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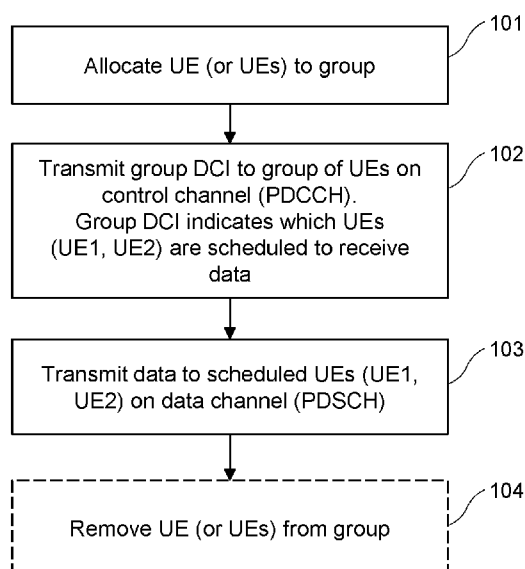


Fig. 3

(57) Abstract: There is provided a method of wireless transmission between a base station (gNB) and a group of UEs (UE1-UE4). The base station transmits (102) a group Downlink Control Information (DCI) message to the group of UEs on a downlink control channel (PDCCH). The group DCI message comprises a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a transmission of data on a downlink data channel. The base station (gNB) transmits (103) a first data transmission to the first UE and a second data transmission to the second UE in accordance with the group DCI on the downlink data channel. The first data transmission and the second data transmission are spatially multiplexed.

Transmission Techniques for a Wireless Communication System**Technical Field**

[0001] The following disclosure relates to transmission techniques for a wireless communication system.

Background

[0002] Wireless communication systems, such as the third-generation (3G) of mobile telephone standards and technology are well known. Such 3G standards and technology have been developed by the Third Generation Partnership Project (3GPP). The 3rd generation of wireless communications has generally been developed to support macro-cell mobile phone communications. Communication systems and networks have developed towards a broadband and mobile system.

[0003] In cellular wireless communication systems User Equipment (UE) is connected by a wireless link to a Radio Access Network (RAN). The RAN comprises a set of base stations which provide wireless links to the UEs located in cells covered by the base station, and an interface to a Core Network (CN) which provides overall network control. As will be appreciated the RAN and CN each conduct respective functions in relation to the overall network. For convenience the term cellular network will be used to refer to the combined RAN & CN, and it will be understood that the term is used to refer to the respective system for performing the disclosed function.

[0004] The 3rd Generation Partnership Project has developed the so-called Long Term Evolution (LTE) system, namely, an Evolved Universal Mobile Telecommunication System Territorial Radio Access Network, (E-UTRAN), for a mobile access network where one or more cells are supported by a base station known as an eNodeB or eNB (evolved NodeB). More recently, LTE is evolving further towards the so-called 5G or NR (new radio) systems where one or more cells are supported by a base station known as a gNB. NR is proposed to utilise an Orthogonal Frequency Division Multiplexed (OFDM) physical transmission format.

[0005] One aim of the 5G system is to support ultra-connectivity by allowing a large number of different types of devices to access the 5G network, e.g. a million connections per square kilometer. Consequently, a 5G cell potentially serves thousands of UEs. It is also foreseen that there would be multi-layer layouts where macro cells may be providing the coverage and the small cells providing high throughputs. To guarantee a minimum quality of service (QoS) to each device, the gNB must be able to transmit and receive data of each device in a limited amount of time. This is difficult to achieve this QoS with a finite time-frequency resources. Most transmissions in uplink or downlink require the signalling of control information to the UE in order to indicate which time-frequency resources to utilise for reception or transmission.

[0006] One solution to achieve ultra-connectivity is by creating small cells with carrier frequencies in the millimeter wave band (30 GHz to 300 GHz). In these higher bands, more spectrum is available and hence more resources for control signalling which in turn can be utilised to serve more UEs. However, the number of users may scale at a greater rate than the additional resources. Therefore, supporting a multitude of low power devices is challenging.

[0007] Another solution is to allocate the same time-frequency resources to multiple users. This transmission scheme is referred to as multi-user multiple-input multiple-output MIMO (MU-MIMO). The interference between the users can be mitigated at the gNB by appropriate precoding and at the UEs via interference-cancellation. One problem of this scheme is to find a set of users with data to receive and channel conditions that allow for the application of MU-MIMO.

[0008] With an increase in a number of users there is more opportunity to apply MU-MIMO, hence MU-MIMO benefits from large number of connected users, this is referred to as MU diversity. While MU-MIMO has the potential of increasing spectral efficiency by multiplexing many users onto the same time-frequency resources, there is still a need to schedule data transmissions for each UE by a transmission of control information.

[0009] One of the problems in data transmission is control blocking. A system can have capacity on a data channel for data scheduling but insufficient resources on a control channel to schedule the data. The control channel in a 5G system is called a control resource set (CORESET). Thus, not all data can be scheduled in a transmission time interval (TTI).

Summary

[0010] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0011] There is provided a method of wireless transmission between a base station and a group of UEs, the method comprising at the base station: transmitting a group Downlink Control Information (DCI) message to the group of UEs on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a transmission of data on a downlink data channel; transmitting a first data transmission to the first UE in accordance with the group DCI on the downlink data channel; transmitting a second data transmission to the second UE in accordance with the group DCI on the downlink data channel, wherein the first data transmission and the second data transmission are spatially multiplexed.

[0012] Optionally, the group DCI comprises a bitmap indicating which of the group of UEs are scheduled to receive a data transmission on the downlink data channel.

[0013] Optionally, the method comprises transmitting to one of the group of UEs, information to indicate an association between that UE and a bit position in the bitmap.

[0014] Optionally, the method comprises transmitting the information to indicate an association when allocating the UE to the group of UEs.

[0015] Optionally, the group DCI comprises a Radio Network Temporary Identifier (RNTI) of each UE scheduled to receive a data transmission on the downlink data channel.

[0016] Optionally, the method comprises transmitting an indication of a modulation and coding scheme (MCS) for the scheduled UEs.

[0017] Optionally, the method comprises transmitting an indication of a modulation and coding scheme comprises transmitting a base MCS value and transmitting a differential value for at least one other scheduled UE.

[0018] Optionally, the method comprises transmitting an indication of a modulation and coding scheme comprises one of: transmitting a base MCS value for one of the scheduled UEs and transmitting a differential value for each of the other scheduled UEs; transmitting a base MCS value and transmitting a differential value for each of the scheduled UEs.

[0019] Optionally, the method comprises transmitting an indication of a resource allocation of at least one of: time resource allocation; frequency resource allocation per scheduled UE.

[0020] Optionally, the method comprises transmitting a resource allocation of at least one of: time resource allocation; frequency resource allocation per scheduled UE by transmitting a base value and transmitting a differential value per scheduled UE.

[0021] Optionally, the method comprises transmitting an indication of an antenna port for at least one of the scheduled UEs, and optionally for each of the scheduled UEs.

[0022] Optionally, the method comprises transmitting to a UE which is not currently part of the group of UEs to allocate the UE to the group of UEs.

[0023] Optionally, the group DCI message is encoded with one or more of: a group-specific Radio Network Temporary Identifier (RNTI) for the group DCI; a group ID for the group DCI; a group-specific resource allocation for the group DCI.

[0024] Optionally, the method comprises sending the UE one or more of: a group-specific Radio Network Temporary Identifier (RNTI); a group ID; a group-specific resource allocation.

[0025] Optionally, each of the spatially multiplexed transmissions use the same set of overlapping time-frequency resources. The set of resources may be fully overlapping, or partially overlapping.

[0026] Optionally, the group DCI indicates a third UE in the group which is scheduled to receive a transmission of data on the downlink data channel, and the method comprises transmitting a data

transmission to the third UE in accordance with the DCI on the downlink data channel, wherein the data transmission to the third UE is not spatially multiplexed with the data transmissions to other scheduled UEs.

[0027] There is provided a method of wireless transmission between a base station and a UE, the method comprising at the UE: receiving a group Downlink Control Information (DCI) message on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a transmission of data on a downlink data channel; determining, from the group DCI, if the UE is scheduled to receive a data transmission and, if the UE is scheduled to receive a data transmission, receiving a first data transmission at the UE in accordance with the group DCI on the downlink data channel, wherein the first data transmission is spatially multiplexed with a second data transmission to another scheduled UE.

[0028] There is provided a method of wireless transmission between a base station and a group of UEs, the method comprising at the base station: transmitting a group Downlink Control Information (DCI) message to the group of UEs on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a further, UE-specific, DCI message on a downlink data channel; transmitting a first DCI message to the first UE on the downlink data channel; transmitting a second DCI message to the second UE on the downlink data channel, wherein the first DCI message and the second DCI message are spatially multiplexed.

[0029] Optionally, the group DCI comprises a bitmap indicating which of the group of UEs are scheduled to receive a UE-specific message on the downlink data channel.

[0030] Optionally, the method comprises transmitting to one of the group of UEs, information to indicate an association between that UE and a bit position in the bitmap.

[0031] Optionally, the method comprises transmitting the information to indicate an association when allocating the UE to the group of UEs.

[0032] Optionally, the group DCI comprises an index to a table of parameters to receive the UE-specific DCI message.

[0033] Optionally, the table of parameters is indicative of one or more of: a modulation and coding scheme (MCS); a time resource allocation; a frequency resource allocation.

[0034] Optionally, the method comprises transmitting the table of parameters to the UE via higher layer signalling, optionally via Radio Resource Control (RRC) signalling.

[0035] Optionally, the UE-specific parameter indicative of frequency resource allocation is a size of a frequency resource allocation, the group DCI also comprising an indication of frequency resource allocation for the group of scheduled messages.

[0036] Optionally, the UE-specific DCI message comprises a plurality of repetitions of a UE-specific DCI.

[0037] Optionally, the method comprises transmitting an indication of a number of repetitions of the UE-specific DCI to at least one of the UEs.

[0038] Optionally, the plurality of repetitions of a UE-specific DCI are encoded with at least two different redundancy versions. This may be transmitted as part of configuration information, e.g. via higher layer signalling.

[0039] Optionally, an indication of the sequence of redundancy versions is transmitted to the scheduled UE. This may be transmitted as part of configuration information, e.g. via higher layer signalling.

[0040] There is provided a method of wireless transmission between a base station and a UE, the method comprising at the UE: receiving a group Downlink Control Information (DCI) message on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a transmission of data on a downlink data channel; determining, from the group DCI, if the UE is scheduled to receive a DCI message and, if the UE is scheduled to receive a DCI message, receiving a first DCI message at the UE in accordance with the group DCI on the downlink data channel, wherein the first DCI message is spatially multiplexed with a second DCI message transmitted to another scheduled UE.

[0041] There is provided a method of wireless transmission between a base station, a first UE and a second UE, the method comprising at the base station: transmitting a first Downlink Control Information (DCI) message to the first UE on a downlink control channel, the first DCI message comprising a first DCI for the first UE; transmitting a second Downlink Control Information (DCI) message to the second UE on the downlink control channel, the second DCI message comprising a second DCI for the second UE, wherein the first DCI message and the second DCI message are spatially multiplexed.

[0042] Optionally, the first DCI is to schedule transmission of data to the first UE, and the method comprises transmitting a first data transmission to the first UE in accordance with the first DCI on the downlink data channel.

[0043] Optionally, the method comprises transmitting a control channel definition comprising an antenna port configuration table to allow the first UE to receive the first DCI.

[0044] Optionally, the method comprises transmitting an antenna port configuration which is an index to the antenna port configuration table.

[0045] Optionally, the method comprises receiving an antenna port capability from the first UE and receiving an antenna port capability from the second UE.

[0046] There is provided a method of wireless transmission between a base station and a first UE, the method comprising at the first UE: receiving configuration information to configure the UE with an antenna port configuration to receive control information on a downlink control channel; using the antenna port to receive a first Downlink Control Information (DCI) message on the downlink control channel, the first DCI message comprising a first DCI for the first UE, wherein the first DCI message is spatially multiplexed with a second DCI message transmitted to a second UE.

[0047] Optionally, the configuration information comprises an antenna port configuration table and an antenna port configuration which is an index to the antenna port configuration table.

[0048] A large-dimensional MIMO antenna array can create multiple sharp beams which can spatially separate users. These can reduce interference from co-scheduled UEs. Thus, the quasi-orthogonal users can be served simultaneously using the same time-frequency resources.

[0049] An advantage of at least one example is reducing control overhead in highly loaded cells by spatially multiplexing control information (e.g. multiple DCIs) in a MU-MIMO like manner.

[0050] Users may be grouped in terms of likelihood to be co-scheduled on the same PDSCH resources in a MU-MIMO transmission. Grouping is configured by higher-layers and every group has a unique RNTI, e.g. MU-RNTI. UEs may monitor for the DCI scrambled with MU-RNTI in a configured PDCCH search space.

[0051] In one example there is a group DCI. The group DCI may indicate resources, antenna port configuration and MCS. The group DCI can include PDSCH configuration per UE.

[0052] In one example control information is spatially multiplexed on a data channel, PDSCH. Instead of data scheduling, control information is transmitted on the PDSCH.

[0053] In one example, DCIs are spatially multiplexed on a control channel, PDCCH. A CORESET can be configured with different antenna port configurations allowing the transmitted DCIs to be efficiently spatially multiplexed.

[0054] An advantage of at least one example is allowing more UEs to share the same transmission resource. By allowing control information to efficiently utilise overlapping resources, control blocking is reduced and transmission resources can be more efficiently utilised.

[0055] There is also provided apparatus for performing any of the methods described herein.

Brief description of the drawings

[0056] Further details, aspects and embodiments of the invention will be described, by way of example only, with reference to the drawings. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. Like reference numerals have been included in the respective drawings to ease understanding.

[0057] Figure 1 shows a wireless communication system;

- [0058] Figure 2 shows resources in the communication system;
- [0059] Figure 3 shows an example method performed by a base station in the system;
- [0060] Figure 4 shows an example method performed by a wireless device;
- [0061] Figures 5A and 5B show examples of resource allocation;
- [0062] Figure 6 shows an example of a DCI with a bitmap to indicate scheduled UEs;
- [0063] Figure 7 shows an example of a DCI with a list of RNTIs to indicate scheduled UEs;
- [0064] Figure 8 shows a table of antenna port values;
- [0065] Figure 9 shows an example of resource allocation;
- [0066] Figure 10 shows an example method performed by a base station in the system;
- [0067] Figure 11 shows an example method performed by a wireless device;
- [0068] Figure 12 shows resources in a communication system to spatially multiplex control information;
- [0069] Figure 13 shows data received/stored at a UE;
- [0070] Figure 14 shows an example method performed by a base station in the system;
- [0071] Figure 15 shows an example method performed by a wireless device;
- [0072] Figure 16 shows example apparatus at a base station or a UE.

Detailed description of the preferred embodiments

[0073] Those skilled in the art will recognise and appreciate that the specifics of the examples described are merely illustrative of some embodiments and that the teachings set forth herein are applicable in a variety of alternative settings.

[0074] Figure 1 schematically shows an example of a wireless communication system with a wireless base station 10 (e.g. wireless base station, gNB) and a plurality of wireless devices UE1, UE2, UE3, UE4. The number of wireless devices may be smaller, or larger, than shown in Figure 1. A wireless device may be called a user equipment (UE) or a terminal. The base station supports communication with a plurality of UEs on downlink (DL) channels and uplink (UL) channels. The downlink channels include Physical Downlink Control Channel (PDCCH) and Physical Downlink Shared Channel (PDSCH). These are physical layer channels. PDCCH is a control channel. PDSCH is a data channel which can be shared by a plurality of UEs. To transmit data from a base station gNB to a UE, the base station schedules a transmission to a UE. The gNB transmits a Downlink Control Information (DCI) message on the PDCCH. The DCI indicates where (in terms of time and frequency resources) the downlink data will be transmitted. The gNB transmits the downlink data on PDSCH. The PDCCH and PDSCH may be implemented

as separate regions in frequency and time within the same slot, with the PDCCH preceding the PDSCH.

[0075] The base station gNB supports multi-user multiple-input multiple-output MIMO (MU-MIMO) communication. This is a technique for spatial multiplex communication with multiple users. A quantity of time-frequency resources are used to simultaneously support communication with multiple users. The base station gNB is provided with a plurality of antennas. Each UE is provided with one or more antennas. For each user, the base station transmits a plurality of transmission streams to that user. The individual streams can be precoded. The base station gNB can form directional beams towards each user to improve directionality of the transmissions and to improve separation, in space, between the transmissions to each of the users UE1, UE2, UE3, UE4.

[0076] Figure 2 shows radio resources for the communication system. The frame structure is similar to conventional LTE. The resources comprise a frequency-time grid. A multicarrier OFDM transmission scheme is used. OFDM symbols are transmitted across a set of frequency sub-carriers. Figure 2 shows one time slot in the time domain. There is a plurality of slots in the time domain. Various channels are transmitted during the time slot. A Control Resource Set (CORESET) is transmitted during the time slot, typically at the start of the time slot. The time slot also comprises a data channel PDSCH. Figure 2 shows one possible region where the PDSCH may be located. The PDSCH may occupy a different region, in frequency and time.

User-grouping

[0077] The gNB transmits a Downlink Control Information (DCI) message on the PDCCH. The DCI message is transmitted in a Control Resource Set (CORESET). The DCI indicates where, in frequency and time, the downlink data will be transmitted. Conventionally, a DCI carries information for a single wireless device. In examples of this disclosure, a DCI carries information for a plurality of wireless devices. This will be called a group DCI, or a multi-user DCI (MU-DCI). A plurality of wireless devices are grouped together, so that they can be served by the same MU-DCI. For example, in Figure 1 the group can comprise UE1-UE4. The group of wireless devices UE1-UE4 receive the same MU-DCI and therefore receive the same control information. This reduces the overall amount of control information transmitted in each slot.

[0078] There are various ways to identify a group. These include:

1. a group-specific Radio Network Temporary Identifier (RNTI);
2. a group ID;
3. a group-specific resource allocation.

The base station gNB informs the wireless devices which group they belong to. This can be achieved via higher layer signalling. For the example of a group-specific RNTI, the group DCI can be encoded with a RNTI value (e.g. 0x6362). UEs of the group are notified of the group RNTI

0x6362. Subsequently, the UEs monitor their assigned CORESETs for DCIs that are encoded (scrambled) using this group RNTI. For the option of a group ID, the group ID may be an identifier (e.g. a number) which can be used to identify messages of that group. The group ID can be included within the DCI message. For the option of a group-specific resource allocation, a dedicated CORESET allocation is provided for a group of users and only members of that group are configured to search this CORESET for DCIs. Thus, this group of users is identified by this CORESET, which has a CORESET ID, hence this CORESET ID can identify the group.

Common DCI for MU-MIMO Scheduling

[0079] In this aspect, a group DCI schedules spatially multiplexed transmissions to a plurality of wireless devices. Referring again to Figure 2, a group DCI (MU-DCI) transmitted in the CORESET schedules a MU-MIMO transmission for a group of wireless devices on PDSCH. Instead of transmitting N DCIs to schedule N users for MU-MIMO, a single MU-DCI schedules the data transmissions for the N users. The MU-DCI schedules data transmissions in a block 20 of time-frequency resources on the data channel PDSCH. The group DCI (MU-DCI) may be encoded with a group-specific RNTI, to schedule a MU-MIMO transmission on PDSCH.

[0080] Figure 3 shows an example method performed by a base station. At block 101 the base station transmits to a UE (or a plurality of UEs) to allocate the UE to a group. As described above, this may be via higher layer signalling. The UE may be provided with a group-specific RNTI or some other way of identifying a group DCI. At block 102 the base station transmits a group DCI message to the group of UEs on a downlink control channel. The group DCI message comprises a group DCI indicating which UEs in the group are scheduled to receive a transmission of data on a downlink data channel. At block 103 the base station transmits data to the scheduled UEs. This can comprise transmitting a first data transmission to a first UE in accordance with the group DCI on the downlink data channel and transmitting a second data transmission to a second UE in accordance with the group DCI on the downlink data channel. The first data transmission and the second data transmission are spatially multiplexed. The first data transmission and the second data transmission may occupy the same, or at least partially overlapping, time-frequency resources. At block 104 the base station transmits to a UE (or a plurality of UEs) to remove the UE from the group.

[0081] Figure 4 shows an example method performed by a wireless device UE. At block 111 the UE receives control information to allocate the UE to a group. As described above, this may be via higher layer signalling. The UE may be provided with a group-specific RNTI or some other way of identifying a group DCI. At block 112 the UE receives a group DCI message on a downlink control channel. The group DCI message comprises a group DCI indicating which UEs in the group are scheduled to receive a transmission of data on a downlink data channel. The UE determines if it is one of the scheduled UEs. If the UE is one of the scheduled UEs then, at block

113, the UE receives data. At block 114 the UE receives control information to remove the UE from the group.

[0082] Figures 5A and 5B show two possible examples of resource allocation. A group DCI is associated with four wireless devices UE1, UE2, UE3, UE4. A block 20 of time-frequency resources comprises the Physical Resource Blocks (PRB) 1-18. In Figure 5A, a block 20 of time-frequency resources is allocated to each of the devices. That is, all of block 20 is used by each of the devices. UE1 uses PRBs 0-17, UE2 uses PRBs 0-17, UE3 uses PRBs 0-17 and UE4 uses PRBs 0-17. Spatial multiplexing allows the transmissions to be separated at each of the devices UE1-UE4. In Figure 5B, a block 20 of time-frequency resources is allocated to the devices UE1-UE4. There is partial overlap between the resources allocated to each of the wireless devices UE1-UE4. Device UE1 is allocated PRBs 0-17; device UE2 is allocated PRBs 12-17; device UE3 is allocated PRBs 6-17 and device UE4 is allocated PRBs 0-5. The amount of resources allocated to each device can be selected based on factors such as the size of the payload (i.e. the transport block) and the channel conditions (MCS).

[0083] An existing DCI (Format 1_1) may be modified to enable a compact scheduling and to trade-off control information overhead and scheduling flexibility. At the UE side, in order to perform efficient channel estimation for data demodulation, it is necessary that the Demodulation Reference Signal (DMRS) associated with the PDSCH of the UE are orthogonal among the co-scheduled users. This allows for UE-transparent precoding and reduces, or prevents, interference between the DMRS/data of the different users. Therefore, it is necessary to inform each UE about the antenna port(s) it has to use for data demodulation.

[0084] The MU-DCI indicates, in each transmission cycle, which of the devices (UE1-UE4) in the group is scheduled a data transmission. The signalling to devices can comprise a bitmap or a list of RNTIs.

Bitmap

[0085] The MU-DCI includes a bitmap. Each bit corresponds to one user in the group. Each device UE is informed which bit of the bitmap is assigned to that device. Figure 6 shows a bitmap for the group of devices UE1-UE4. The first bit position is associated with UE1, the second bit position is associated with UE2, and so on. Other associations are possible. In this example, the bitmap indicates that data transmissions are scheduled to devices UE1, UE3 and UE4. The association of a device to a bitmap position can be signalled via higher layer signalling, such as the signalling which allocates a device UE to a group in the UE grouping phase. The bitmap provides the UE with the information about whether it is scheduled for transmission or not, how many UEs are co-scheduled, as well as any user-specific parameter in the DCI is associated to, such as an antenna port. Advantageously, the size of a group is limited to a maximum number to limit the amount of control overhead.

List of RNTIs

[0086] The MU-DCI comprises a list of RNTIs to identify the UEs. This method requires more bits in the DCI if the user pool is small but may be advantageous if the number of users in the group is large. Figure 7 shows an example DCI with a list of RNTIs. In this example, the list indicates that data transmissions are scheduled to devices UE1, UE3 and UE4. An advantage of this option is that no additional signalling is required prior to transmission to associate a device to a bit position, as the RNTIs are already known to the UEs. The first RNTI in the list can be defined to correspond to the first entry in a user-specific parameter list in the DCI.

[0087] The above two techniques can be used to send UE-specific parameters in the DCI. UE-specific parameters include: antenna port; MCS; resource allocation. Each of these will now be described.

UE-specific antenna port

[0088] An antenna port configuration is required for MU-MIMO transmissions. One way of communicating antenna port is to include a list of antenna port configurations, one per UE. Some information in this list may be redundant. For example, consider the antenna port configuration table in Figure 8, taken from TS 38.212. It shows what value to transmit in the DCI for parameter “Antenna port(s)” if only one codeword is enabled and up to 4 antenna ports are used. For example:

value 0 means the UE uses antenna port 0 to demodulate PDSCH and can assume that there is nothing transmitted on antenna port 1;

value 1 means the UE uses antenna port 1 to demodulate PDSCH and can assume that there is nothing transmitted on antenna port 0;

value 2 means data is transmitted using both antenna ports 0 and 1, which indicates spatial multiplexing;

value 3 means antenna port 0 is used but the other antenna ports might be in use as well (for other UEs, e.g. MU-MIMO) etc.;

value 11 means UE uses antenna ports 0 and 2 but antenna ports 1 and 3 might be used for other UEs.

There are other tables for 2 codewords and/or more supported antenna ports.

[0089] To schedule 3 UEs (UE1-UE3) the DCI may contain the list {7,5,6} which means UE1 uses antenna ports 0 and 1, UE2 uses antenna port 2, UE3 uses antenna port 3.

[0090] To schedule 4 UEs (UE1-UE4) the DCI may contain the list {3,4,5,6} which means UE1 uses antenna port 0, UE2 uses antenna port 1, UE3 uses antenna port 2, UE4 uses antenna port 3, given all UEs are configured to use the same table. In this example the last antenna port does not need to be signalled in this case as the number of scheduled UEs is already known from the bitmap or list of RNTIs.

[0091] It is also possible to pre-configure, i.e. fix, the antenna port per UE by a convention which is known by the base station and the UEs. One possible convention is that the first UE always

uses antenna port 0 (or a plurality of antenna ports), the second UE always uses antenna port 1 (or a plurality of antenna ports), etc. Such a convention would eliminate the need for explicit signalling.

UE-specific Modulation and Coding Scheme (MCS)

[0092] In a case where MCS is the same for all scheduled UEs in the group, there is no need to signal MCS per UE. However, this might be undesirable (e.g. if UEs experience different SINRs). If there is a need to signal MCS per UE, then a simplest option is to signal an MCS value per UE. Which MCS belongs to which UE may be signalled by the gNB prior to transmission, or a convention can be followed (first UE = first value in list of MCS values, second UE = second value in list of MCS values, etc.) If a bitmap is used for user-selection, the position of the bit can be used as an indication which MCS to use. For example, the highest '1' bit (MSB) corresponds to the first MCS etc.

[0093] An alternative option to reduce signalling overhead is to signal a differential MCS, i.e. signal a difference between the MCS value of the second UE compared to the MCS value of the first UE. This requires signalling one base MCS value and a small, low resolution, delta MCS per UE. For example, the MCS value in the DCI is 5 bits. So we could choose to signal a base MCS value of 20 and then use 3 bits for delta MCS, 1 bit indicating the sign and the 2 bits indicating a difference (delta) value. In this example it allows the signalling of values from 17 to 23 (20-3; 20-2; 20-1; 20; 20+1; 20+2; 20+3). Another option is to specify the step size. Consider a step size of 4 and a 3 bit delta MCS (1 bit sign, 2 bits value). This allows delta MCS values of +/- 0, 4, 8, 12.

[0094] In the above examples, the base MCS value may be one of the MCS values of a scheduled UE and the differential values. For example, to signal the MCS values UE1=18, UE2=19, UE3=20, the base MCS value 18 is sent (which, in this case, is the value of UE1), along with the differential values +1, +1. In another example, the base MCS may not correspond to one of the MCS values of a UE. For example, to signal the MCS values UE1=18, UE2=19, UE3=23, the base MCS value 20 is sent, along with the differential values -2 (=UE1), -1 (=UE2) and +3 (=UE3). The gNB and UEs are both aware of which scheme is in use, and use the same scheme. The scheme may be selected to minimise the overall amount of signalled data to encode values of all of the MCS values.

UE-specific resource allocation

[0095] Time-frequency resources may be common to all UEs in the group, or may be allocated per UE. In a case of a resource allocation per UE, it may be desirable to reduce the amount of signalling data. The resource allocation may be indicated per UE, or as a differential.

[0096] Currently, DCI format 1_1 has two fields for scheduling time and frequency resources. One option is to signal only UE-specific time allocation and keep the frequency allocation common to all UEs in the group, or to signal only UE-specific frequency allocation and keep the time-allocation common to all UEs in the group.

[0097] Another option is to use differential signalling. One reference resource allocation is signalled in full. Other resource allocations are signalled as delta values compared to the resource allocation which has been signalled in full, or as a delta value compared to the last entry in the list of delta values.

Spatially multiplexed control information on PDSCH

[0098] In this aspect, a group DCI schedules spatially multiplexed transmissions to a plurality of wireless devices. However, unlike the example described in Figures 3 to 7, the group DCI schedules spatially multiplexed transmissions of control data on the data channel (PDSCH). This frees resources on the control channel PDCCH. Referring again to Figure 2, a group DCI (MU-DCI) transmitted in the CORESET schedules a MU-MIMO transmission for a group of wireless devices on PDSCH. A single MU-DCI schedules transmissions of control data to N users. The MU-DCI schedules control data transmissions in a block 20 of time-frequency resources on the data channel PDSCH. The group DCI (MU-DCI) may be encoded with a group-specific RNTI, to schedule a MU-MIMO transmission on PDSCH.

[0099] One advantage is control overhead reduction. One DCI on PDCCH is used to schedule N DCIs in parallel for N UEs. Another advantage is flexible offloading of control resources. For example, DCIs scheduling DL/UL transmission for future slots can be transmitted anywhere in the slot, e.g. at the end. Note that CORESETs are usually allocated at the beginning of a slot.

[00100] The per UE DCI may be any kind of DCI. For example, DCI formats 2_0, 2_1, 2_2 and 2_3 are defined in 3GPP TS 38.2.12. These DCI can also be encoded with a UE-specific RNTI. For example, DCI format 2_0 is the slot format indication scrambled with SFI-RNTI which can be configured per UE (or be common to multiple UEs). The slot format indicates which OFDM symbols are for UL/DL, or unspecified. Another example is the DCI format 2_1 which indicates pre-emption. It is scrambled with INT-RNTI which is also UE specific. It indicates that some of the DL resources of the UE have been overwritten by a higher priority transmission and it allows the UE to take necessary actions. The per-UE DCI may be used to indicate scheduling of data in a PDSCH of a subsequent time slot, or time unit.

[00101] This technique may be used in any scenario where MU-MIMO is applicable. MU-MIMO is particularly applicable to low mobility scenarios with medium to good signal-to-interference-plus-noise ratio (SINR). Typically, the PDSCH does not provide the same reliability as PDCCH and co-scheduling UEs will result in some interference. Control information generally requires a higher transmission reliability than data and therefore good radio conditions are desirable to reliably decode control information on PDSCH. Control information typically requires a very small packet (e.g. 140 bits are foreseen for DCI in Rel.15).

[00102] Some techniques are proposed to optimise the MU-DCI overhead. UE-specific parameters in the DCI include: antenna port; MCS; resource allocation. Per-UE antenna ports

can be signalled to the scheduled UEs in one of the ways described above for “Common DCI for MU-MIMO Scheduling”.

Discrete combination of decoding parameters

[00103] The possible DCI sizes of per-UE DCIs to be transported on the PDSCH are limited (i.e. there is a small number of possible sizes). The requirement for high reliability of transmission also requires low MCS. It is proposed to gather possible combinations of relevant parameters in tables and include the index for the entry in the table in the MU-DCI. Figure 8 shows an example resource allocation for a per-UE DCI for each of UE1-UE4. The resource allocations overlap in time and (at least partially) in frequency. The resource allocations for each of UE1-UE4 are shown side-by-side to improve clarity. It will be understood that a MU-MIMO transmission will transmit DCI UE1 – DCI UE4 in parallel using the same block 20 of resources.

[00104] Referring again to Figure 2, the group MCI (MU-DCI) indicates the location of block 20 in time and frequency. Within this block of these resources the UEs will blindly attempt to decode the PDSCH using the possible combinations signalled in the table. An example table is shown in below as Table 1. Each entry in the table is a combination of three values: MCS, frequency resource allocation in PRBs, time resource allocation in OFDM symbols. As an example, frequency allocation in multiples of 6 PRBs are chosen. This is the same size as a Control Channel Element (CCE) in the PDCCH resource allocation.

Index	{MCS, Frequency allocation in PRBs, Time allocation in OFDM symbols}
0	{0,6,3}, {0,12,3}, {1,18,3}, {2,18,3}
1	{0,6,3}, {0,12,3}, {9,18,3}, {9,6,2}
2	{9,18,2}, {12,6,2}
3	{12,6,2}, {16,6,2}

Table 1 - Example of MCS and resource allocation for PDSCH decoding

In the example shown in Figure 9 there is partial overlap between the resources allocated to each of the wireless devices UE1-UE4. DCI UE1 is allocated PRBs 0-17 (18 PRBs in total); DCI UE2 is allocated PRBs 12-17 (6 PRBs in total); DCI UE3 is allocated PRBs 6-17 (12 PRBs in total) and DCI UE4 is allocated PRBs 0-5 (6 PRBs in total). Each resource allocation is 3 OFDM symbols in time. In the example of Figure 9 the DCI UEs are multiplexed with the properties of table index 0. The group DCI (MU-DCI) sent to the UEs indicates Index 0. The amount of resources allocated to each DCI may depend on one or more of: the payload size, the encoding (MCS, number of repetitions).

[00105] Upon decoding the MU-DCI, a UE receives the Index specifying properties of the DCI UEs, and will then try all possible decoding combinations. Index 0 has two entries with 18

PRBs: {1,18,3}, {2,18,3}. This requires one decoding attempt with MCS = 1 and one decoding attempt with MCS = 2. As the block 20 is 18 PRBs in length, there is no ambiguity with the starting position (in frequency) for block 20. To limit the number of blind decoding attempts it is proposed to limit the start of the frequency resource allocation to multiples of PRBs (e.g. 6 PRBs) starting with the first RE signalled in the MU-DCI. The combination {0,6,3} requires three decoding attempts: a first attempt starting at PRB 0; a second attempt starting at PRB 6; and a third attempt starting at PRB 12. The combination {0,12,3} requires two decoding attempts: a first attempt starting at PRB 0 and a second attempt starting at PRB 6. Therefore, in total there are 7 decoding attempts. This can be easily handled by the UEs since the TBs are small.

[00106] There can be a plurality of possible tables. A gNB signals to a UE to inform the UE which table to use. The signalling of which table to use may be performed via higher layer signalling, such as signalling to configure the group of UEs. The configured table may be the same for all UEs in the group, or at least the same for the scheduled UEs in a TTI. The plurality of tables may comprise a table for repetition and tables for different number layers. The use of tables helps to reduce the overall amount of signalled data in each DCI, as the DCI can simply carry an index which refers to an entry in the table stored at a UE.

[00107] A table, or an association of a table to a UE, may be updated semi-statically through higher layer signalling. Alternatively, the MU-DCI can be used to send a message (in the form of a special DCI) to all UEs in the group to update the group configuration.

[00108] The group DCI (MU-DCI) described above in the section "Common DCI for MU-MIMO" can be used for this aspect.

[00109] Figure 10 shows an example method performed by a base station. At block 201 the base station transmits to a UE (or a plurality of UEs) to allocate the UE to a group. As described above, this may be via higher layer signalling. The UE may be provided with a group-specific RNTI or some other way of identifying a group DCI. At block 202 the base station transmits a group DCI message to the group of UEs on a downlink control channel. The group DCI message comprises a group DCI indicating which UEs in the group are scheduled to receive a transmission of a per-UE DCI on a downlink data channel. At block 203 the base station transmits a DCI to each of the scheduled UEs. This can comprise transmitting a first DCI to a first UE on the downlink data channel and transmitting a second DCI to a second UE on the downlink data channel. The first DCI and the second DCI are spatially multiplexed. The first data transmission and the second data transmission may occupy the same, or at least partially overlapping, time-frequency resources. At block 204 the base station transmits to a UE (or a plurality of UEs) to remove the UE from the group.

[00110] Figure 11 shows an example method performed by a wireless device UE. At block 211 the UE receives control information to allocate the UE to a group. As described above, this may be via higher layer signalling. The UE may be provided with a group-specific RNTI or some

other way of identifying a group DCI. At block 212 the UE receives a group DCI message on a downlink control channel. The group DCI message comprises a group DCI indicating which UEs in the group are scheduled to receive a transmission of a per-UE DCI on a downlink data channel. The UE determines if it is one of the scheduled UEs. If the UE is one of the scheduled UEs then, at block 213, the UE receives the DCI. At block 214 the UE receives control information to remove the UE from the group.

Including repetitions to enhance reliability

[00111] The encoding in PDCCH is designed to achieve acceptable BLER even at very low signal-to-noise ratio (SNR). It is difficult to achieve this performance in the PDSCH. Therefore, to increase reliability of control information on PDSCH it is proposed to use data repetition. A first possibility is to repeat control data multiple times before encoding, thus creating a larger transport block which can be more reliably encoded. A second possibility is to encode a transport block with different redundancy versions (RVs) which are concatenated and sent to the UE. The UE can combine these transmissions before attempting to decode. The RV sequence can be pre-defined, e.g. RV: 0 1 2 3 for 4 repetitions or RV: 0 1 2 3 0 1 for 6 repetitions. In both cases, the number of repetitions, or at least the maximum number of repetitions, can be signalled to the UE. This can be included in the decoding table. An example table is shown in Table 2.

Index	{MCS, Frequency allocation in PRBs, Time allocation in OFDM symbols, Number of repetitions}
0	{0,6,3,1}, {0,12,3,2}, {1,18,3,4}, {2,18,3,4}
1	{0,6,3,1}, {0,12,3,2}, {9,18,3,4}, {9,6,2,1}
2	{9,18,2,2}, {12,6,2,1}
3	{12,6,2,1}, {16,6,2,1}

Table 2 - Example of MCS and resource allocation for PDSCH decoding with repetitions

[00112] The PDSCH allows for multi-layer transmission. The control data of one user can be mapped to multiple layers. The number of layers can also be included in the table.

[00113] One way of reducing the amount of control information is to encode all control information on PDSCH identically. The same MCS is used to encode the DCI for every UE identically. Each DCI UE has the same resource allocation. This only requires the antenna port to be signalled to the UEs. This can be signalled via a bitmap and a list of antenna port configurations. A disadvantage is that no UE-specific link adaptation is applied and hence the worst-case MCS is applied to all UEs. The size of the TB is identical for all UEs which implies that the payload/size of the DCI is identical as well.

Spatially multiplexed DCI on PDCCH

[00114] Typically, the PDCCH is transmitted in a pre-configured control resource set (CORESET) on a single antenna port. No spatial multiplexing is possible. The reasoning is that the PDCCH carrying control information should be reliably received by all UEs in the cell.

[00115] In this aspect, a CORESET supports spatial multiplexing of DCIs on the control channel PDCCH. Figure 12 schematically shows radio resources for the communication system. A CORESET includes a DCI for UE1, a DCI for UE2 and a DCI for UE3. A wireless device is configured to receive the CORESET.

[00116] Control information is configured by *ControlResourceSet* in the *PDCCH-Config* and common CORESETs in *PDCCH-ConfigCommon*. A parameter *antennaPorts* is added to *ControlResourceSet*. This is an index to a table of possible antenna port configurations. The table itself can be indicated by a different parameter, e.g. *antennaPortTable*, in *ControlResourceSet*. This allows the CORESET to support various antenna port configurations similar to PDSCH.

[00117] The UE is configured with its UE-specific PDCCH configuration via a RRC message *PDCCH-Config* (see TS38.331). This *PDCCH-Config* comprises several fields to configure the CORESETs and the search spaces for the UE. It can be configured with up to 4 CORESETs. The CORESET configuration is specified in the field *ControlResourceSet*. The *ControlResourceSet* comprises all the parameters necessary to configure one CORESET, e.g. the ID, frequency domain resources, duration, etc.

[00118] An additional parameter *antennaPortTable* may be added to *ControlResourceSet*. The *antennaPortTable* can be the same as for PDSCH, i.e. Figure 8. It will be understood that the table may have a different form.

[00119] A UE configured with this CORESET knows that it supports a PDCCH with up to 4 antenna ports. This information does not inform the UE which antenna port it should use to attempt to blindly decode the DCI. The UE could blindly try each of the 4 antenna ports, but that would increase the number of blind decodes significantly, e.g. a factor of 4 with 4 antenna ports.

[00120] A UE-specific *antennaPorts* parameter may be added to the *PDCCH-Config* message. This is an index in the *antennaPort* table, similar to the approach described above for receiving DCIs on PDSCH.

[00121] A worked example is now provided. Both UE1 and UE2 are configured with a CORESET with ID 0. This CORESET supports spatial multiplexing and an *antennaPortTable* is configured (Figure 8). In the *PDCCH-Config*, UE1 is signalled *antennaPorts* 3, which means that it should use antenna port 0. UE1 is signalled *antennaPorts* 4 meaning, use antenna port 1. Both UEs know that the three remaining antenna ports could be used by other UEs. In this approach, the antenna port is semi-statically configured per UE.

[00122] This approach has an advantage that if antennaPorts = 0, antenna port 0 is used, and nothing changes for the UE compared to the conventional PDCCH decoding.

[00123] If a CORESET supports more than one antenna port, there is a DMRS per antenna port. The DMRSs are (quasi-) orthogonal. These additional DMRSs are defined, e.g. similarly to PDSCH. A UE is configured to blindly try the DMRS for each antenna port to attempt PDCCH decoding. This increases the PDCCH decoding complexity.

[00124] Although a CORESET can be configured with multiple antenna ports, not all DCIs within the CORESET are necessarily transmitted through all antenna ports. There can be DCIs for UEs that do not support multiple antenna ports for PDCCH and their DCI is transmitted through a single antenna port. That is, those UEs monitor the CORESET as usual by attempting demodulation through the single port DMRS. On the other hand, UEs capable of multi-antenna port PDCCH demodulation will monitor the CORESETs by attempting demodulation for all DMRS candidates. The capability of how many antenna ports a UE supports for PDCCH demodulation is signalled to the gNB prior to transmission.

[00125] Figure 14 shows an example method performed by a base station. At block 301 the base station receives capabilities of a UE. At block 302 the gNB transmits configuration information to configure the UE to receive the CORESET. This includes antenna port configuration information. At block 303 the gNB transmits a first DCI message to a first UE on a downlink control channel, the first DCI message comprising a first DCI for the first UE. The gNB also transmits a second DCI message to the second UE on the downlink control channel, the second DCI message comprising a second DCI for the second UE. The gNB spatially multiplexes the first DCI message and the second DCI message, i.e. they are transmitted to the first UE and second UE the same, or at least partially overlapping, time-frequency resources.

[00126] Figure 15 shows an example method performed by a wireless device UE. At block 311 the UE sends antenna port capabilities of the UE to the gNB. At block 312 the UE receives configuration information to configure the UE to receive a CORESET. This includes antenna port configuration information. At block 313 the first UE receives a first DCI message on the downlink control channel using the configuration. The first DCI message comprises a first DCI for the first UE. The first DCI message is spatially multiplexed with a second DCI message transmitted to a second UE.

[00127] Although not shown in detail, any of the devices or apparatus that form part of the network may include at least a processor, a storage unit and a communications interface, wherein the processor unit, storage unit, and communications interface are configured to perform the method of any aspect of the present invention.

[00128] Figure 16 shows apparatus which can be used to implement the gNB or the UE. The apparatus which may be implemented as any form of a computing and/or electronic device.

Processing apparatus 500 comprises one or more processors 501 which may be microprocessors, controllers or any other suitable type of processors for executing instructions to control the operation of the device. The processor 501 is connected to other components of the device via one or more buses 506. Processor-executable instructions 503 may be provided using any computer-readable media, such as memory 502. The processor-executable instructions 503 can comprise instructions for implementing the functionality of the described methods. The memory 502 is of any suitable type such as read-only memory (ROM), random access memory (RAM), a storage device of any type such as a magnetic or optical storage device. Data 504 used by the processor may be stored in memory 502, or in additional memory. The processing apparatus 500 comprises one or more wireless transceivers 508.

[00129] Further options and choices are described below. The signal processing functionality of the embodiments of the invention may be achieved using computing systems or architectures known to those who are skilled in the relevant art. Computing systems such as, a desktop, laptop or notebook computer, hand-held computing device (PDA, cell phone, palmtop, etc.), mainframe, server, client, or any other type of special or general purpose computing device as may be desirable or appropriate for a given application or environment can be used. The computing system can include one or more processors which can be implemented using a general or special-purpose processing engine such as, for example, a microprocessor, microcontroller or other control module.

[00130] The computing system can also include a main memory, such as random access memory (RAM) or other dynamic memory, for storing information and instructions to be executed by a processor. Such a main memory also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor. The computing system may likewise include a read only memory (ROM) or other static storage device for storing static information and instructions for a processor.

[00131] The computing system may also include an information storage system which may include, for example, a media drive and a removable storage interface. The media drive may include a drive or other mechanism to support fixed or removable storage media, such as a hard disk drive, a floppy disk drive, a magnetic tape drive, an optical disk drive, a compact disc (CD) or digital video drive (DVD) read or write drive (R or RW), or other removable or fixed media drive. Storage media may include, for example, a hard disk, floppy disk, magnetic tape, optical disk, CD or DVD, or other fixed or removable medium that is read by and written to by media drive. The storage media may include a computer-readable storage medium having particular computer software or data stored therein.

[00132] In alternative embodiments, an information storage system may include other similar components for allowing computer programs or other instructions or data to be loaded into the computing system. Such components may include, for example, a removable storage unit and an

interface, such as a program cartridge and cartridge interface, a removable memory (for example, a flash memory or other removable memory module) and memory slot, and other removable storage units and interfaces that allow software and data to be transferred from the removable storage unit to computing system.

[00133] The computing system can also include a communications interface. Such a communications interface can be used to allow software and data to be transferred between a computing system and external devices. Examples of communications interfaces can include a modem, a network interface (such as an Ethernet or other NIC card), a communications port (such as for example, a universal serial bus (USB) port), a PCMCIA slot and card, etc. Software and data transferred via a communications interface are in the form of signals which can be electronic, electromagnetic, and optical or other signals capable of being received by a communications interface medium.

[00134] In this document, the terms 'computer program product', 'computer-readable medium' and the like may be used generally to refer to tangible media such as, for example, a memory, storage device, or storage unit. These and other forms of computer-readable media may store one or more instructions for use by the processor comprising the computer system to cause the processor to perform specified operations. Such instructions, generally referred to as 'computer program code' (which may be grouped in the form of computer programs or other groupings), when executed, enable the computing system to perform functions of embodiments of the present invention. Note that the code may directly cause a processor to perform specified operations, be compiled to do so, and/or be combined with other software, hardware, and/or firmware elements (e.g., libraries for performing standard functions) to do so.

[00135] The non-transitory computer readable medium may comprise at least one from a group consisting of: a hard disk, a CD-ROM, an optical storage device, a magnetic storage device, a Read Only Memory, a Programmable Read Only Memory, an Erasable Programmable Read Only Memory, EPROM, an Electrically Erasable Programmable Read Only Memory and a Flash memory. In an embodiment where the elements are implemented using software, the software may be stored in a computer-readable medium and loaded into computing system using, for example, removable storage drive. A control module (in this example, software instructions or executable computer program code), when executed by the processor in the computer system, causes a processor to perform the functions of the invention as described herein.

[00136] Furthermore, the inventive concept can be applied to any circuit for performing signal processing functionality within a network element. It is further envisaged that, for example, a semiconductor manufacturer may employ the inventive concept in a design of a stand-alone device, such as a microcontroller of a digital signal processor (DSP), or application-specific integrated circuit (ASIC) and/or any other sub-system element.

[00137] It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to a single processing logic. However, the inventive concept may equally be implemented by way of a plurality of different functional units and processors to provide the signal processing functionality. Thus, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organisation.

[00138] Aspects of the invention may be implemented in any suitable form including hardware, software, firmware or any combination of these. The invention may optionally be implemented, at least partly, as computer software running on one or more data processors and/or digital signal processors or configurable module components such as FPGA devices.

[00139] Thus, the elements and components of an embodiment of the invention may be physically, functionally and logically implemented in any suitable way. Indeed, the functionality may be implemented in a single unit, in a plurality of units or as part of other functional units. Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in accordance with the invention. In the claims, the term 'comprising' does not exclude the presence of other elements or steps.

[00140] Furthermore, although individually listed, a plurality of means, elements or method steps may be implemented by, for example, a single unit or processor. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined, and the inclusion in different claims does not imply that a combination of features is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather indicates that the feature is equally applicable to other claim categories, as appropriate.

[00141] Furthermore, the order of features in the claims does not imply any specific order in which the features must be performed and in particular the order of individual steps in a method claim does not imply that the steps must be performed in this order. Rather, the steps may be performed in any suitable order. In addition, singular references do not exclude a plurality. Thus, references to 'a', 'an', 'first', 'second', etc. do not preclude a plurality.

[00142] Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the accompanying claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognise that various features of the described embodiments may be combined in

accordance with the invention. In the claims, the term 'comprising' or "including" does not exclude the presence of other elements.

Claims

1. A method of wireless transmission between a base station and a group of UEs, the method comprising at the base station:
 - transmitting a group Downlink Control Information (DCI) message to the group of UEs on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a transmission of data on a downlink data channel;
 - transmitting a first data transmission to the first UE in accordance with the group DCI on the downlink data channel;
 - transmitting a second data transmission to the second UE in accordance with the group DCI on the downlink data channel, wherein the first data transmission and the second data transmission are spatially multiplexed.
2. A method according to claim 1 wherein the group DCI comprises a bitmap indicating which of the group of UEs are scheduled to receive a data transmission on the downlink data channel.
3. A method according to claim 2 comprising transmitting to one of the group of UEs, information to indicate an association between that UE and a bit position in the bitmap.
4. A method according to claim 3 comprising transmitting the information to indicate an association when allocating the UE to the group of UEs.
5. A method according to any one of the preceding claims wherein the group DCI comprises a Radio Network Temporary Identifier (RNTI) of each UE scheduled to receive a data transmission on the downlink data channel.
6. A method according to any one of the preceding claims comprising transmitting an indication of a modulation and coding scheme (MCS) for the scheduled UEs.
7. A method according to a claim 6 wherein transmitting an indication of a modulation and coding scheme comprises transmitting a base MCS value and transmitting a differential value for at least one other scheduled UE.
8. A method according to claim 6 wherein transmitting an indication of a modulation and coding scheme comprises one of:

transmitting a base MCS value for one of the scheduled UEs and transmitting a differential value for each of the other scheduled UEs;

transmitting a base MCS value and transmitting a differential value for each of the scheduled UEs.

9. A method according to any one of the preceding claims comprising transmitting an indication of a resource allocation of at least one of: time resource allocation; frequency resource allocation per scheduled UE.

10. A method according to any one of the preceding claims comprising transmitting a resource allocation of at least one of: time resource allocation; frequency resource allocation per scheduled UE by transmitting a base value and transmitting a differential value per scheduled UE.

11. A method according to any one of the preceding claims comprising transmitting an indication of an antenna port for at least one of the scheduled UEs.

12. A method according to any one of the preceding claims comprising allocating a UE to the group of UEs.

13. A method according to claim 12 comprising transmitting to the UE one or more of: a group-specific Radio Network Temporary Identifier (RNTI) for the group DCI; a group ID for the group DCI; a group-specific resource allocation for the group DCI.

14. A method according to any one of the preceding claims wherein the group DCI message is one of: encoded with a group-specific Radio Network Temporary Identifier (RNTI); transmitted with a group-specific group ID; transmitted in a group-specific resource allocation.

15. A method according to any one of the preceding claims wherein each of the spatially multiplexed transmissions use the same set of overlapping time-frequency resources.

16. A method according to any one of the preceding claims wherein the group DCI indicates a third UE in the group which is scheduled to receive a transmission of data on the downlink data channel, and the method comprises transmitting a data transmission to the third UE in accordance with the DCI on the downlink data channel, wherein the data transmission to the third UE is not spatially multiplexed with the data transmissions to other scheduled UEs.

17. A method of wireless transmission between a base station and a UE, the method comprising at the UE:

receiving a group Downlink Control Information (DCI) message on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a transmission of data on a downlink data channel;

determining, from the group DCI, if the UE is scheduled to receive a data transmission and, if the UE is scheduled to receive a data transmission, receiving a first data transmission at the UE in accordance with the group DCI on the downlink data channel, wherein the first data transmission is spatially multiplexed with a second data transmission to another scheduled UE.

18. A method of wireless transmission between a base station and a group of UEs, the method comprising at the base station:

transmitting a group Downlink Control Information (DCI) message to the group of UEs on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a further, UE-specific, DCI message on a downlink data channel;

transmitting a first DCI message to the first UE on the downlink data channel;

transmitting a second DCI message to the second UE on the downlink data channel, wherein the first DCI message and the second DCI message are spatially multiplexed.

19. A method according to claim 18 wherein the group DCI comprises a bitmap indicating which of the group of UEs are scheduled to receive a UE-specific message on the downlink data channel.

20. A method according to claim 19 comprising transmitting to one of the group of UEs, information to indicate an association between that UE and a bit position in the bitmap.

21. A method according to claim 20 comprising transmitting the information to indicate an association when allocating the UE to the group of UEs.

22. A method according to any one of claims 18 to 21 wherein the group DCI comprises an index to a table of parameters to receive the UE-specific DCI message.

23. A method according to claim 22 wherein the table of parameters is indicative of one or more of: a modulation and coding scheme (MCS); a time resource allocation; a frequency resource allocation.

24. A method according to claim 23 comprising transmitting the table of parameters to the UE via higher layer signalling, optionally via Radio Resource Control (RRC) signalling.

25. A method according to any one of claims 18 to 24 wherein the UE-specific parameter indicative of frequency resource allocation is a size of a frequency resource allocation, the group DCI also comprising an indication of frequency resource allocation for the group of scheduled messages.
26. A method according to any one of claims 18 to 25 wherein the UE-specific DCI message comprises a plurality of repetitions of a UE-specific DCI.
27. A method according to claim 26 comprising transmitting an indication of a number of repetitions of the UE-specific DCI to at least one of the UEs.
28. A method according to any one of claims 18 to 27 wherein the plurality of repetitions of a UE-specific DCI are encoded with at least two different redundancy versions.
29. A method according to claim 28 wherein an indication of the sequence of redundancy versions is transmitted to the scheduled UE.
30. A method of wireless transmission between a base station and a UE, the method comprising at the UE:
- receiving a group Downlink Control Information (DCI) message on a downlink control channel, the group DCI message comprising a group DCI indicating at least a first UE in the group and a second UE in the group which are scheduled to receive a transmission of data on a downlink data channel;
 - determining, from the group DCI, if the UE is scheduled to receive a DCI message and, if the UE is scheduled to receive a DCI message, receiving a first DCI message at the UE in accordance with the group DCI on the downlink data channel, wherein the first DCI message is spatially multiplexed with a second DCI message transmitted to another scheduled UE.
31. A method of wireless transmission between a base station, a first UE and a second UE, the method comprising at the base station:
- transmitting a first Downlink Control Information (DCI) message to the first UE on a downlink control channel, the first DCI message comprising a first DCI for the first UE;
 - transmitting a second Downlink Control Information (DCI) message to the second UE on the downlink control channel, the second DCI message comprising a second DCI for the second UE, wherein the first DCI message and the second DCI message are spatially multiplexed.

32. A method according to claim 31 wherein the first DCI is to schedule transmission of data to the first UE, and the method comprises transmitting a first data transmission to the first UE in accordance with the first DCI on the downlink data channel.
33. A method according to claim 31 or 32 comprising transmitting a control channel definition comprising an antenna port configuration table to allow the first UE to receive the first DCI.
34. A method according to claim 33 comprising transmitting an antenna port configuration which is an index to the antenna port configuration table.
35. A method according to any one of claims 31 to 34 comprising receiving an antenna port capability from the first UE and receiving an antenna port capability from the second UE.
36. A method of wireless transmission between a base station and a first UE, the method comprising at the first UE:
- receiving configuration information to configure the UE with an antenna port configuration to receive control information on a downlink control channel;
 - using the antenna port to receive a first Downlink Control Information (DCI) message on the downlink control channel, the first DCI message comprising a first DCI for the first UE, wherein the first DCI message is spatially multiplexed with a second DCI message transmitted to a second UE.
37. A method according to claim 36 wherein the configuration information comprises an antenna port configuration table and an antenna port configuration which is an index to the antenna port configuration table.
38. Apparatus configured to perform the method according to any one of the preceding claims.

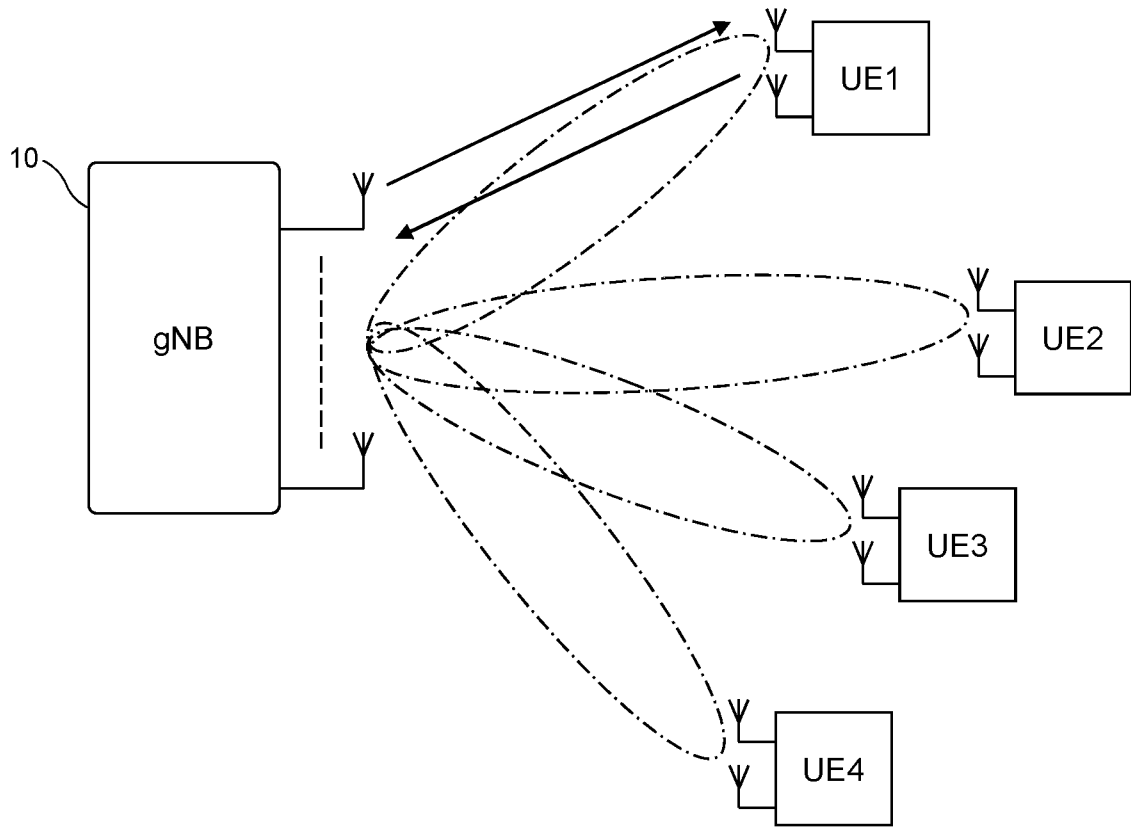


Fig. 1

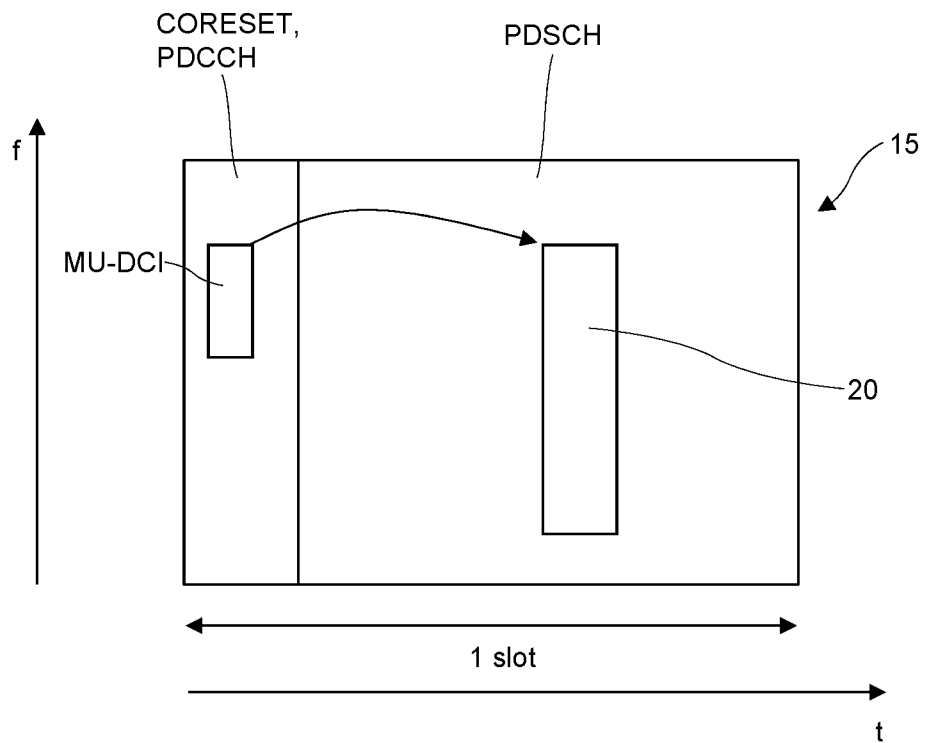


Fig. 2

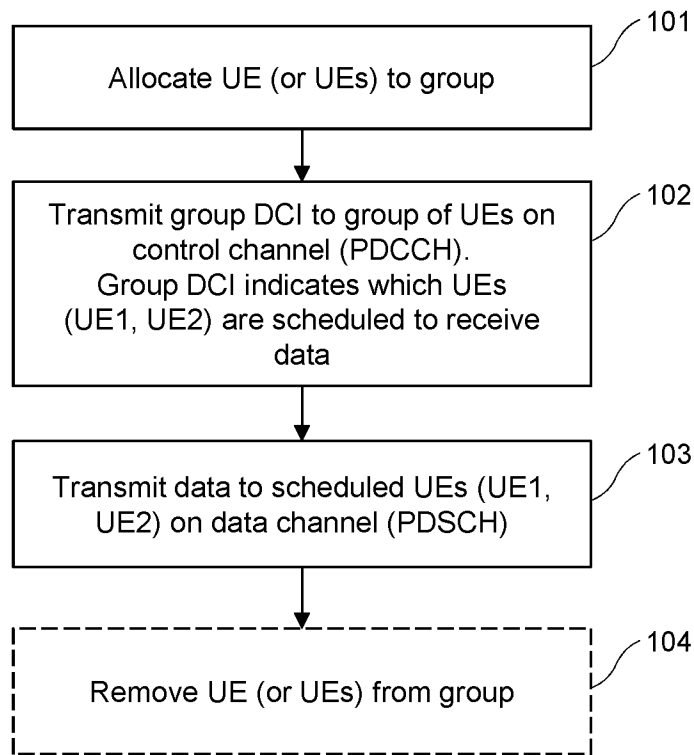


Fig. 3

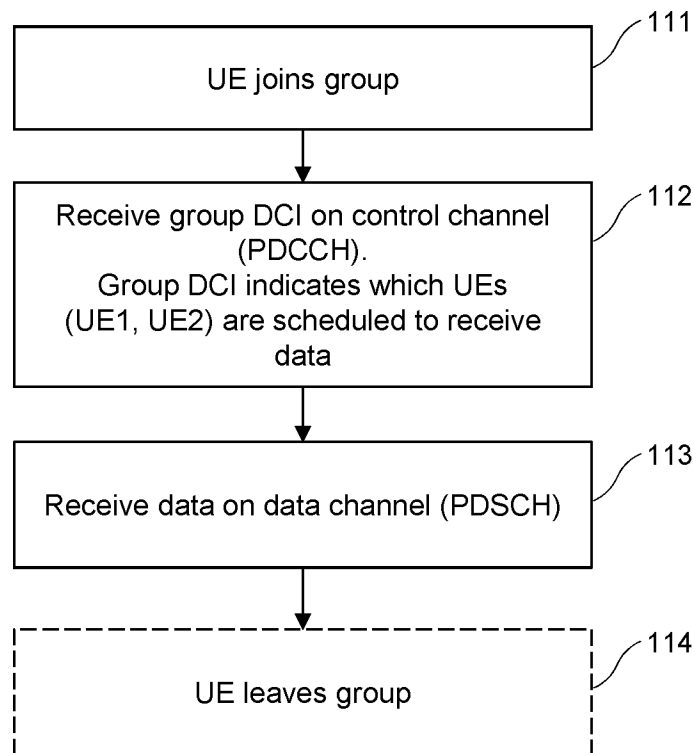


Fig. 4

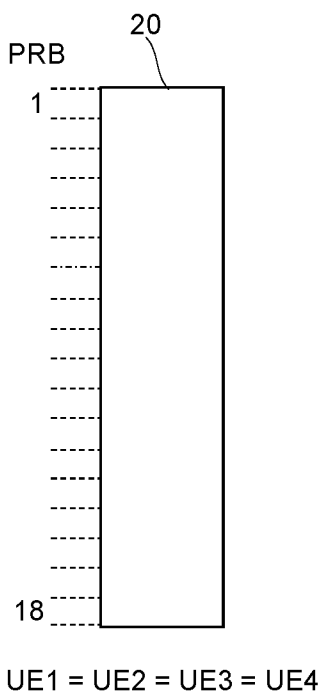


Fig. 5A

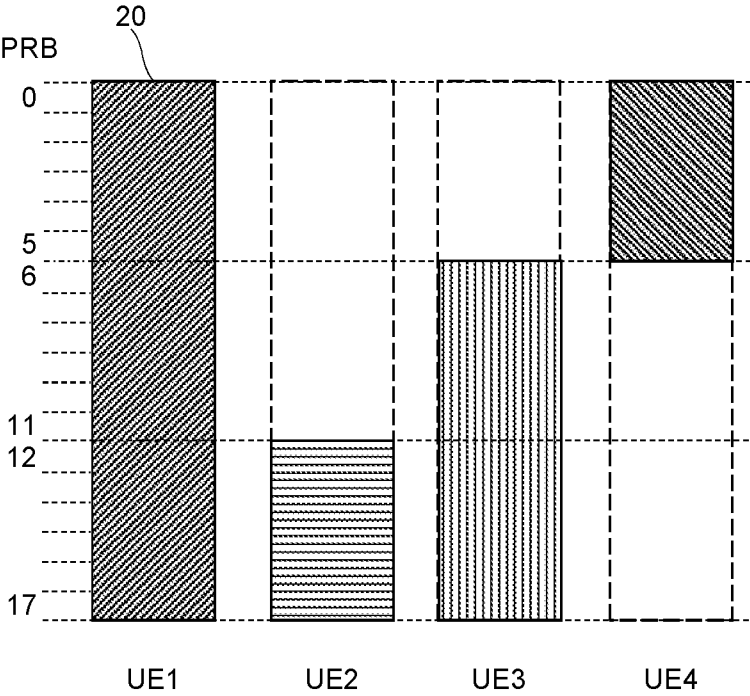


Fig. 5B

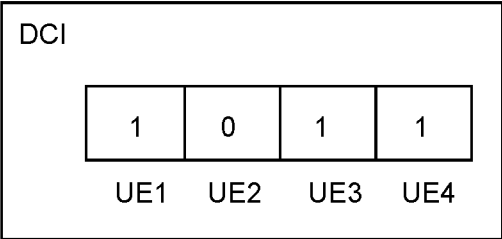


Fig. 6

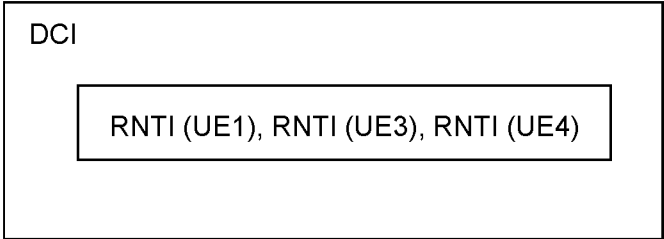


Fig. 7

Table 7.3.1.2.2-1: Antenna port(s) (1000 + DMRS port), *DL-DMRS-config-type*=1, *DL-DMRS-max-len*=1

One Codeword: Codeword 0 enabled, Codeword 1 disabled		
Value	Number of DMRS CDM group(s) without data	DMRS port(s)
0	1	0
1	1	1
2	1	0,1
3	2	0
4	2	1
5	2	2
6	2	3
7	2	0,1
8	2	2,3
9	2	0,2
10	2	0,3
11	2	0,2
12-15	Reserved	Reserved

Fig. 8

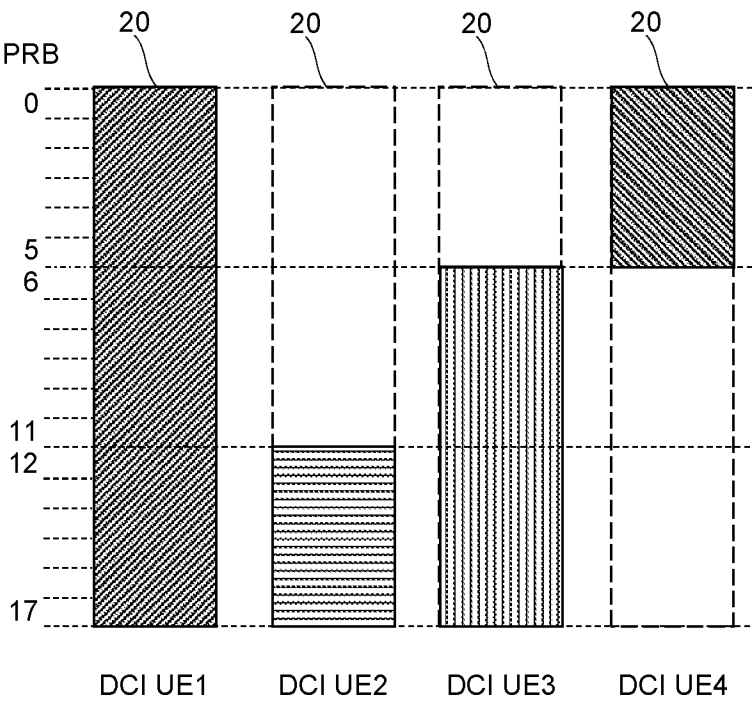


Fig. 9

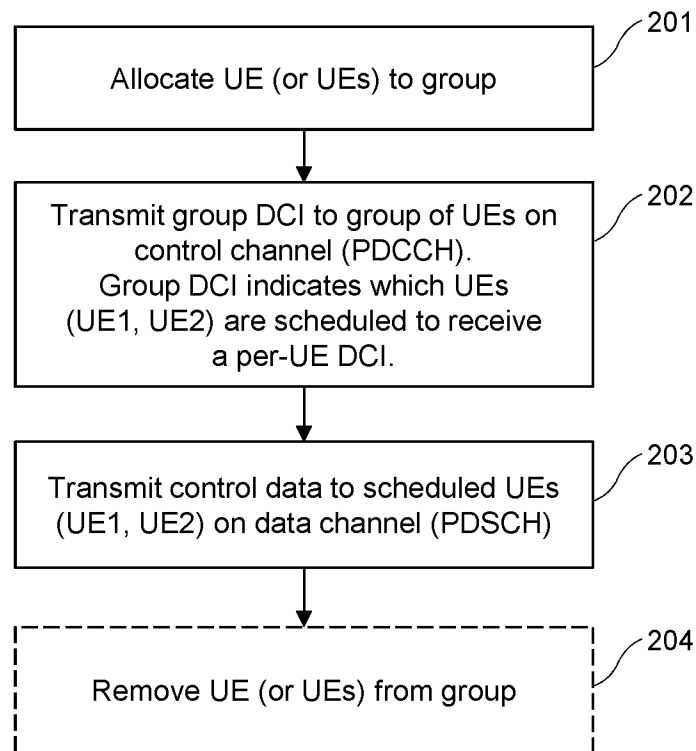


Fig. 10

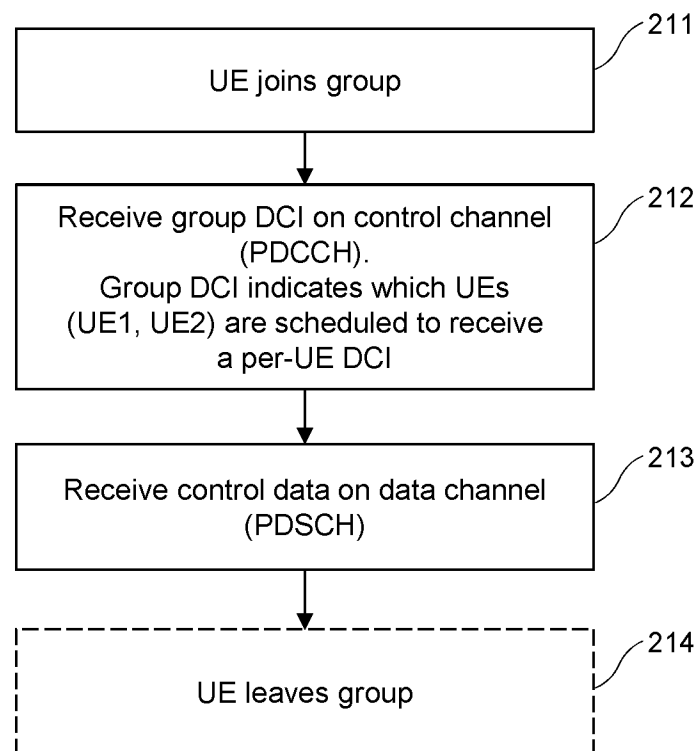


Fig. 11

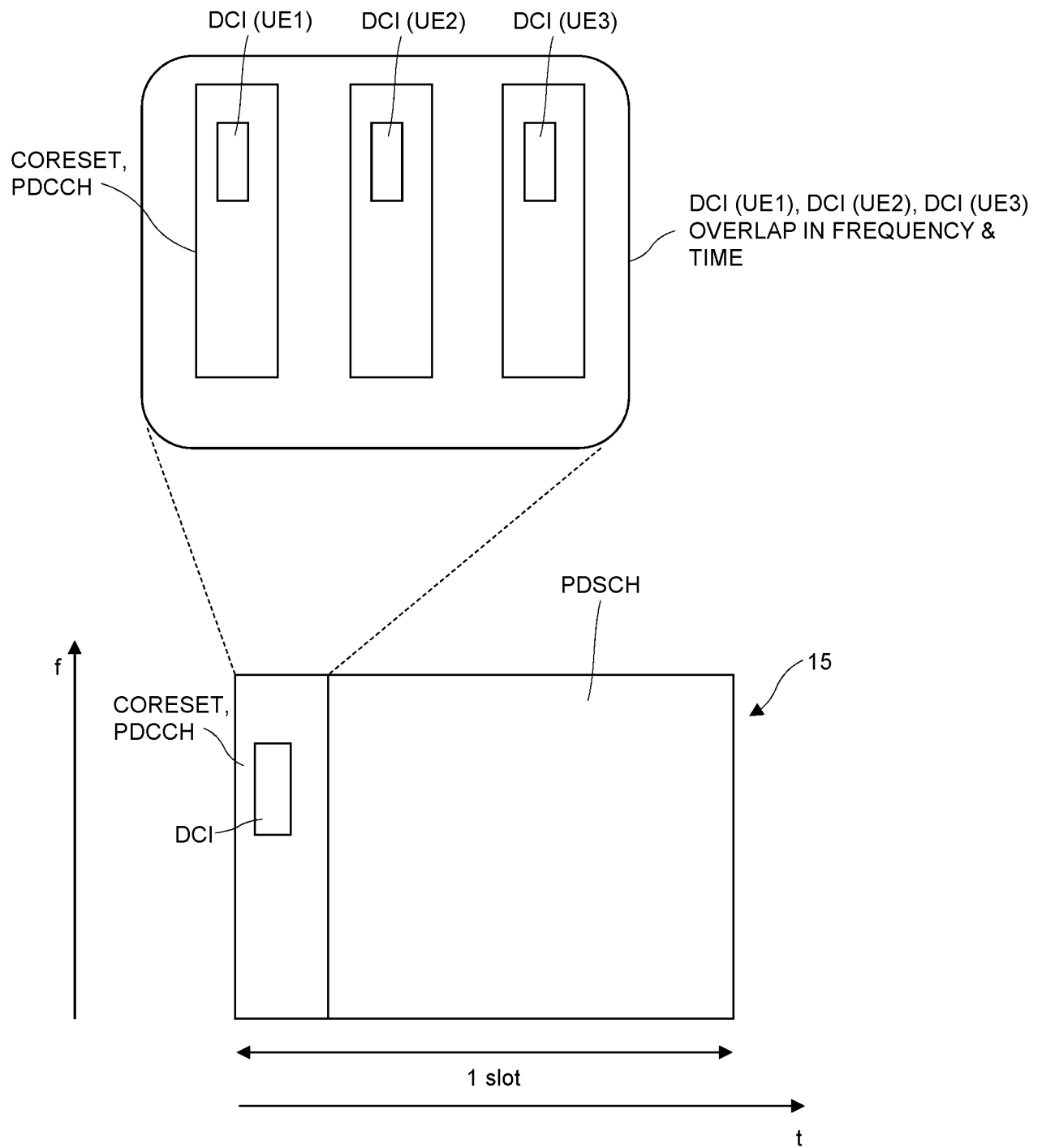


Fig. 12

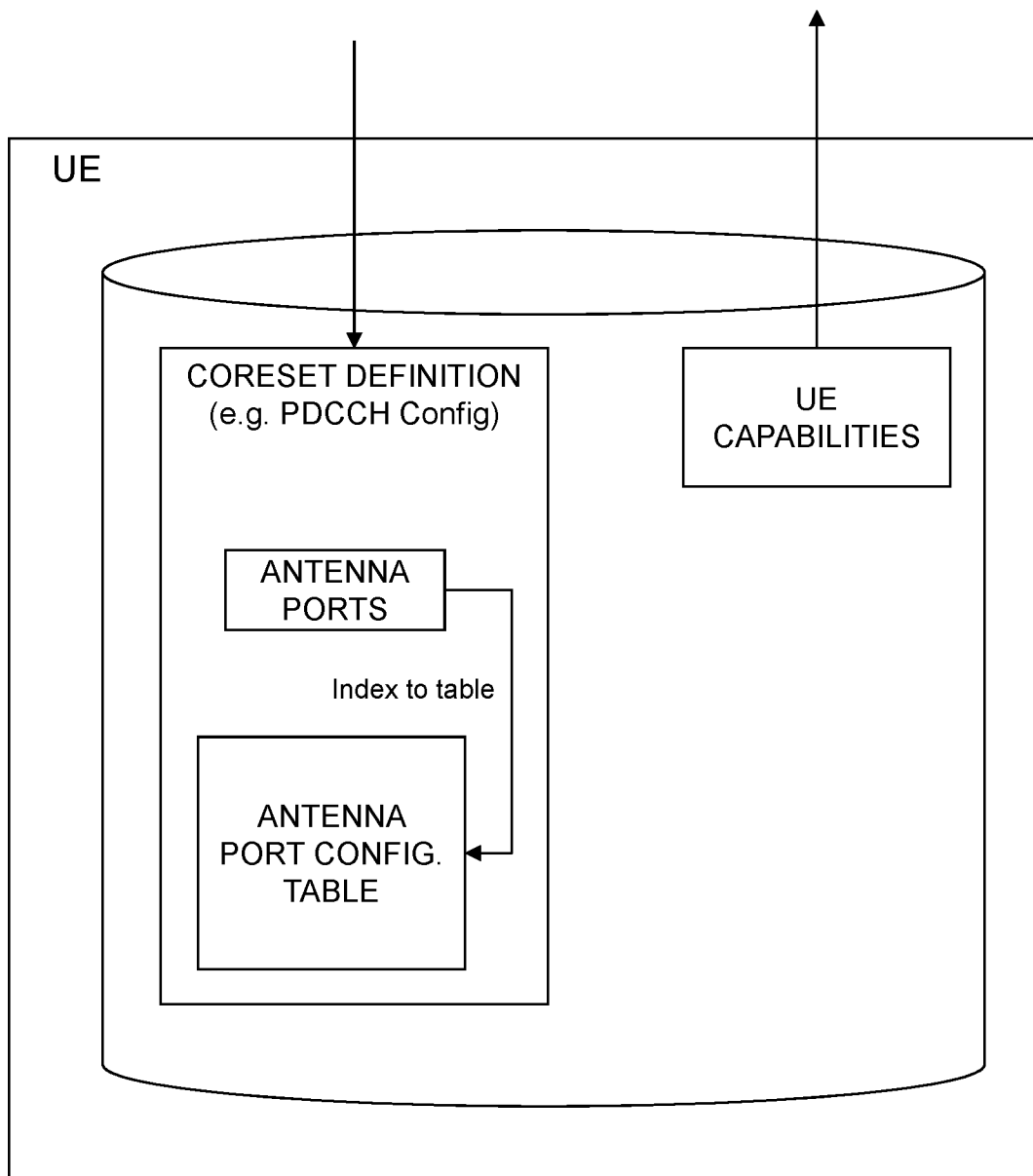


Fig. 13

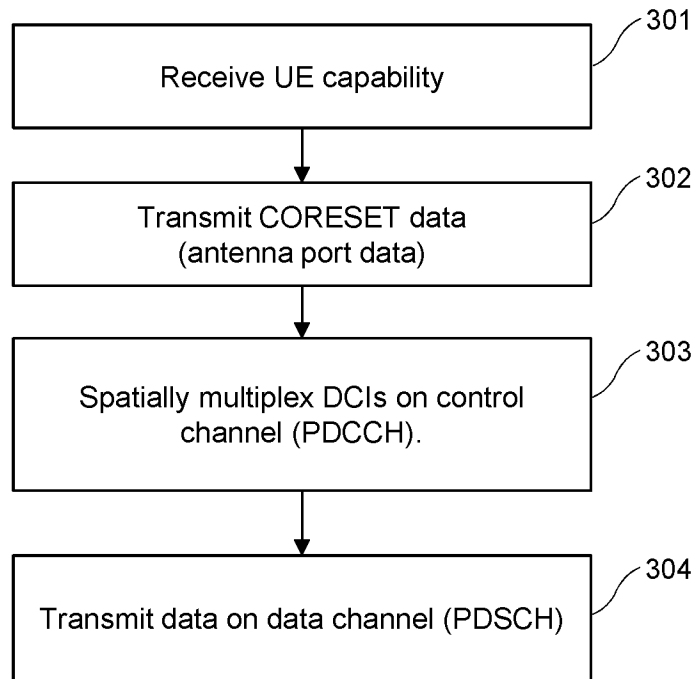


Fig. 14

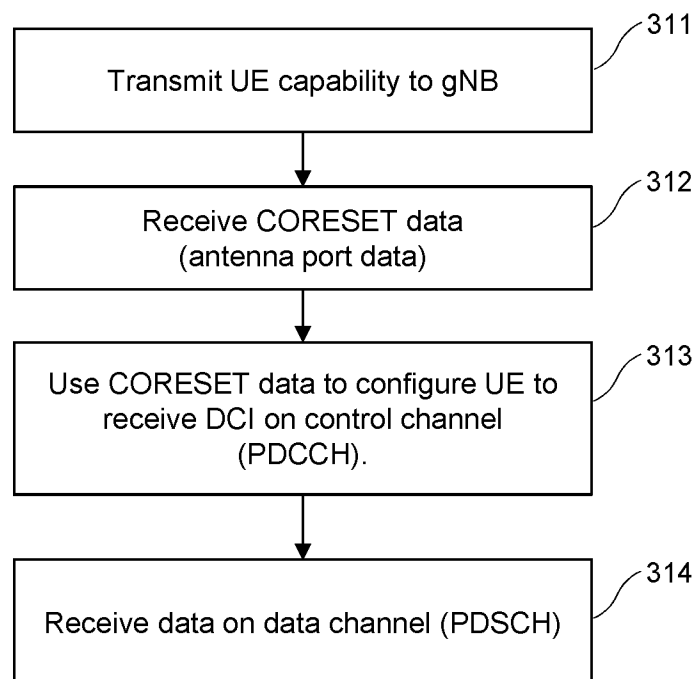


Fig. 15

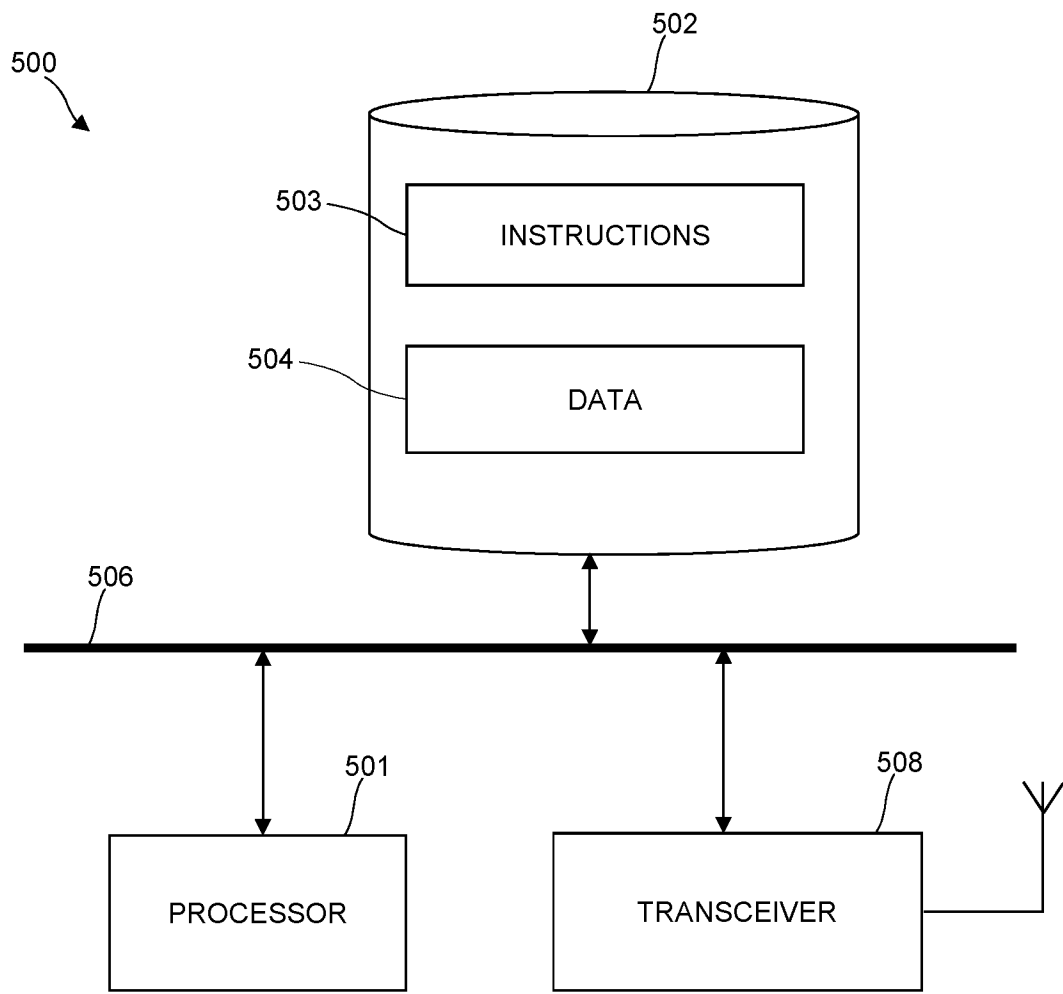


Fig. 16

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2019/108061

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/00(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)

H04W; H04Q; 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)

CNPAT, CNKI, EPODOC, WPI, 3GPP: group DCI, MU-DCI, UE-specific DCI, MULTIPLEX+, RNTI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2018108057 A1 (MEDIATEK INC.) 21 June 2018 (2018-06-21) description, paragraphs [0019]-[0026] and figures 1, 2	1-38
X	CN 101998611 A (HUAWEI TECHNOLOGIES CO., LTD.) 30 March 2011 (2011-03-30) description, paragraphs [0045]-[0071]	1-38
X	CN 108174453 A (ZTE CORPORATION) 15 June 2018 (2018-06-15) description, paragraphs [0060]-[0145]	1-38
A	HUAWEI, HISILICON. "SRS configurations for eLAA" 3GPP TSG RAN WG1 Meeting #85 R1-164074, 27 May 2016 (2016-05-27), the whole document	1-38

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

* Special categories of cited documents:

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

22 November 2019

Date of mailing of the international search report

27 December 2019

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Telephone No. 86-(10)-53961587

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2019/108061

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
WO	2018108057	A1	21 June 2018	EP	3530046	A1	28 August 2019
				US	2018167959	A1	14 June 2018
				CN	108432307	A	21 August 2018
				TW	201831001	A	16 August 2018
CN	101998611	A	30 March 2011	None			
CN	108174453	A	15 June 2018	WO	2018103558	A1	14 June 2018