IS DETERMINED FOR A SET OF CELLS AND EACH OF CELL WITHIN THE SET OF CELLS 504
BASED ON A DETERMINATION OF THE AVAILABLE PROCESSING CAPABILITY, PREPARING TO RECEIVE AND PROCESS A UNICAST DCI FORMAT FROM A NETWORK NODE DURING THE SLOT, VIA A PHYSICAL DOWNLINK CONTROL CHANNEL (PDCCH) 506

FIG. 5

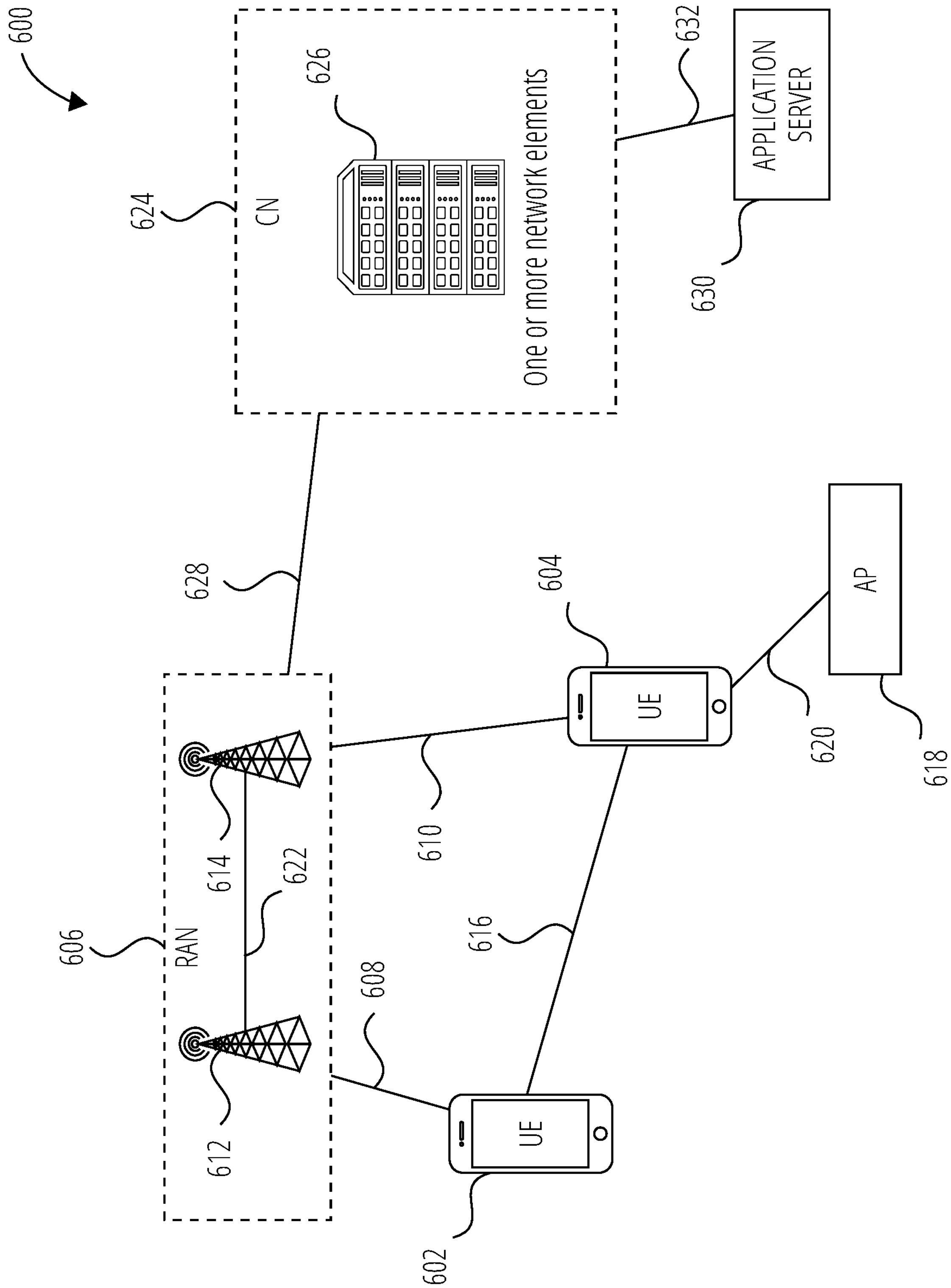
600
CN
624
626
One or more network elements
632
APPLICATION SERVER
630
628
RAN
606
614
622
612
608
610
616
UE
602
UE
604
AP
620
618

FIG. 6

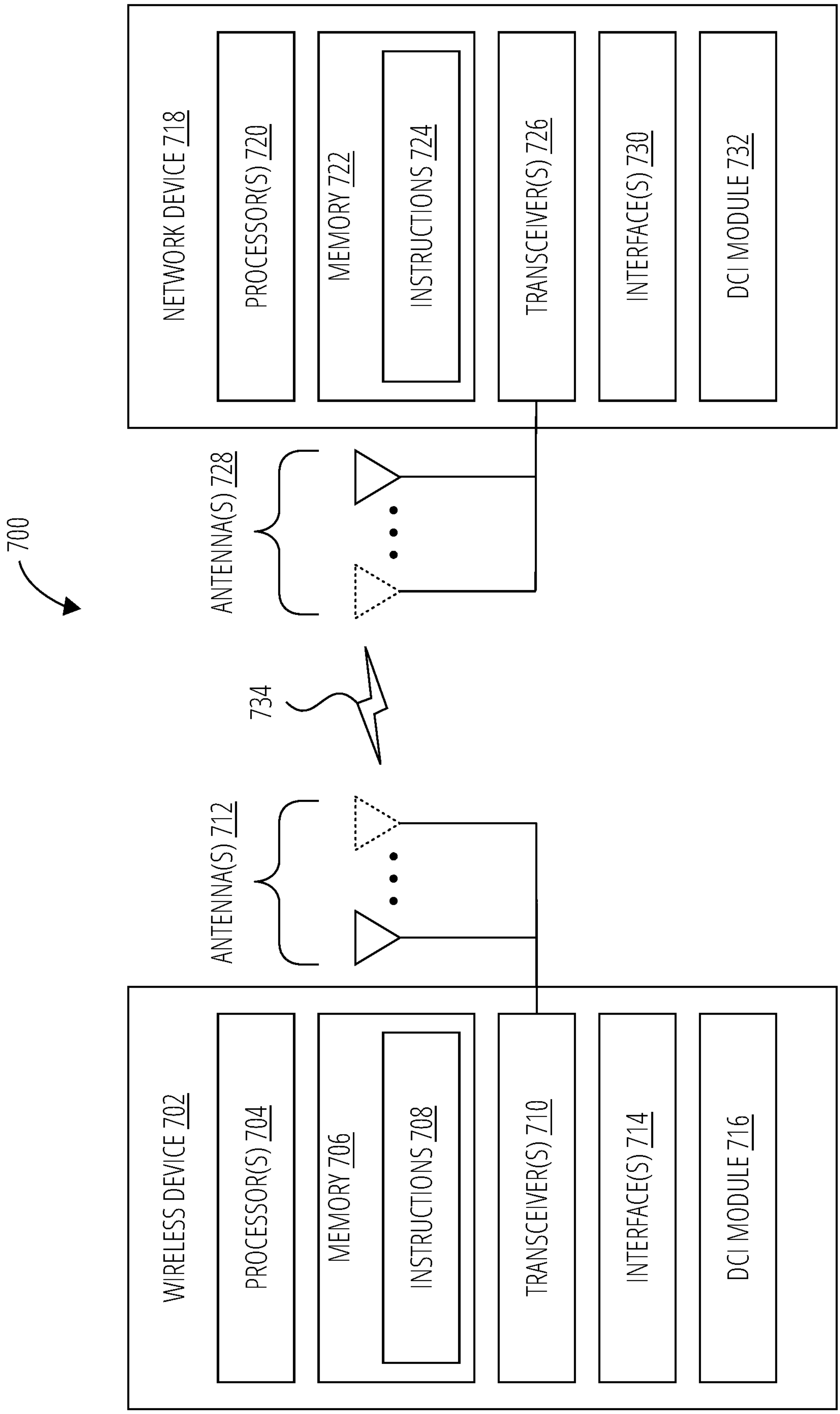
NETWORK DEVICE 718
PROCESSOR(S) 720
MEMORY 722
INSTRUCTIONS 724
TRANSCEIVER(S) 726
INTERFACE(S) 730
DCI MODULE 732
ANTENNA(S) 728
700
734
ANTENNA(S) 712
WIRELESS DEVICE 702
PROCESSOR(S) 704
MEMORY 706
INSTRUCTIONS 708
TRANSCEIVER(S) 710
INTERFACE(S) 714
DCI MODULE 716

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/041527

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W72/23 H04L5/00
ADD.

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 2023/057605 A1 (MOLAVIANJAZI EBRAHIM [US] ET AL) 23 February 2023 (2023-02-23) abstract paragraph [0069] paragraph [0073] paragraph [0082] - paragraph [0084] paragraph [0150] paragraph [0328] -----	1,2,12, 13,23-25 10,11, 21,22 3-9, 14-20
Y	US 2022/086867 A1 (PAPASAKELLARIOU ARIS [US]) 17 March 2022 (2022-03-17) abstract paragraph [0143] - paragraph [0145] -----	10,11, 21,22

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 October 2024	31/10/2024

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/041527

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		WO 2023008971 A1	02-02-2023
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		JP 2023541948 A	04-10-2023
		KR 20230066546 A	16-05-2023
		US 2022086867 A1	17-03-2022
		WO 2022060103 A1	24-03-2022