(54) **METHODS AND APPARATI FOR AN EXTENSIBLE AND SCALABLE CONTROL CHANNEL FOR WIRELESS NETWORKS**

VERFAHREN UND VORRICHTUNGEN FÜR EINEN ERWEITERBAREN UND SKALIERBAREN STEUERKANAL FÜR DRAHTLOSE NETZWERKE

PROCÉDÉS ET APPAREILS POUR UN CANAL DE COMMANDE EXTENSIBLE ET ÉVOLUTIF DANS DES RÉSEAUX SANS FIL

(72) Inventor: **AHMADI, Sassan**
Cupertino, CA 95014 (US)

(74) Representative: **Barnfather, Karl Jon**
Withers & Rogers LLP
4 More London Riverside
London SE1 2AU (GB)

(56) References cited:
WO-A1-2011/137383

• **LG ELECTRONICS INC: "R-PDCCH interleaving alternatives", 3GPP DRAFT; R1-103736 R-PDCCH INTERLEAVING ALTERNATIVES_FINAL, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Dresden, Germany; 20100628, 22 June 2010 (2010-06-22), XP050449167, [retrieved on 2010-06-22]**
• **INTEL CORPORATION: "Performance Analysis of the Enhanced Downlink Control Signalling", 3GPP DRAFT; R1-113202_EPDCCH, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Zhuhai; 20111010, 4 October 2011 (2011-10-04), XP050538324, [retrieved on 2011-10-04]**
• **HUAWEI: "Considerations on R-PDCCH for Type 1 relays", 3GPP DRAFT; R1-092375, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, no. Los Angeles, USA; 20090624, 24 June 2009 (2009-06-24), XP050350893, [retrieved on 2009-06-24]**

EP 2 777 209 B1

- **LG ELECTRONICS: "Performance evaluation of multiplexing schemes for enhanced PDCCH transmission", 3GPP DRAFT; R1-113195_PERFORMANCE EVALUATION OF MULTIPLEXING SCHEMES FOR ENHANCED PDCCH TRANSMISSION, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Zhuhai; 20111010, 4 October 2011 (2011-10-04), XP050538317, [retrieved on 2011-10-04]**
- **ZTE: "The interleaving schemes of R-PDCCH", 3GPP DRAFT; R1-101822 INTERLEAVING R-PDCCH, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Beijing, china; 20100412, 6 April 2010 (2010-04-06), XP050419210, [retrieved on 2010-04-06]**
- **ERICSSON ET AL: "On enhanced PDCCH design", 3GPP DRAFT; R1-112928, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Zhuhai; 20111010, 4 October 2011 (2011-10-04), XP050538137, [retrieved on 2011-10-04]**

Description

Priority

[0001] This application claims priority to U.S. Patent Application Serial No. 13/557,121 filed July 24, 2012, entitled "METHODS AND APPARATUS FOR AN EXTENSIBLE AND SCALABLE CONTROL CHANNEL FOR WIRELESS NETWORKS", which claims priority to U.S. Provisional Patent Application Serial No. 61/557,329 filed November 8, 2011, entitled "METHODS AND APPARATUS FOR AN EXTENSIBLE AND SCALABLE CONTROL CHANNEL FOR WIRELESS NETWORKS".

Background

1. Technical Field

[0002] The present disclosure relates generally to the field of wireless communication and data networks. More particularly, in one exemplary aspect, the disclosure is directed to methods and apparatus for an extensible and scalable control channel for wireless networks.

2. Description of Related Technology

[0003] A cellular network operator provides mobile telecommunications services to a population of cellular user devices via a network infrastructure of e.g., cellular base stations (BS), base station controllers, infrastructure nodes, etc. One important aspect of cellular network operation relates to the control and management of the network resources. Within certain cellular technologies, a so-called "control channel" is dedicated to exchanging control information between the cellular base station, and the population of cellular user equipment.

[0004] Control channel design faces many challenges. In particular, a device is unaware of network operation until after the device has successfully decoded the control channel. For this reason, prior art control channels have allocated a pre-determined set of resources for control channel operation. Thus, even if a mobile device has no other information about a network, the mobile device can find the control channel based on the known predetermined set of resources.

[0005] However. while control channels are necessary for network operation, they reduce the amount of resources available for data transfer. Consequently, given the pre-determined nature of existing control channel implementations. existing networks are typically inefficient, as the pre-determined control resources are purposely conservative, and not always fully utilized.

[0006] Still further, due to the importance of control channel information, significant effort is spent ensuring that control channel information is accurately received by the receiver. Existing solutions employ multiple countermeasures to protect control channel delivery, including for example robust coding schemes, and relatively higher transmission power for control channels. Unfortunately, these countermeasures also contribute to network underutilization. For example, robust coding schemes are based on increasing redundancy (i.e., useful data is padded with redundant information); similarly, higher transmission power can increase interference in other channels.

Higher control channel power also can adversely impact battery longevity in e.g., mobile cellular devices.

[0007] Accordingly, improved solutions for control channel operation within existing and future cellular networks is needed. Improved control channel operation would ideally: (i) increase control channel capacity, (ii) improve control channel scalability (iii) provide interference avoidance coordination, and (iv) reduce control channel overhead. Another example of a prior art system can be found disclosed in, for example, WO2011/137383 A1.

Summary

[0008] The present disclosure satisfies the aforementioned needs by providing, *inter alia,* improved apparatus and method for an extensible and scalable control channel for wireless networks, according, respectively , to appended claims 1 and 5. The embodiments that do not fall under the scope of the claims have to be interpreted as examples useful for understanding the invention.

Brief Description of the Drawings

[0009]

FIG. 1 is a graphical illustration of the prior art Long Term Evolution (LTE) control channel structure.

FIG. 2A illustrates one exemplary Enhanced NodeB (eNB) and an array of Remote Radio Heads (RRH) which are used to provide improved coverage for a population of User Equipments (UEs), useful in conjunction with various aspects of the present disclosure.

FIG. 2B is a graphical illustration of one embodiment of a structure for enhanced Physical Downlink Control Channel (ePDCCH) regions according to the present disclosure.

FIG. 2C is a graphical representation of one exemplary procedure for forming ePDCCH regions over a slot according to one embodiment of the present disclosure.

FIG. 3 is a graphical representation of the contents of the ePDCCH region according to one embodiment of the present disclosure.

FIG. 4 is a graphical representation of the structure of the physical resource block according to one embodiment of the present disclosure.

FIG. 5 is a graphical representation of the relative location of ePDCCH in time and frequency in backward compatible and non-backward compatible car-

rier types according to one embodiment of the present disclosure.

FIG. 6 is a functional block diagram illustrating one embodiment of a client or user device incorporating the enhanced control channel functionality of the present disclosure.

FIG. 7 is a functional block diagram illustrating one embodiment of a server device incorporating the enhanced control channel functionality of the present disclosure.

FIG. 8 is a functional block diagram illustrating one embodiment of a method for dynamic allocation of resources for transmission of control information within an extensible and scalable control channel of a wireless network, according to the present disclosure.

Detailed Description

[0011] Reference is now made to the drawings, wherein like numerals refer to like parts throughout.

Detailed Description of Exemplary Embodiments

[0012] Exemplary embodiments of the present disclosure are now described in detail. While these embodiments are primarily discussed in the context of a third generation UMTS wireless network (3G), and more specifically in one variant to LTE (3.9G) and fourth generation LTE-A (4G) networks, it will be recognized by those of ordinary skill that the present disclosure is not so limited. In fact, the various aspects of the disclosure are useful in any wireless network that can benefit from extensible and scalable control channels for wireless networks described herein.

[0013] As used herein, the term "wireless" means any wireless signal, data, communication, or other interface including without limitation Wi-Fi, Bluetooth, 3G (e.g., 3GPP, 3GPP2, and UMTS), HSDPA/HSUPA, TDMA, CDMA (e.g., IS-95A, WCDMA, etc.), FHSS, DSSS, GSM, PAN/802.15, WiMAX (802.16), 802.20, narrowband/FDMA, OFDM, PCS/DCS, analog cellular, CDPD, satellite systems, millimeter wave or microwave systems, acoustic, and infrared (i.e., IrDA).

[0014] Furthermore, as used herein, the term "network" refers generally to any type of data, telecommunications or other network including, without limitation, data networks (including MANs, PANs, WANs, LANs, WLANs, micronets, piconets, internets, and intranets), satellite networks, cellular networks, etc.

Prior Art Physical Downlink Control Channel (PD-CCH) -

[0015] Referring now to FIG. 1, one illustration of the prior art Long Term Evolution (LTE) control channel structure 100 is shown. Each frame spans 10ms and, consists of ten (10) subframes (numbered #0 to #9); where each subframe consists of two (2) slots (numbered #0, #1); and each slot consists of seven (7) OFDM symbols (numbered #0 to #6). The entire LTE bandwidth is split into N "sub-carriers" where N denotes the size of the FFT/IFFT. LTE data is transferred according to this time-frequency "resource grid". As shown, the downlink control signaling is located at the start of each downlink subframe, and may span up to the first three (3) OFDM symbols.

[0016] Downlink control signaling consists of three physical channels: (i) the Physical Control Format Indicator Channel (PCFICH), (ii) the Physical Hybrid-ARQ (Automatic Repeat Request) Indicator Channel (PHICH), and (iii) the Physical Downlink Common Control Channel (PDCCH). Each of the foregoing is described in greater detail hereinafter.

[0017] The PCFICH indicates the number of Orthogonal Frequency Division Multiplexing (OFDM) symbols (1, 2, or 3) used for control signaling in this subframe. The PCFICH contains a codeword which corresponds to the appropriate length of the PDCCH. The PCFICH is mapped onto the first OFDM symbol when present, however the PCFICH is only transmitted when the number of OFDM symbols for PDCCH is greater than zero.

[0018] The PHICH contains an acknowledgement (ACK) or non-acknowledgement (NACK) for uplink data transmission. PHICHs are located in the first OFDM symbol of each subframe, and are sent four (4) subframes after the HARQ-ed transmission across several (for example, if an uplink transmission occurs in subframe n, the corresponding PHICH will be in subframe n+4). A PHICH is carried by several Resource Element Groups (REGs); as a brief aside, each REG contains four (4) time-frequency Resource Elements (RE) and each RE corresponds to a specific time-frequency unit defined by a subcarrier and a symbol. Multiple PHICHs can share the same set of REGs using orthogonal spreading sequences as a so-called "PHICH group". Each PHICH is identified by two parameters: the PHICH group number, and the orthogonal sequence index within the group.

[0019] The PDCCH carries the downlink scheduling assignments and uplink scheduling grants for each UE. In slightly more detail, the PDCCH is transmitted on one or more consecutive Control Channel Elements (CCEs), where a CCE corresponds to a multiple of nine (9) Resource Element Groups (REGs). Briefly, the PDCCH carries scheduling assignments and other control information in the form of Downlink Control Information (DCI) messages. Each DCI is generated based on a set of parameters that includes: the number of downlink Resource Blocks (RBs), the DCI format, etc. The DCI messages are processed (e.g., channel coded, scrambled, modulated, precoded, and mapped to complex symbols), and mapped onto REs. The REGs/CCEs allocated for each downlink control signaling transmission are composed

of these resultant REs.

[0020] As previously mentioned, the control region of a subframe (e.g., the first one, two or three OFDM symbols spanning the entire frequency band) contains PDCCHs for multiple UEs, thus each UE has to monitor a comparatively large area to extract its own control information (which is only a fraction of the entire control region). Since the UE does not know ahead of time the control channel structure, the UE has to decode the entire control region (the first three symbols of the entire spectral bandwidth). This imposes a substantial burden on the UE; the significant burden of control channel decoding increases the component complexity (and cost), and also reduces the performance of the UE and to some degree adds to battery drain.

[0021] More generally, the existing PDCCH structure was designed to provide control signaling and resource assignments for User Equipments (UEs) based on a single transmission point per macro-cell usage scenario. However, many usage scenarios have emerged which do not fall into a single transmission point paradigm. Several of these scenarios are described in greater detail hereinafter.

[0022] In one such example, significant research has been directed to Coordinated Multiple Point (CoMP) techniques that enable transmission and reception of signals from multiple cell sites. In various CoMP scenarios, multiple cell sites can coordinate transactions. For instance, in so-called "CoMP scenario 4" (as described within 3GPP TR 36.819 Technical Specification Group Radio Access Network; Coordinated multipoint operation for LTE physical layer aspects (Release 11) published September 2011), several Remote Radio Heads (RRH) having the same physical Cell Identifier (Cell ID) are deployed within a single macro-cell. Existing implementations of RRH can be considered geographically distinct antennas that are controlled by an eNB via a fiber (or other high-speed data link). Since each RRH has the same Cell ID, the RRHs are indistinguishable from the eNB by the UE. Thus, each RRH provides a virtually identical radio interface at a different physical location which results in improved physical coverage of the cell within an area. While CoMP scenario 4 provides improved coverage, CoMP scenario 4 does not provide any increase in capacity.

[0023] In another such example, within so-called "CoMP scenario 3", each RRH has a different Cell ID relative to the associated macro-cell. Since the eNB and RRHs share the same time/frequency resources but are no longer indistinguishable from one another, the eNB and RRH will interfere with one another causing significant intra-cell interference. Furthermore, in the context of CoMP scenario 3, the resource assignments corresponding to each RRH are under control of the eNB; each assignment has to be simultaneously transmitted to the RRHs to ensure proper coordination. However, this control overhead causes a significant increase in the number of resource assignments, and reduces the number of

available Control Channel Elements (CCEs) per subframe. Thus, the requirements of CoMP scenario 3 can significantly strain the limited capacity of existing PDCCH operation. Moreover, in this context, techniques for detecting existing PDCCH structures in subframes with strong interference may be unsatisfactory. Proposed solutions include, for example, scheduling an Almost Blank Subframe (ABS) in one node to reduce interference while other nodes are transmitting. Unfortunately, ABS schemes require the blanking network node to reduce its own activity (e.g., transmission power) in the ABS, which is very inefficient from a spectral utilization standpoint. As with CoMP scenario 4, CoMP scenario 3 consumes significant control channel capacity.

[0024] Furthermore, several improvements have been made since the initial PDCCH design (PDCCH is described within 3GPP TS 36.300, "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 11), published September 2011). Specifically, new transmission modes have been implemented or proposed based on UE-specific reference signals that have been designed to support Multi-User Multiple Input Multiple Output (MU-MIMO). For example, it is anticipated that so-called "Transmission Mode 9" will be widely used in future deployments (Transmission Mode 9 is described within 3GPP TS 36.213 Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures, published March 2012). Transmission Mode 9 enables seamless switching between Single User MIMO (SU-MIMO) and MU-MIMO. Unfortunately, the Downlink Control Information (DCI) format used with Transmission Mode 9 (i.e., DCI format 2C) has a very large payload size. Since, the existing PDCCH structure has a fixed format (only 1, 2, or 3 of the first OFDM symbols of a subframe), the PDCCH must operate with fewer resource assignments (i.e., fewer CCEs per subframe) in order to support the large payloads of e.g., DCI format 2C. Thus, existing PDCCH structures are poorly suited to handle new payload structures and/or payload structures of significant size.

[0025] Moreover, in certain environments, neighboring transmission nodes may interfere with each other. The existing PDCCH mechanisms in earlier releases of LTE may not be sufficient for robust transmission of control channels in dense and diverse deployments. For example, the enhancement of MIMO performance through improved Channel State Information (CSI) feedback for high priority scenarios is not directly targeted by the feedback enhancements in 3GPP TS 36.213 Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures, published March 2012. In fact, scenarios where multiple (e.g., four (4)) transmit antennas operate in a cross-polarized configuration have yet to be studied in homogeneous and heterogeneous scenarios. While it

is currently not known whether existing solutions can provide sufficient performance, it is likely that current solutions provide inadequate interference avoidance coordination.

[0026] Furthermore, due to capacity limits of existing PDCCH structures, some data resources may not be timely allocated. For example, existing PDCCH structures use a hashing function to map CCEs within the so-called "control region". Those of ordinary skill in the related arts will recognize that a hashing function does not guarantee unique mappings, and in some cases two or more candidate sets can collide. The probability of collision is further exacerbated when UEs choose aggregation levels greater than one. During collisions, the number of assignments that can be transmitted on the PDCCH are limited (i.e., only the one of the candidate sets is transmitted), which reduces the overall user throughput and increases the overall transmission latency.

[0027] Additionally, existing PDCCH structures were designed based on an assumed single frequency partition in each slot/subframe with a frequency reuse factor of one. Colloquially, this is known as "hard" frequency partitioning. In contrast, "soft" frequency partitioning schemes can be dynamically changed in software to adjust to different partitioning schemes and accommodate different frequency reuse schemes. Hard frequency partitioning cannot be used with Fractional Frequency Reuse (FFR) techniques. FFR in conjunction with soft frequency partitioning can be used to mitigate interference, resulting in improved robustness and reliability of control and data signaling. Furthermore, use of frequency division multiplexing of data and control regions would allow for finer power control for each channel.

[0028] Still further, existing PDCCH operation relies on Cell-specific Reference Signals (CRS) for channel estimation and coherent detection. Empirically, CRS schemes require significant overhead (e.g., the CRS does not contain any useful information and is broadcast at significant power) and are ineffective for certain applications (e.g., closed-loop precoding techniques, beamforming and Multi-User Multiple Input Multiple Output (MU-MIMO)).

[0029] Finally, existing PDCCH operation is based on a resource allocation granularity of one, two, or three OFDM symbols for the PDCCH. Each OFDM symbol consumes approximately 7% of network overhead; this resource allocation granularity is quite large, and contributes to an excessive amount of wasted resources.

[0030] Existing solutions for LTE PDCCH have significant limitations, including: (i) limited capacity, (ii) limited payload capabilities, (iii) inadequate interference avoidance coordination, (iv) poor user throughput, (v) insufficient frequency reuse capabilities, (vi) no beamforming capabilities, and (vii) excessive overhead. Accordingly, an improved extensible and scalable solution for control channel operation within existing and future cellular networks is needed.

"Enhanced" Physical Downlink Control Channel -

[0031] In view of the deficiencies of the existing PDCCH structure, new and improved solutions for an Enhanced Physical Downlink Control Channel (ePDCCH) are desired. Ideally, an improved ePDCCH should exhibit one or more of the following attributes: (i) support increased control channel capacity, (ii) support frequency-domain Enhanced Inter-cell Interference Coordination (eICIC), (iii) achieve improved spatial reuse of control channel resource, (iv) support beamforming and/or diversity, (v) operate on new carrier types and support future enhancements to physical layer features such as e.g., Multicast Broadcast Single Frequency Networks (MBSFN) subframes (see e.g., 3GPP TS 36.211 Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 10), published March 2011), (vi) coexist on the same carrier technologies with legacy UEs, and/or (vii) use frequency-selective scheduling to mitigate inter-cell interference.

[0032] Accordingly, in one exemplary embodiment of the present disclosure, an ePDCCH region is defined in the time and frequency domain. Unlike prior art PDCCH channel structures which are limited to the first few symbols of each subframe and transmitted over the entire spectral bandwidth of a cell, in one variant the ePDCCH is distributed throughout the spectral bandwidth according to a frequency, time, and/or transmitter. In one such variant, each Remote Radio Head (RRH) is allocated an ePDCCH region that is defined according to according to a set of one or more enhanced CCE (eCCE), where each eCCE is further encapsulated within a single Physical Resource Block (PRB) in each slot/subframe. Each exemplary PRB consists of twelve (12) consecutive subcarriers for a single slot. Moreover, each RRH is associated with a subset of the users of the cell; thus each ePDCCH region can be reduced to only the spectral resources necessary to serve the subset of users associated with the RRH.

[0033] As a brief aside, a PRB is the smallest granularity of spectral resources that an exemplary LTE evolved NodeB (eNB) can schedule. Depending on the size of the eCCE, there may be one or more eCCEs within a PRB. As described in greater detail hereinafter, this configurable structure enables, *inter alia,* frequency division multiplexing of ePDCCH with other channels such as e.g., Physical Downlink Shared Channels (PDSCH). For example, PDSCH can advantageously be interleaved into spectral bandwidths that are unused by the ePDCCH (and *vice versa*).

[0034] Additionally, the flexible eCCE structure can accommodate multiple DCI formats which are necessary to support current and future applications and enhanced modes (e.g., Multiple Input Multiple Output (MIMO), etc.). Furthermore, the resource blocks used for ePDCCH may be permuted and allocated in a localized or distributed manner to exploit frequency diversity gain.

[0035] In one exemplary variant, Demodulation Reference Signals (DM-RS) are exclusively used for channel estimation and coherent detection within resource blocks assigned to a particular user. By removing the reliance on Cell-specific Reference Signals (CRS) for channel estimation and coherent detection, various embodiments of the present disclosure can be further leveraged with MU-MIMO and beamforming schemes for providing ePDCCH. Specifically, the UE can adjust reception according to existing DM-RS signaling according to existing beamforming techniques. Using the beamforming weighting vectors, the UE can receive ePDCCH from the serving BS. The ability to receive a beamformed ePDCCH greatly improves network reliability and coverage.

[0036] Moreover, in one backward compatible variant, the ePDCCH can be further subdivided into an "even-region" and an "odd-region". The even-region ePDCCH shares the even numbered slots with legacy PDCCH formats. The odd-region ePDCCH occupies the odd numbered slots. This configuration ensures backward compatibility and legacy support while introducing a new frequency division multiplexed (FDM) control structure.

[0037] In one such embodiment, the search spaces (both common and UE specific) of the Release 11 UEs is separated from those of earlier releases. This allows independent operation of Release 11 UEs and eNBs in so-called "green-field" deployments (i.e., where no previous network infrastructure has been deployed) without depending on legacy configurations, which results in lower overhead.

[0038] Additionally it will be appreciated, that similar (if not identical) structures can be used for time division duplexing (TDD) and frequency division duplexing (FDD) networks. This dual natured structure for ePDCCH in TDD and FDD operation can reduce the cost and complexity of multi-mode devices.

[0039] Finally, since some networks have favored small-sized cells and small-range dense deployments, some variants may use higher modulation orders such as 16QAM (Quadrature Amplitude Modulation) for baseband processing of the control channels. Specifically, the lower path loss and higher operational SINRs (Signal to Interference plus Noise Ratios) enabled by various aspects of the present disclosure are particularly well suited to small and dense cell deployments, although by no means limited thereto.

[0040] One exemplary embodiment of an Enhanced Physical Downlink Control Channel (ePDCCH) structure that satisfies the current expectations while also remaining extensible and scalable for future improvements and modifications is now described in greater detail herein. FIG. 2A illustrates one exemplary Enhanced NodeB (eNB) 202 and an array of Remote Radio Heads (RRH) 204 which are used to provide improved coverage for a population of User Equipments (UEs) 206. As shown, each RRH provides a small area of coverage which augments the cell that is provided by the eNB. However, it is important to note that the coverage area for each RRH (~100ft) is significantly smaller than the range of the cell (e.g., up to a mile).

[0041] FIG. 2B illustrates one high-level conceptualization of the exemplary ePDCCH structure and design 250. The frequency resources in each slot (or subframe depending on the desired time-domain granularity and the choice of Transmission Time Interval (TTI)) are partitioned into a number of Frequency Partitions (FP), where each frequency partition contains one or more ePDCCH regions. Each ePDCCH region consists of an integer number of physically consecutive (localized) or logically consecutive (distributed) physical resource blocks (PRBs). Each ePDCCH region may be assigned to one or more Remote Radio Heads (RRH) associated with a macro-cell.

[0042] As shown in FIG. 2B, the ePDCCH regions 252 are located in the same or different frequency partitions 254. In one exemplary embodiment, the partitioning of frequency resources is flexible and can be dynamically configured, e.g., the frequency resources may change over time based on a cell-specific, semi-static or dynamic pattern. The ePDCCH regions are located in predetermined (configurable) frequency partitions and the beginning of each region is calculated based on a frequency offset (FO) 256 from the reference location.

[0043] Referring now to FIG. 2C, the exemplary procedure 260 for forming the frequency partitions and the ePDCCH regions is illustrated. At step 262 of the method 260, the PRBs are permuted over the entire available system bandwidth to exploit frequency diversity gain. The permuted PRBs are regrouped and form frequency partitions FP_0 to FP_K (step 264). The number of frequency partitions is configurable and depends on the network deployment parameters and topology. At step 266, a second-level permutation may be applied to the PRBs within each frequency partition to further exploit frequency diversity gain. Once the PRBs have been evenly distributed over the spectral bandwidth, at step 268 the permuted PRBs within each partition can be divided into one or more ePDCCH regions. The grouping and the number of ePDCCH regions depend on the number and the relative position of the RRHs that may or may not share the same cell ID within a macro-cell. In one exemplary embodiment, RRHs which are in close proximity to one another will have different ePDCCH regions to minimize ePDCCH interference.

[0044] FIG. 3 illustrates one exemplary ePDCCH region in further detail. As shown, each ePDCCH region 302 contains one or more ePDCCH 304 corresponding to the UEs that are served by the eNB (e.g., ePDCCH1 corresponds to UE1, ePDCCH2 corresponds to UE2, etc.). The location of the ePDCCH regions and individual ePDCCH channels are coordinated across neighboring eNBs to reduce the inter-cell interference (e.g., across multiple eNBs, ePDCCH allocations for each eNB are scheduled so as to minimize collision with neighboring eNBs). Within each cell, the eNB coordinates the ePDCCH regions corresponding to Remote Radio Heads

(RRHs) managed within a cell. Each ePDCCH is mapped to a number of enhanced Control Channel Elements (eC-CEs) 306 depending on the desired aggregation level. One or more eCCEs are mapped to one or more PRB 308.

[0045]   FIG. 4 illustrates one exemplary structure of a Physical Resource Block (PRB) including Demodulation Reference Signals (DM-RS). As shown, the exemplary PRB 402 is 12 sub-carriers by 7 symbols. For an exemplary eCCE of 36 sub-carriers (or alternatively resource elements), the exemplary PRB (which consists of 84 resource elements) can hold up to two eCCE. As shown, the Demodulation Reference Signal (DM-RS) locations are based on one exemplary scenario where the same Orthogonal Cover Code (OCC) is used for multiplexing of two DM-RS corresponding to two transmit antennas. Higher order antenna configurations will include more DM-RS signals to support e.g., beamforming of the UE-specific control channels. Specifically, higher order antenna configurations can use additional DM-RS to create sharper and/or more complex beam footprints by adjusting the antenna powers to constructively interfere (i.e., within the beam footprint), and destructively interfere (i.e., out of the beam footprint). Moreover, where multiple eCCE are aggregated together (where multiple eCCEs are grouped for an ePDCCH), the aggregated eCCE units may be mapped to different PRBs to ensure maximal use of frequency diversity.

[0046]   Referring now to FIG. 5, two exemplary configurations (500, 550) are illustrated, the first configuration 500 remains compatible with legacy equipment, and the second configuration 550 is incompatible with legacy equipment. Since user traffic is allocated in PRB pairs over a subframe, in consideration for downlink link budget, the ePDCCH may or may not exist in each downlink slot. For smaller cell size variants, the existing minimum transmission time interval (TTI) of 1 ms may be further reduced to 0.5 ms (one slot). This shorter TTI further reduces the user-plane and control-plane latency and increases the spectral efficiency. In such variants, an eP-DCCH is required for each downlink slot, enabling resource allocations on a slot-by-slot basis. Moreover, it is recognized that this structure is the same for TDD and FDD duplex schemes. For example, depending on the TDD frame configuration mode, the ePDCCH can be transmitted in the downlink slots (or subframes) similar to that of FDD systems.

[0047]   Referring now to the first configuration 500, each subframe is split into an even and an odd slot. During the even slot, the legacy PDCCH is transmitted, and ePDCCH. During the odd slot, ePDCCH can be transmitted. It is appreciated that a legacy device can decode the legacy PDCCH normally within the first configuration; however, in addition enhanced devices can decode eP-DCCH in accordance with various aspects of the present disclosure. Moreover, it should be appreciated that the amount of information provided via the legacy PDCCH can be greatly reduced to only the information necessary

to service legacy devices, and enhanced devices can rely primarily on the ePDCCH. Furthermore, since the DPCCH has relatively large granularity (e.g., 7%), it is appreciated that a subset of enhanced devices may receive information via the PDCCH to fully utilize allocated PDCCH resources (as opposed to receiving information via a ePDCCH, while allocated PDCCH resources are left unused).

[0048]   In contrast to the first configuration 500, the second configuration 550 relies solely on ePDCCH for control information signaling. Operation of the second configuration requires either a population of enabled user devices, or alternately that legacy devices are precluded from access, or combinations thereof. In some variants, operation of the second configuration may be offered in tandem with a secondary bandwidth specifically to service legacy devices only (i.e., a first bandwidth is provisioned for enabled users and a second bandwidth is provisioned for legacy users).

[0049]   In comparison to prior art PDCCH structures, the ePDCCH is advantageously much more flexible and scalable. For example, the eDPCCH can support control signaling and resource assignments from multiple transmission points within macro-cell deployments. Consider Coordinated Multiple Point (CoMP) scenario 3 and CoMP scenario 4 operation (described *supra*) in conjunction with ePDCCH operation according to various aspects of the present disclosure; each RRH may transmit ePDCCH assignments without interfering with other RRHs, because their corresponding ePDCCH's time frequency resources are not shared among neighboring RRHs (i.e., neighboring RRHs are assigned to different ePDCCH regions). Since each RRH does not interfere with its neighbor RRHs, interference avoidance coordination can be handled much more effectively via extant interference mitigation. Specifically, since the neighbor RRHs only contribute unrelated interference, their transmissions can be treated effectively as uncorrelated noise.

[0050]   Similarly, arbitrarily large payloads can be accomodated by allocating more eCCE where necessary. This flexible payload capability can accommodate larger format DCIs (e.g., Transmission Mode 9, etc.). Moreover, since the size of ePDCCH regions can be larger (or smaller), collisions across different cells and inter-cell interference can be more effectively and flexibly mitigated]

[0051]   Furthermore, the ePDCCH can accommodate multiple frequency partitions to support e.g., soft frequency partitioning and/or Fractional Frequency Reuse (FFR) techniques. Specifically, the ePDCCH can be flexibly allocated across various PRBs to support various frequency allocations including e.g., several soft and configurable frequency partitions in each slot/subframe and frequency division multiplexing of control and data regions. Frequency division multiplexing of data and control regions allow for separate power control for each channel type.

[0052]   Moreover, various embodiments of the ePD-CCH perform channel estimation and coherent detection

via Demodulation Reference Signals (DM-RS) which are specific to a subscriber device, thus mitigating many of the inefficiencies of Cell-specific Reference Signals (CRS) based schemes (which are uniform for the entire cell and are not user specific). Additionally, the use of DM-RS (instead of CRS) is necessary to enable beamforming of control channels; in particular, user specific DM-RS can be configured on an antenna-by-antenna basis, to create a beamformed transmission. There is no such benefit to beamforming CRS which is cell-specific and used across the entire cell.

[0053] Finally, control channel overhead for a PRB-based ePDCCH can be much more efficient than prior art solutions. For example, prior art solutions reserve one or more OFDM symbols over the entire system bandwidth which consumes approximately 7% of overall system bandwidth for each OFDM symbol. In contrast, the resource allocation granularity (L1/L2 overhead per PRB) in the exemplary implementations of the disclosure is 2% for a 10 MHz system, and only 1% in a 20 MHz system.

Other Scenarios

[0054] Moreover, those of ordinary skill in the related arts will further recognize, given the contents of the present disclosure, that various aspects of the present disclosure are further useful in other applications. For example, in Carrier Aggregation (CA) based Enhanced Inter-cell Interference Coordination (eICIC) and heterogeneous networks, the ePDCCHs of macro nodes and low-power nodes can be transmitted on different component carriers. As a brief aside, CA allows a network to provision large chunks of bandwidth by aggregating multiple smaller bandwidths.]. Thus, in one exemplary embodiment, cross-carrier scheduling can be provided for the CA-enabled UEs. In cross-carrier scheduling, the ePDCCH is provided in a first carrier, and provides information regarding the operation of a second carrier of a CA system. In one variant, the ePDCCH resources on the cross-scheduled carrier are limited (thus the cross-scheduled carrier maintains some resources for its own traffic operation, etc.). In some further variants, the ePDCCH resource limitation can be adjusted to depend on the number of UEs configured with carrier aggregation in CA-based heterogeneous networks.

[0055] In another such example, inter-band carrier aggregation functionality includes scenarios where a lower frequency band is aggregated with a higher frequency band. Typically, larger coverage is achieved on the lower frequency band due to desirable propagation loss resistance of lower frequency bands. Accordingly, it is possible to increase the traffic channel coverage on the higher frequency band through cross-carrier scheduling from an ePDCCH on the lower frequency band. Specifically, unlike prior art solutions which use a fixed allocation for providing the PDCCH, the ePDCCH can be flexibly allocated within various frequency bands.

[0056] In yet other examples, additional carrier types can be supported in future systems (e.g., Release 11). For example, future releases may not be backward compatible; i.e., legacy PDCCH may not be transmitted on future spectrum. Without further enhancements in the downlink control channels, the PDSCH/PUSCH channels on the non-backward compatible carriers may only rely on cross-carrier scheduling from a backward compatible carrier. Given that the bandwidth and the number of UEs connected to the non-backward compatible carriers can be similar to backward compatible carriers, the PDCCH resource on the cross-carrier scheduling carrier (i.e., where PDCCH is sent) can be significantly limited. By providing more flexibility with an ePDCCH, future releases are no longer limited to cross-carrier scheduling from backward compatible carriers.

[0057] Various enhanced MIMO modes can also be supported with the new ePDCCH structure. The new ePDCCH substantially improves the robustness of the control channels and thus mitigates the interference among neighboring transmission nodes in dense and diverse deployments. Consequently, the ePDCCH structure allows interference avoidance/coordination by orthogonalizing the UEs in neighboring cells. Additionally, CoMP scenarios 3 and 4 will benefit from the ePDCCH structural flexibility, and capacity. Downlink control enhancement for carrier aggregation is primarily used in scenarios where cross-carrier scheduling is applied. The number of UEs configured with cross-carrier scheduling in each carrier aggregation scenario will determine whether ePDCCH is needed to support carrier aggregation scenarios.

[0058] In Release 8, Release 9 and Release 10, the control region of the PDCCH only supports transmit diversity transmission mode. The transmit diversity scheme is a robust transmission scheme but the efficiency may not be as good as beamforming based on spatial information especially in correlated environment. Unfortunately, increasing the number of transmit antennas may not yield higher MIMO gain for transmit-diversity-based PDCCH transmission, in fact in some preliminary testing transmit diversity actually results in performance degradation in some scenarios. Various embodiments of the present disclosure support beamforming which should further improve coverage.

[0059] Finally, in Release 8, Release 9 and Release 10, PDCCH only supports QPSK modulation. The ePDCCH should significantly improve link quality (e.g., due to precoding/beamforming), thus, ePDCCH should also support higher order modulation in high SINR region. Higher order modulation will increase the spectral efficiency, and reduce overall system overhead of control channel. In small-cell and dense deployments where the SINR is higher, ePDCCH can support higher order modulation (e.g., 16QAM) for the control channel.

Exemplary User Equipment (UE) Apparatus -

[0060] Referring now to FIG. 6, exemplary client or UE apparatus 600 useful in implementing the methods of the present disclosure is illustrated. As used herein, the terms "client" and "UE" may include, but are not limited to cellular telephones, smartphones (such as for example an *iPhone™*), personal computers (PCs), such as for example an *iMac™*, *Mac Pro™*, *Mac Mini™* or *MacBook™*, and minicomputers, whether desktop, laptop, or otherwise, as well as mobile devices such as handheld computers (e.g. *iPad™*), PDAs, personal media devices (PMDs), such as for example an *iPod™*, or any combinations of the foregoing. The configuration of control channel reception is preferably performed in software, although firmware and/or hardware embodiments are also envisioned; this apparatus is described subsequently herein with respect to FIG. 6.

[0061] The UE apparatus 600 includes a processor subsystem 605 such as a digital signal processor, microprocessor, field-programmable gate array, or plurality of processing components mounted on one or more substrates 608. The processing subsystem may also include an internal cache memory. The processing subsystem 605 is connected to a memory subsystem 607 including memory which may for example, include SRAM, flash and SDRAM components. The memory subsystem may implement one or a more of DMA type hardware, so as to facilitate data accesses as is well known in the art. In the illustrated embodiment, the processing subsystem additionally includes subsystems or modules for implementing the enhanced control channel functionality described previously herein. These subsystems may be implemented in software or hardware which is coupled to the processing subsystem. Alternatively, in another variant, the subsystems may be directly coupled to the digital baseband.

[0062] In one exemplary embodiment, the UE is additionally configured to identify control information regions according to one or more predetermined schemes. In some embodiments, the client device may be required to try decoding multiple "hypotheses" to determine the location of control channel information. For example, a UE may be configured to identify one or more physical resources containing or likely to contain control channel information. While it is undesirable to blindly search for control regions, searching a small set of hypotheses can significantly reduce network coordination requirements without undue performance losses in the UE operation. It will be appreciated, however, that the apparatus may also use external or provided information to help identify the control information regions of interest.

[0063] In one exemplary embodiment, the UE is configured to determine the control region according to a flexible frequency partitioning. In one such variant, the frequency partitioning is dynamically configured, e.g., the resources may change over time based on a cell-specific, semi-static or dynamic pattern. In other variants, the fre-

quency partitioning is fixed but distinct for each transmitter. For example, in cell-specific schemes the UE may be able to determine the control region according to the particular cell identifier it is connected to (e.g., the control region is selected based on a hash function based on the cell identifier, etc.). It is further appreciated that the control region may be applicable for only a subset of a cell; for instance, Remote Radio Head (RRH) may only provide enough coverage for a subset of the entire cell.

[0064] In still other embodiments, it is appreciated that the configurability of the control channel structure previously described enables dynamic decoding based on resource, usage, and/or network considerations. For instance, a UE could decode various elements of the ePDCCH to support certain applications or operations and/or disregard other elements of the ePDCCH for unnecessary applications or operations.

[0065] Various other aspects of the present disclosure are readily appreciated by those of ordinary skill in the related arts.

Exemplary Base Station (BS) Apparatus -

[0066] Referring now to FIG. 7, exemplary server or base station (BS) apparatus 700 useful in implementing the methods of the present disclosure is illustrated. As used herein, the terms "server" and "BS" include, but are not limited to base stations (e.g., NodeB, eNodeB, etc.), access points, relay stations, etc. The configuration of control channel transmission is preferably performed in software, although firmware and/or hardware embodiments are also envisioned; this apparatus is described subsequently herein with respect to FIG. 7.

[0067] The BS apparatus 700 includes a processor subsystem 705 such as a digital signal processor, microprocessor, field-programmable gate array, or plurality of processing components mounted on one or more substrates 708. The processing subsystem may also include an internal cache memory. The processing subsystem 705 is connected to a memory subsystem 707 including memory which may for example, include SRAM, flash and SDRAM components. The memory subsystem may implement one or a more of DMA type hardware, so as to facilitate data accesses as is well known in the art. In the illustrated embodiment, the processing subsystem additionally includes subsystems or modules for implementing the enhanced control channel functionality described previously herein. These subsystems may be implemented in software or hardware which is coupled to the processing subsystem. Alternatively, in another variant, the subsystems may be directly coupled to the digital baseband.

[0068] In one exemplary embodiment, the BS is additionally configured to transmit one or more dynamically configurable control information regions according to one or more predetermined schemes. In some variants, the dynamically configurable control information regions augment existing legacy schemes for control information

regions. In other variants, the dynamically configurable control information wholly supplants the legacy control information regions; these regions can be configured and/or signaled by the network to assist in faster acquisition.

[0069] In one exemplary embodiment, a user equipment (UE) is configured to determine the control region according to a flexible frequency partitioning. In one such variant, the frequency partitioning is dynamically configured, e.g., the resources may change over time based on a cell-specific, semi-static or dynamic pattern. In other variants, the frequency partitioning is fixed but distinct for each transmitter. For example, in cell-specific schemes the UE may be able to determine the control region according to the particular cell identifier it is connected to (e.g., the control region is selected based on a hash function based on the cell identifier, etc.). It is further appreciated that the control region may be applicable for only a subset of a cell; for instance, Remote Radio Head (RRH) may only provide enough coverage for a subset of the entire cell.

[0070] In still other embodiments, it is appreciated that the configurability of the control channel structure previously described enables dynamic decoding based on resource, usage, and/or network considerations. For instance, a UE could decode various elements of the eP-DCCH to support certain applications or operations and/or disregard other elements of the ePDCCH for unnecessary applications or operations. In yet other embodiments, the UE is configured to identify one or more physical resources containing or likely to contain control channel information. For example, the UE may attempt to decode multiple "hypotheses"; which it is undesirable to blindly search for control regions, searching a small set of hypotheses can significantly reduce network coordination requirements without undue burden on the UE. Specifically, the network has some flexibility in providing control information to resolve e.g., resource contentions, network congestion, network expansion, etc.

[0071] Various other aspects of the present disclosure are readily appreciated by those of ordinary skill in the related arts.

Method -

[0072] Referring now to FIG. 8, one embodiment of a generalized method 800 for dynamic allocation of resources for transmission of control information within an extensible and scalable control channel of a wireless network is illustrated and described.

[0073] In one aspect of the present disclosure, the extensible and scalable control channel of the wireless network is based on a frequency division multiplexing (FDM) scheme. Specifically, each control region is demarcated according to a relevant frequency range. Moreover, as bandwidth increases or decreases, the control regions can be expanded, or contracted accordingly. In alternate embodiments, the control region may be based on a time

division multiplexing (TDM) scheme, where each control region is specified according to a relevant time range.

[0074] In a second aspect of the present disclosure, the control regions are spatially distributed so as to reduce interference with one another within the same cell. For example, consider a cell having multiple RRHs; each RRH can be assigned to a control region so as to minimize interference with its neighboring RRHs (for an FDM based scheme, each RRH is assigned a different spectral range). Moreover, it is appreciated that due to the relatively low transmission power of each RRH (typical RRH transmit at approximately 20dBm, as compared to an eNB which transmits at 43dBm - 49dBm), a cell may be contain multiple RRHs which are assigned to the same control region but which are sufficiently separated to avoid interference.

[0075] In a third aspect, it is appreciated that within each control region the physical resource blocks (PRBs) assigned to each user can be further logically permuted, so as to maximize frequency diversity for each user. More directly, such randomization ensures that the effects of any interferer that impacts only a few PRBs will be distributed among the population of users serviced by that control region.

[0076] In a fourth aspect, the mobile device is notified of its associated control region. In one embodiment, a cell management entity determines (for at least a subset of its serviced population) an appropriate control region for the mobile device. The cell management entity is further configured to update the associated control region as the mobile devices move from RRH to RRH. Depending on certain mobility considerations, the mobile device may be assigned to a particular RRH (e.g., for a designated number of transmission time intervals (TTI), etc.), or the eNB. For example, where a mobile device is quickly moving, the cell management entity may not assign the mobile device to a RRH at all. In contrast, where a mobile device is largely stationary, the control entity may assign the mobile device to a RRH and/or a specific control region for a large number of TTI.

[0077] Moreover, those of ordinary skill in the related arts will recognize that unlike legacy schemes for control channel operation (e.g., see Prior Art Physical Downlink Control Channel (PDCCH)) which are based on a number of OFDM symbols at the start of each subframe, various embodiments of the present disclosure may operate on varying degrees of granularity. For example, a control region for a mobile device can be specified on a TTI basis, slot basis, subframe basis, frame basis, etc. The control channel overhead can be optimized according to various network considerations. For instance, where mobile device management requires significant control overhead, the network may switch to shorter time intervals for the control region(s) (e.g., slot based transmissions). In contrast, where control channel overhead is low, the network may opt for longer time intervals (e.g., subframe based transmissions).

[0078] In a fifth aspect of the present disclosure, fine

control over the control region for each mobile device enables beamforming capabilities. As a brief aside, legacy control channel operation was limited to a broadcast of the control information over several symbols at the start of each subframe. Prior art mobile devices needed to: (i) decode the Physical Control Format Indicator Channel (PCFICH), (ii) decode the cell specific reference signals (CRS), (iii) perform channel estimation based on the CRS, and (iv) decode the control symbols. In particular, the CRS is broadcast as a cell-specific signal, and is not device specific. In contrast, various embodiments of the present disclosure can be configured so as to use device specific reference signals with the appropriate control region (e.g., demodulation reference signals (DM-RS)). In particular, the DM-RS of a specific control region are specific to a particular device. This specificity can be leveraged by the network and device to adjust transmission and reception weights, so as to enable beamforming of the device specific control channels.

[0079] At step 802, one or more control information for a population of devices is determined. Common examples of control information include, without limitation, scheduling information, operational information, formatting information, etc. For instance, scheduling information may include: resource requests, resource grants, resource allocations, etc. Typical resources for use in wireless networks include: time slots, frequency bands, spreading codes, or any combination of the foregoing. Operational information may include: supported features, non-supported features, identifying information (e.g., network identification, serving station identification, etc.). Formatting information may include: requests for a transport format, grants for a transport format, assignments to a transport format, etc. In one exemplary embodiment, resources are based on a combination of time slots and frequency subcarriers.

[0080] In one exemplary embodiment, the control channel information is formatted for transmission as a Downlink Control Information (DCI) message. A DCI is generated based on a set of parameters that includes: the number of downlink Resource Blocks (RBs), the DCI format, etc.

[0081] At step 804, a suitable number of dynamically determined resources is determined for bearing at least a subset of the one or more control information. Generally, control channel information is determined based on current network activity and distributed to the population of devices to optimize network performance. In one embodiment, the suitable number of dynamically determined resources is based on a population of legacy devices. In other embodiments, the suitable number of dynamically determined resources is based on the type of control information. In still other embodiments, the number of dynamically determined resources is based on network configuration. Moreover, it is appreciated that in some embodiments, the dynamically determined resources are sufficient for all control information.

[0082] Each of the at least subset of one or more con-

trol information is dynamically assigned to a resource at step 806. In one exemplary embodiment, the one or more control information is assigned to a resource which is quickly identifiable by the receiving client device. Specifically, it may be desirable to limit the overall decoding burden for the client device. In some embodiments, the client device may be required to try decoding multiple "hypotheses" which are still significantly less than the entire bandwidth. By limiting the distribution of control information to only a few hypotheses, a client device can try each hypothesis to determine the location of control channel information.

[0083] For example, in one such variant, the frequency resources in each slot are partitioned into a number of Frequency Partitions (FP) where each frequency partition contains one or more control information regions. Each region consists of an integer number of physically consecutive or logically consecutive resources. In some embodiments, each control information region may be further associated with a transmitter of a network of transmitters. For example, in one exemplary embodiment, an enhanced Physical Downlink Control Channel (ePD-CCH) region is associated with a Remote Radio Head (RRH) of a cellular network cell. Within the foregoing system, a client device does not have to search the entire spectral bandwidth to find the appropriate control information, rather the client device can quickly identify the appropriate control information within the control region and decode it accordingly.

[0084] In one exemplary embodiment, the partitioning of resources is flexible and can be dynamically configured, e.g., the resources may change over time based on a cell-specific, semi-static or dynamic pattern. For example, the resource partitioning may be based on e.g., overall network complexity, network capabilities, device capabilities, device population size, etc. Dynamic sizing can be used to support arbitrarily large payloads; for example, within LTE networks flexible payload capabilities can accommodate larger format DCIs (e.g., Transmission Mode 9, etc.). Moreover, since the size of ePDCCH regions can be larger (or smaller), collisions across different cells and inter-cell interference can be more effectively and flexibly mitigated.

[0085] In certain schemes, control information can be distributed over network resources to maximize diversity techniques. For example, by permuting control information (and in some cases redundant control information) throughout the available time and frequency ranges of resources, reception issues which affect certain resources (e.g., momentary interference that affects a time slot and/or subcarrier) can be mitigated. For example, in one exemplary embodiment an ePDCCH region contains one or more ePDCCH, where each ePDCCH is mapped to a number of enhanced Control Channel Elements (eC-CEs), and each eCCE is mapped to one or more Physical Resource Blocks (PRBs). The PRBs are distributed in both time and frequency such that if one or more PRB is lost, the remaining PRBs can be used to reconstruct the

ePDCCH.

[0086] Additionally, it is recognized that the flexible allocation of control information can support features including soft frequency partitioning and/or Fractional Frequency Reuse (FFR) techniques. For instance, control information can be flexibly allocated across frequency to create configurable frequency partitions in control and data regions. Frequency partitioning can be particularly useful for aggregated spectral resources (e.g., where the total network bandwidth is composed of multiple disparate frequency bands). Frequency partitioning can provide control information over only a subset of the aggregated bandwidth, where the client device does not have to receive the entire aggregated spectrum to determine the control information. Additionally, frequency control can be used to control the amount of power distributed for providing data and control. For example, in prior art LTE networks, the PDCCH was transmitted across the entire spectral bandwidth, thus a change to power would affect the entire bandwidth. Various embodiments of the present disclosure can increase transmit power for only the control region of the ePDCCH.

[0087] One benefit to providing configurable control information is that control information does not have to be broadcast over the entire cell. In particular, control information need only be transmitted within the relative vicinity of the applicable user. For this reason, rather than broadcasting control information for all devices within the cell, various embodiments of the present disclosure are particularly useful for implementing user-specific control information. In one exemplary embodiment, a RRH only transmits control information which is applicable for its set of serviced subscribers. This can contribute greatly to overall network resource utilization.

[0088] Additionally, certain user-specific functionalities can be leveraged for further improvements. For instance, the control information may be provided to the subscriber in conjunction with user-specific reference signals. For example, in one exemplary embodiment, the ePDCCH is provided in conjunction with Demodulation Reference Signals (DM-RS) to assist in channel estimation and coherent detection for a specific subscriber device. Each user-specific DM-RS can be additionally beamformed for the specific user. During beamforming, the transmitter modifies the transmission power from each antenna so as to constructively interfere at a target receiver, and in some cases reducing interference for unintended receivers. Beamforming DM-RS can greatly improve channel estimates, etc.

[0089] In still another embodiment, control information can be provided to users based on the finest data granularity provided by the communications network. For example, within LTE networks, the smallest increment of data transmission is the Physical Resource Block PRB). Each PRB is approximately 2% of the bandwidth resources for a 10 MHz system, and only 1% in a 20 MHz system. Providing higher granularity control resources can reduce underutilization of network resources. Consider a prior art LTE network that could only allocate one, two or three OFDM symbols for control data (e.g., 7%, 14%, and 21% of network resources, respectively), if the PDCCH exceeds the capacity of one OFDM symbol, then the PDCCH is stepped to the next increment. If only marginally more information was transmitted, then the bulk of that newly allocated OFDM symbol is wasted. In contrast, exemplary embodiments of the present disclosure may simply allocate the additional PRBs necessary to provision the additional ePDCCH information.

[0090] Referring back to FIG. 8, at step 808, the one or more control information is transmitted according to the assigned resources. In one exemplary embodiment, the control information is transmitted from multiple transmission points, where the transmission point need not have identical transmission schedules for the control information. For example, within a cellular network, multiple Remote Radio Heads (RRHs) may each transmit control information according to individually distinct schedules.

[0091] Myriad other schemes for implementing dynamic allocation of resources will be recognized by those of ordinary skill given the present disclosure.

[0092] It will be recognized that while certain aspects of the disclosure are described in terms of a specific sequence of steps of a method, these descriptions are only illustrative of the broader methods of the disclosure, and may be modified as required by the particular application. Certain steps may be rendered unnecessary or optional under certain circumstances. Additionally, certain steps or functionality may be added to the disclosed embodiments, or the order of performance of two or more steps permuted. All such variations are considered to be encompassed within the present disclosure and claims herein.

[0093] While the above detailed description has shown, described, and pointed out novel features of the present disclosure as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the device or process illustrated may be made by those skilled in the art without departing from the present disclosure. The foregoing description is of the best mode presently contemplated. The scope of the present disclosure should be determined with reference to the claims.

Claims

1. A wireless network apparatus, comprising:

   a wireless interface, the wireless interface configured to communicate with wireless devices;
   a processor adapted to perform the steps of;
   configuring a plurality of frequency partitions of aggregated spectral resources, where the number of the frequency partitions is dynamically configured based on a parameter of the wire-

less network, where each frequency partition contains one or more enhanced Physical Control Channel, ePDCCH, regions, and each ePDCCH region comprises a logical mapping of resource blocks and a scalable size, wherein the scalable size of each ePDCCH region is dependent on a frequency range of the aggregated spectral resources;

wherein the logical mapping of resource blocks is permuted over a plurality of physical resource blocks, PRSs, the PRBs being distributed in both time and frequency such that when one of the plurality of PRBs is lost during transmission, the ePDCCH regions corresponding to the lost one of the plurality of PRBs are determined based on the one or more remaining PRBs;

associating one or more wireless devices to a corresponding one of the one or more ePDCCH regions;

assigning the corresponding one of the one or more ePDCCH regions to one or more remote radio heads; and

identifying one of the one or more ePDCCH regions for transmitting control channel information; and

transmitting the control channel information for the associated one or more wireless devices, only over partitions of the aggregated spectral resources.

2. The wireless network apparatus of Claim 1, wherein the configuration of the one or more frequency partitions is performed dynamically.

3. The wireless network apparatus of Claim 1, wherein the control channel information comprises one or more reference signals specific to the wireless device.

4. The wireless network apparatus of Claim 1, wherein the identification of the one ePDCCH region is based at least on a message received from at least one wireless device of the wireless devices.

5. A method of transmitting control information, by a wireless network apparatus , the method comprising:

configuring a plurality of frequency partitions of aggregated spectral resources, where the number of the frequency partitions is dynamically configured based on a parameter of the wireless network, where each frequency partition contains one or more ePDCCH regions, and each ePDCCH region comprises a logical mapping of resource blocks and a scalable size, wherein the scalable size of each ePDCCH region is dependent on a frequency range of the

aggregated spectral resources;

wherein the logical mapping of resource blocks is permuted over a plurality of physical resource blocks, PRBs, the PRBs being distributed in both time and frequency such that when one of the plurality of PRBs is lost during transmission, the ePDCCH regions corresponding to the lost one of the plurality of PRBs are determined based on the one or more remaining PRBs; associating one or more wireless devices to a corresponding one of the one or more ePDCCH regions;

assigning the corresponding one of the one or more ePDCCH regions to one or more remote radio heads; and

transmitting control channel information for the associated one or more wireless devices, only over partitions of the aggregated spectral resources.

6. The method of Claim 5, wherein the logical mapping of resource blocks is dynamically determined.

7. The method of Claim 5, wherein:

the one or more remote radio heads are geographically distinct; and
the associating of one or more wireless devices to the corresponding one of the one or more ePDCCH regions is based at least in part on a location of the one or more wireless devices.

8. The method of Claim 5, wherein the one or more remote radio heads share a common identifier.

9. The method of Claim 5, wherein the logical mapping is permuted over a number of transmissions.

Patentansprüche

1. Drahtloses Netzwerkgerät, umfassend:

eine drahtlose Schnittstelle, wobei die drahtlose Schnittstelle konfiguriert ist zum Kommunizieren mit drahtlosen Vorrichtungen;
einen Prozessor, der eingerichtet ist zum Ausführen der folgenden Schritte:

Konfigurieren einer Vielzahl von Frequenzpartitionen von aggregierten spektralen Ressourcen, wobei die Anzahl der Frequenzpartitionen basierend auf einem Parameter des drahtlosen Netzwerks dynamisch konfiguriert wird, wobei jede Frequenzpartition einen oder mehrere Enhanced Physical Control Channel, ePDCCH, -Bereiche enthält und jeder ePDCCH-Bereich eine logische Abbildung von Ressour-

cenblöcken und eine skalierbare Größe umfasst, wobei die skalierbare Größe jedes ePDCCH-Bereichs von einem Frequenzbereich der aggregierten spektralen Ressourcen abhängig ist;
wobei die logische Abbildung von Ressourcenblöcken über eine Vielzahl von physikalischen Ressourcenblöcken, PRBs, permutiert wird, wobei die PRBs sowohl in der Zeit als auch in der Frequenz verteilt sind, so dass, wenn einer aus der Vielzahl von PRBs während Übertragung verloren geht, die ePDCCH-Bereiche, die dem Verlorenen aus der Vielzahl von PRBs entsprechen, basierend auf dem einen oder den mehreren restlichen PRBs bestimmt werden;
Verknüpfen einer oder mehrerer drahtloser Vorrichtungen mit einem entsprechenden des einen oder der mehreren ePDCCH-Bereiche;
Zuordnen des entsprechenden einen des einen oder der mehreren ePDCCH-Bereiche zu einem oder mehreren entfernten Funkköpfen; und
Identifizieren eines des einen oder der mehreren ePDCCH-Bereiche zum Übertragen von Steuerkanalinformation; und

Übertragen der Steuerkanalinformation für die verknüpften eine oder mehreren drahtlosen Vorrichtungen nur über Partitionen der aggregierten spektralen Ressourcen.

2. Drahtloses Netzwerkgerät nach Anspruch 1, wobei die Konfiguration der einen oder mehreren Frequenzpartitionen dynamisch durchgeführt wird.

3. Drahtloses Netzwerkgerät nach Anspruch 1, wobei die Steuerkanalinformation ein oder mehrere Referenzsignale umfasst, die für die drahtlose Vorrichtung spezifisch sind.

4. Drahtloses Netzwerkgerät nach Anspruch 1, wobei die Identifizierung des einen ePDCCH-Bereichs zumindest auf einer Nachricht basiert, die von mindestens einer drahtlosen Vorrichtung der drahtlosen Vorrichtungen empfangen wird.

5. Verfahren zum Übertragen von Steuerinformation durch ein drahtloses Netzwerkgerät, das Verfahren umfassend:

Konfigurieren einer Vielzahl von Frequenzpartitionen von aggregierten spektralen Ressourcen, wobei die Anzahl der Frequenzpartitionen basierend auf einem Parameter des drahtlosen Netzwerks dynamisch konfiguriert wird, wobei jede Frequenzpartition einen oder mehrere

ePDCCH-Bereiche enthält, und jeder ePDCCH-Bereich eine logische Abbildung von Ressourcenblöcken und eine skalierbare Größe umfasst, wobei die skalierbare Größe jedes ePDCCH-Bereichs von einem Frequenzbereich der aggregierten spektralen Ressourcen abhängig ist;
wobei die logische Abbildung von Ressourcenblöcken über eine Vielzahl von physikalischen Ressourcenblöcken, PRBs, permutiert wird, wobei die PRBs sowohl in der Zeit als auch in der Frequenz verteilt sind, so dass, wenn einer der Vielzahl von PRBs während Übertragung verloren geht, die ePDCCH-Bereiche, die dem Verlorenen der Vielzahl von PRBs entsprechen, basierend auf dem einen oder den mehreren restlichen PRBs bestimmt werden;
Verknüpfen einer oder mehrerer drahtloser Vorrichtungen mit einem entsprechenden des einen oder der mehreren ePDCCH-Bereiche;
Zuordnen des entsprechenden einen des einen oder der mehreren ePDCCH-Bereiche zu einem oder mehreren entfernten Funkköpfen; und
Übertragen von Steuerkanalinformation für die verknüpften eine oder mehreren drahtlosen Vorrichtungen nur über Partitionen der aggregierten spektralen Ressourcen.

6. Verfahren nach Anspruch 5, wobei die logische Zuordnung der Ressourcenblöcke dynamisch bestimmt wird.

7. Verfahren nach Anspruch 5, wobei:

der eine oder die mehreren entfernten Funkköpfe geographisch voneinander getrennt sind; und
das Verknüpfen von einer oder mehreren drahtlosen Vorrichtungen mit dem entsprechenden des einen oder der mehreren ePDCCH-Bereiche zumindest teilweise auf einem Standort der einen oder mehreren drahtlosen Vorrichtungen basiert.

8. Verfahren nach Anspruch 5, wobei der eine oder die mehreren entfernten Funkköpfe sich eine gemeinsame Kennung teilen.

9. Verfahren nach Anspruch 5, wobei das logische Abbilden über eine Anzahl von Übertragungen permutiert wird.

Revendications

1. Un appareil de réseau sans fil, comprenant :

une interface sans fil, l'interface étant configurée pour communiquer avec des dispositifs sans fil ;

un processeur apte à exécuter les étapes suivantes :

la configuration d'une pluralité de partitions de fréquences de ressources spectrales agrégées, le nombre des partitions de fréquences étant configuré dynamiquement sur la base d'un paramètre du réseau sans fil, chaque partition de fréquences contenant une ou plusieurs régions de canal de contrôle physique renforcé, ePDCCH, et chaque région ePDCCH comprenant un mappage logique de blocs de ressources et une taille redimensionnable, la taille redimensionnable de chaque région ePDCCH étant fonction d'une plage de fréquences des ressources spectrales agrégées ;

dans lequel le mappage logique des blocs de ressources est permuté sur une pluralité de blocs de ressources physiques, PRB, les PRB étant distribués à la fois en temps et en fréquences de sorte que lorsque l'un de la pluralité de PRB se perd en cours de transmission, les régions ePDCCH correspondant à celui de la pluralité de PRB qui s'est perdu sont déterminées sur la base des un ou plusieurs PRB restants ;

l'association d'un ou plusieurs dispositifs sans fil à l'une correspondante des une ou plusieurs régions ePDCCH ;

l'attribution à une ou plusieurs têtes radio distantes de ladite une correspondante des une ou plusieurs régions ePDCCH ; et

l'identification de l'une des une ou plusieurs régions ePDCCH pour la transmission d'une information de canal de contrôle ; et

la transmission, seulement sur les partitions des ressources spectrales agrégées, de l'information de canal de contrôle pour les un ou plusieurs dispositifs sans fil associés.

2. L'appareil de réseau sans fil de la revendication 1, dans lequel la configuration des une ou plusieurs partitions de fréquences est effectuée dynamiquement.

3. L'appareil de réseau sans fil de la revendication 1, dans lequel l'information de canal de contrôle comprend un ou plusieurs signaux de référence spécifiques au dispositif sans fil.

4. L'appareil de réseau sans fil de la revendication 1, dans lequel l'identification de ladite une région ePDCCH est au moins basée sur un message reçu en provenance d'au moins un dispositif sans fil faisant partie des dispositifs sans fil.

5. Un procédé de transmission, par un appareil de réseau sans fil, d'une information de contrôle, le procédé comprenant :

la configuration d'une pluralité de partitions de fréquences de ressources spectrales agrégées, le nombre des partitions de fréquences étant configuré dynamiquement sur la base d'un paramètre du réseau sans fil, chaque partition de fréquences contenant une ou plusieurs régions ePDCCH, et chaque région ePDCCH comprenant un mappage logique de blocs de ressources et une taille redimensionnable, la taille redimensionnable de chaque région ePDCCH étant fonction d'une plage de fréquences des ressources spectrales agrégées ;

dans lequel le mappage logique des blocs de ressources est permuté sur une pluralité de blocs de ressources physiques, PRB, les PRB étant distribués à la fois en temps et en fréquences de sorte que lorsque l'un de la pluralité de PRB se perd en cours de transmission, les régions ePDCCH correspondant à celui de la pluralité de PRB qui s'est perdu sont déterminées sur la base des un ou plusieurs PRB restants ;

l'association d'un ou plusieurs dispositifs sans fil à l'une correspondante des une ou plusieurs régions ePDCCH ;

l'attribution à une ou plusieurs têtes radio distantes de ladite une correspondante des une ou plusieurs régions ePDCCH ; et

la transmission, seulement sur les partitions des ressources spectrales agrégées, d'une information de canal de contrôle pour les un ou plusieurs dispositifs sans fil associés.

6. Le procédé de la revendication 5, dans lequel le mappage logique des blocs de ressources est déterminé dynamiquement.

7. Le procédé de la revendication 5, dans lequel :

les une ou plusieurs têtes radio distantes sont géographiquement distinctes ; et

l'association de un ou plusieurs dispositifs sans fil à ladite une correspondante des une ou plusieurs régions ePDCCH est au moins en partie basée sur un emplacement des un ou plusieurs dispositifs sans fil.

8. Le procédé de la revendication 5, dans lequel les une ou plusieurs têtes radio distantes partagent un identifiant commun.

9. Le procédé de la revendication 5, dans lequel le mappage logique est permuté sur un certain nombre de transmissions.
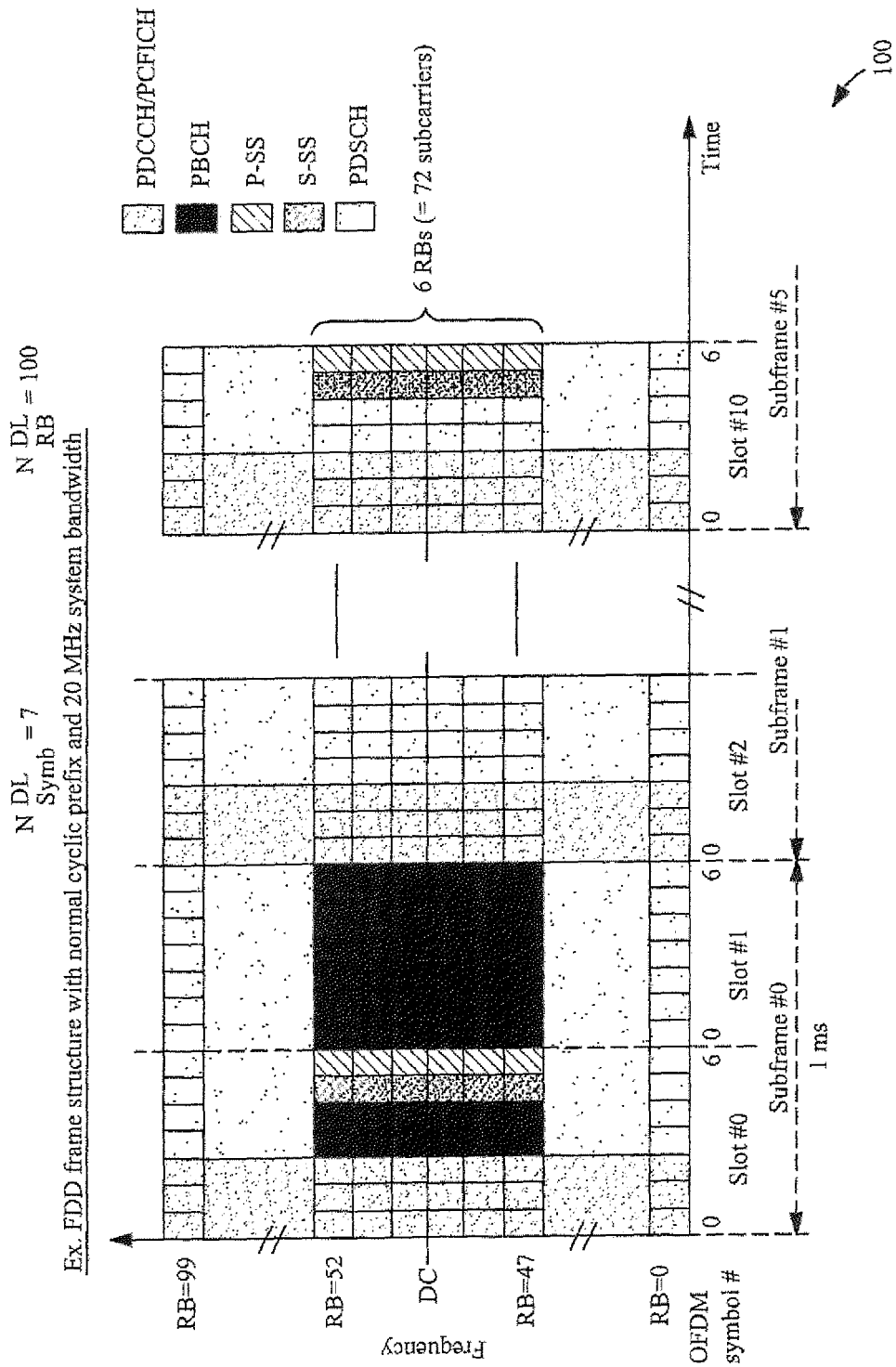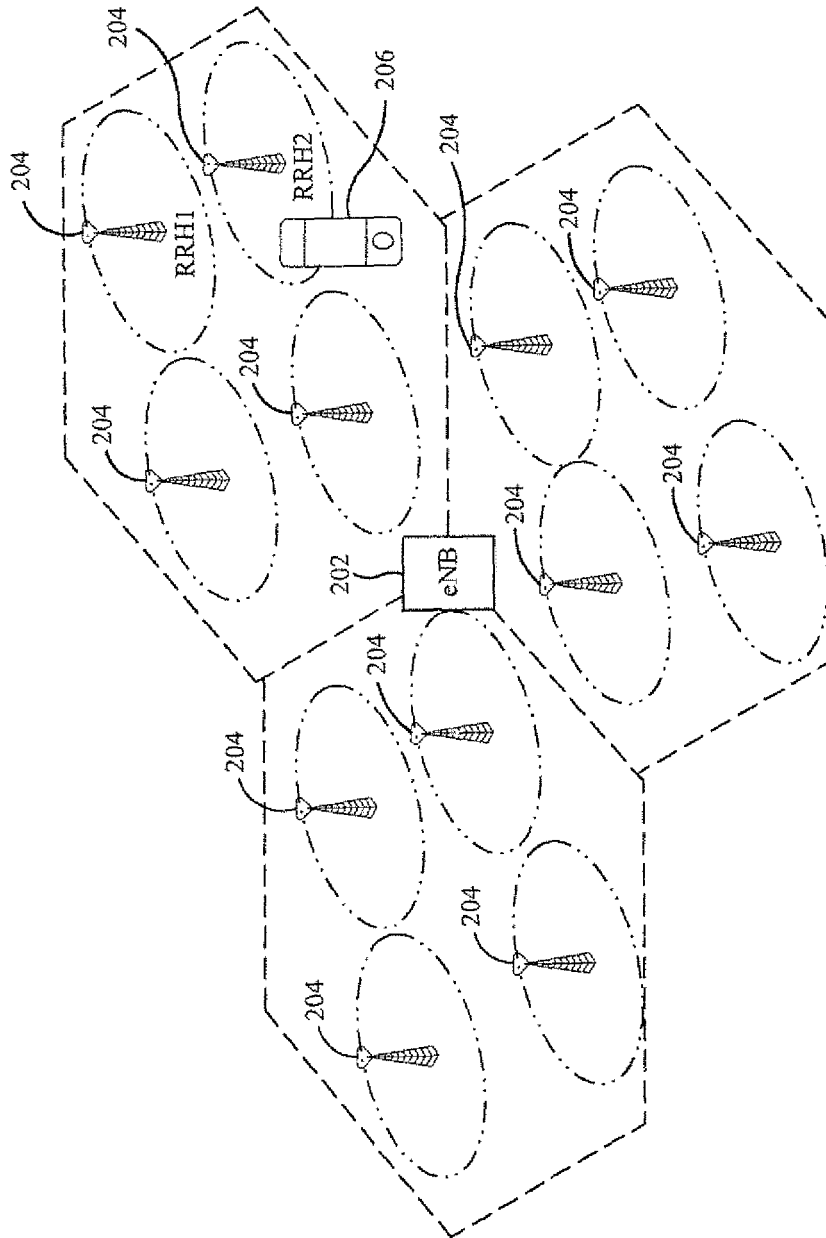
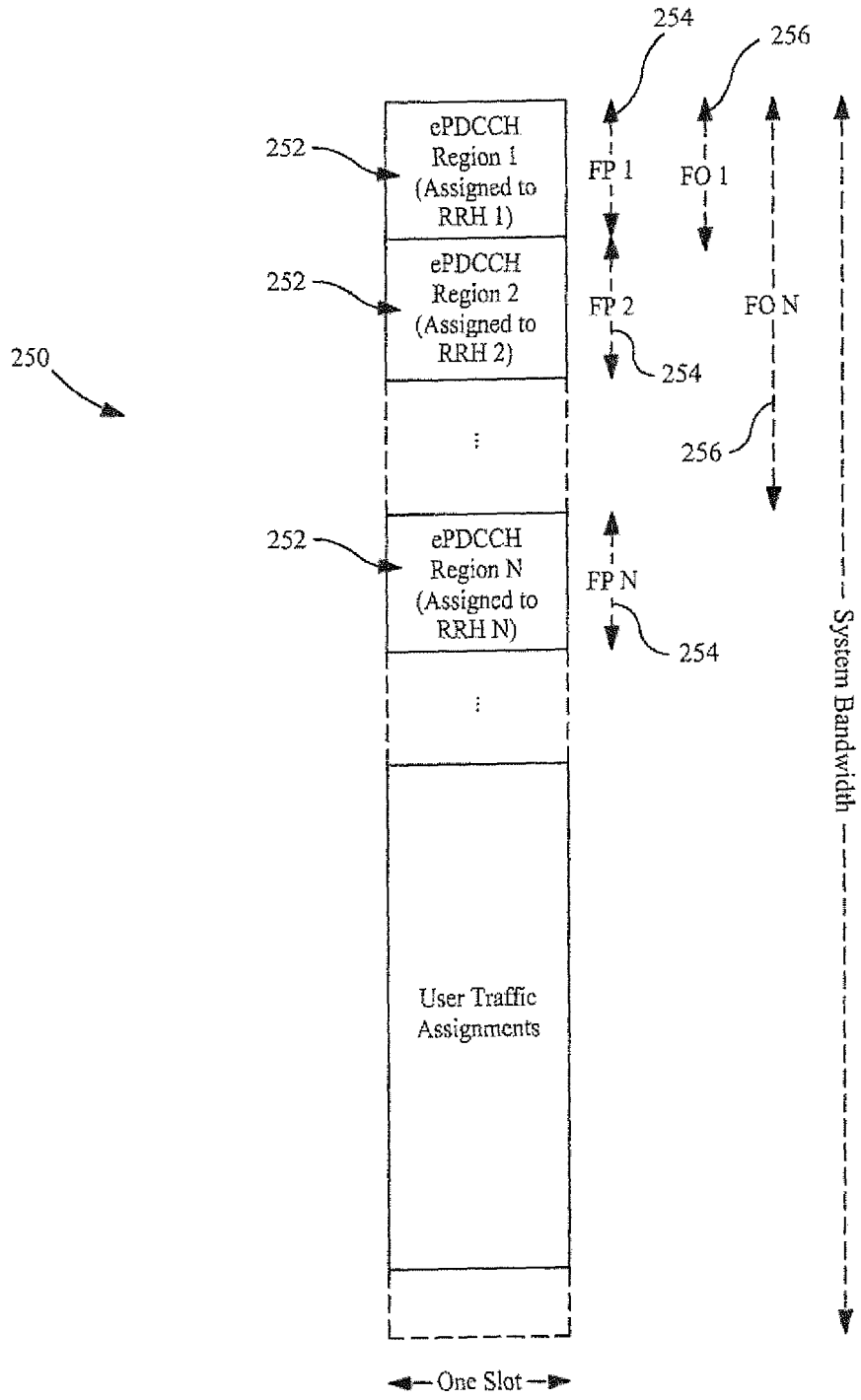Ex. FDD frame structure with normal cyclic prefix and 20 MHz system bandwidth

$N_{Symb}^{DL} = 7$ $N_{RB}^{DL} = 100$

PDCCH/PCFICH

PBCH

P-SS

S-SS

PDSCH

6 RBs (= 72 subcarriers)

Time

RB=99

RB=52

DC

RB=47

RB=0

OFDM
symbol #

Frequency

Slot #0   Subframe #0   Slot #1   Subframe #1   Slot #2
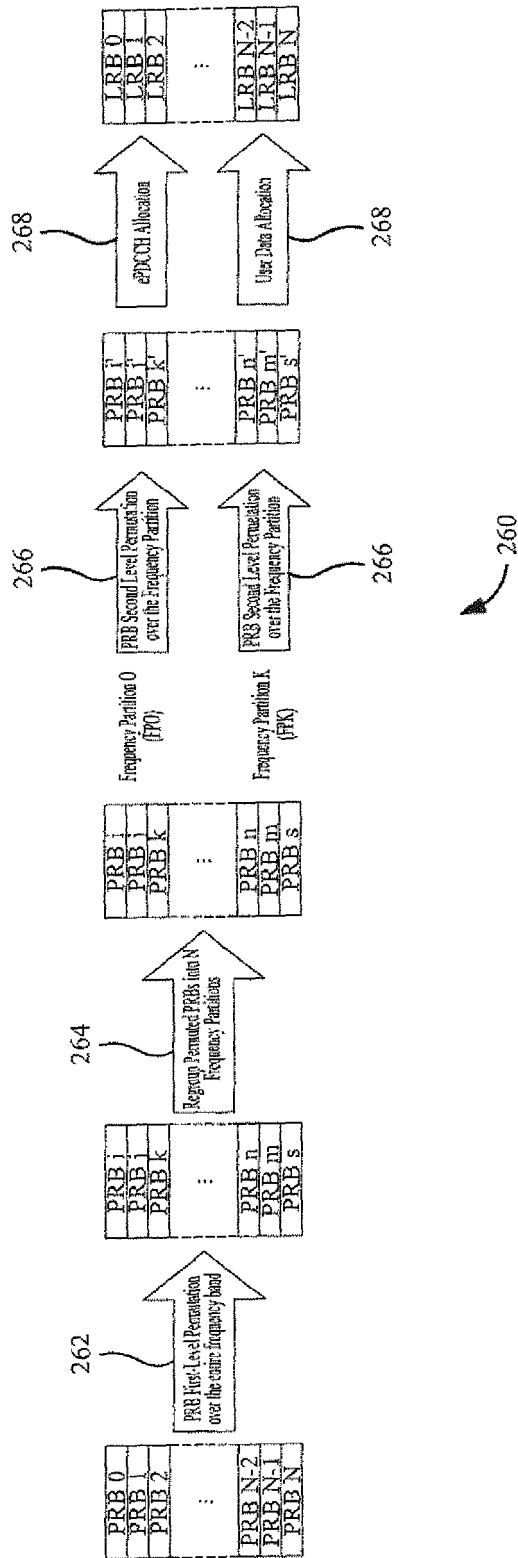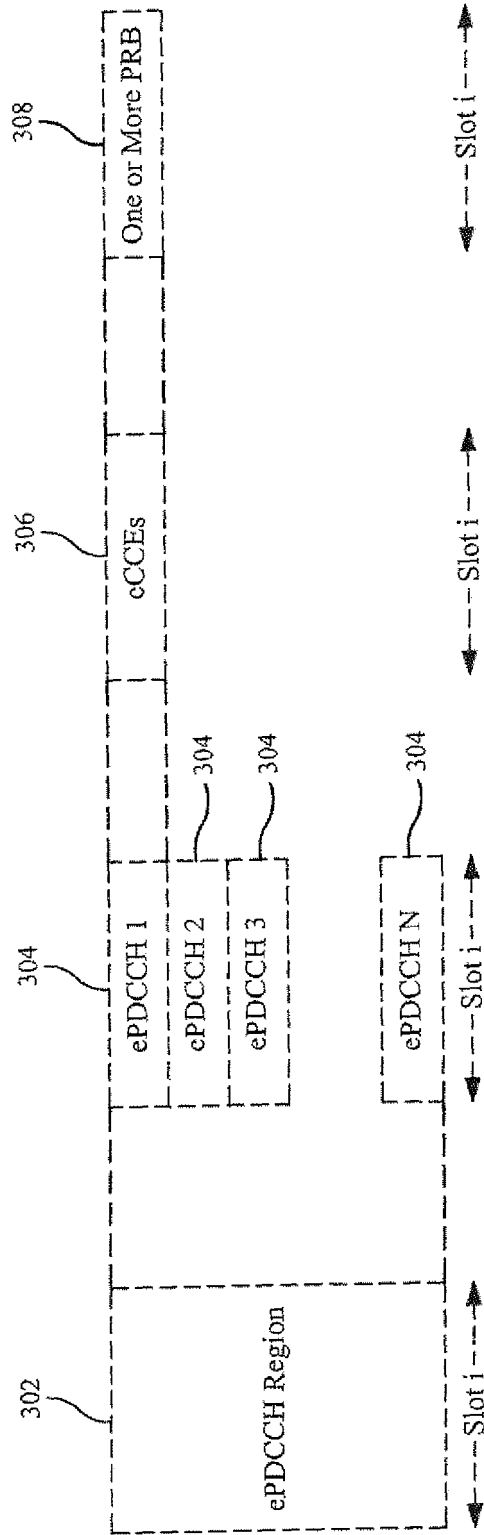
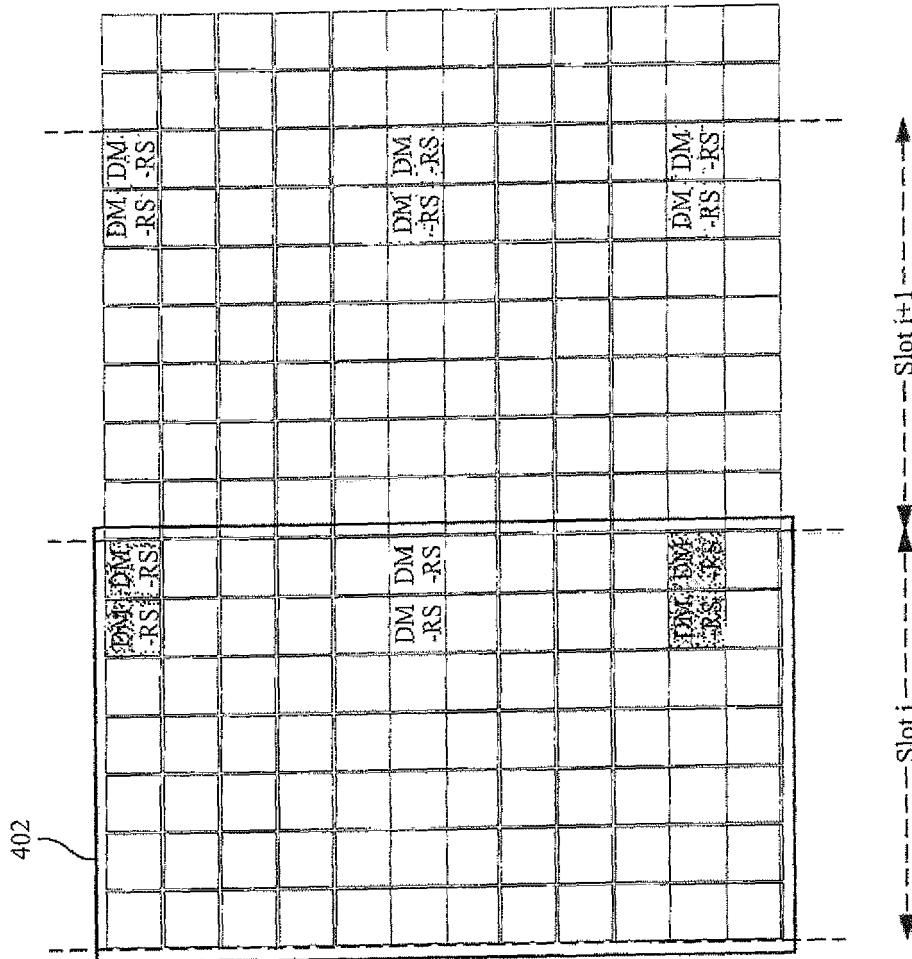Slot #10   Subframe #5

1 ms

FIG. 1

100

FIG. 2A

FIG. 2B

FIG. 2C

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7

START

DETERMINE CONTROL INFORMATION FOR ONE OR MORE DEVICES — 802

DETERMINE A SUITABLE NUMBER OF DYNAMICALLY DETERMINED RESOURCES — 804

DYNAMICALLY ASSIGN ONE OR MORE RESOURCES TO CONTROL INFORMATION — 806

TRANSMIT CONTROL INFORMATION — 808

END

800
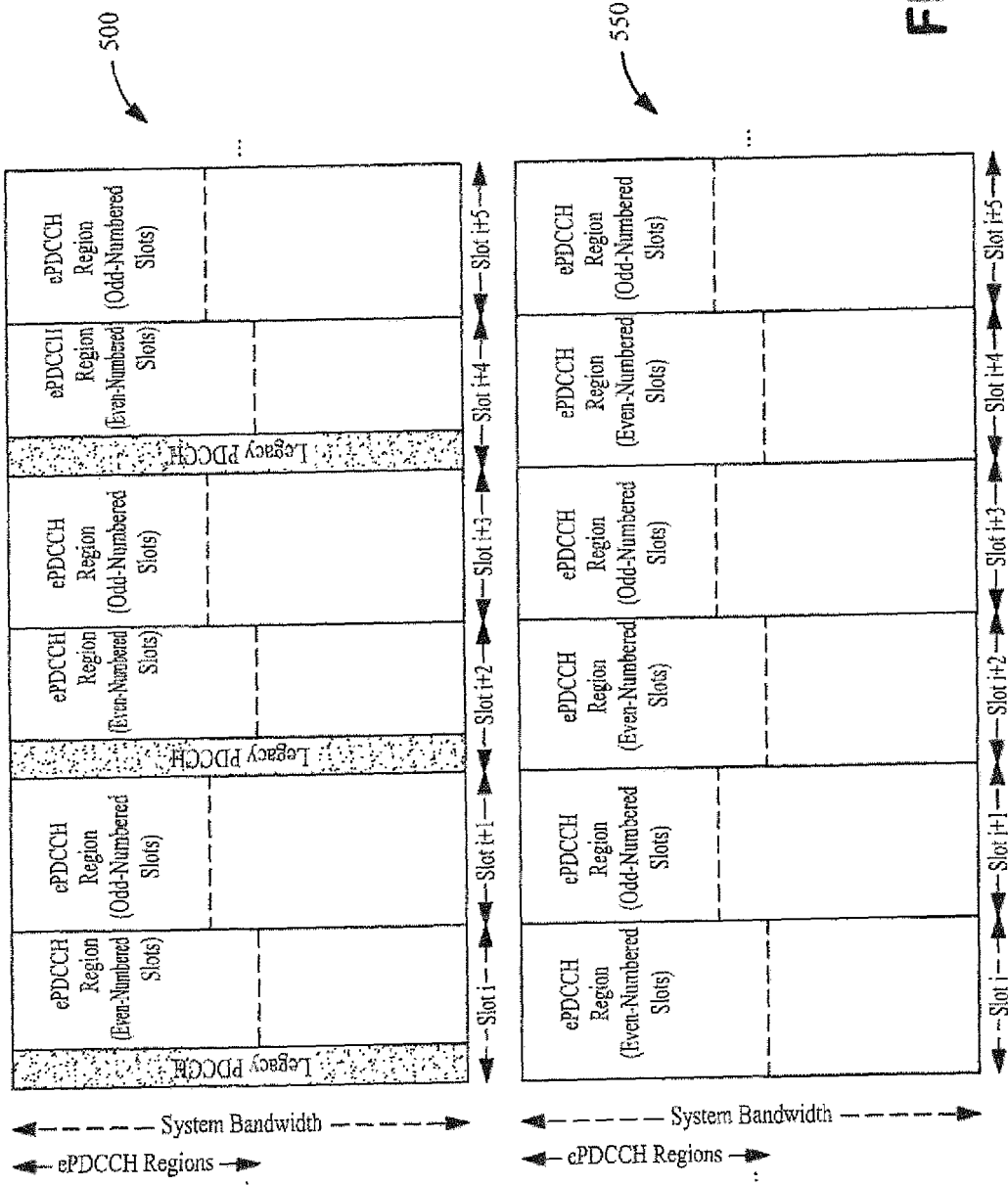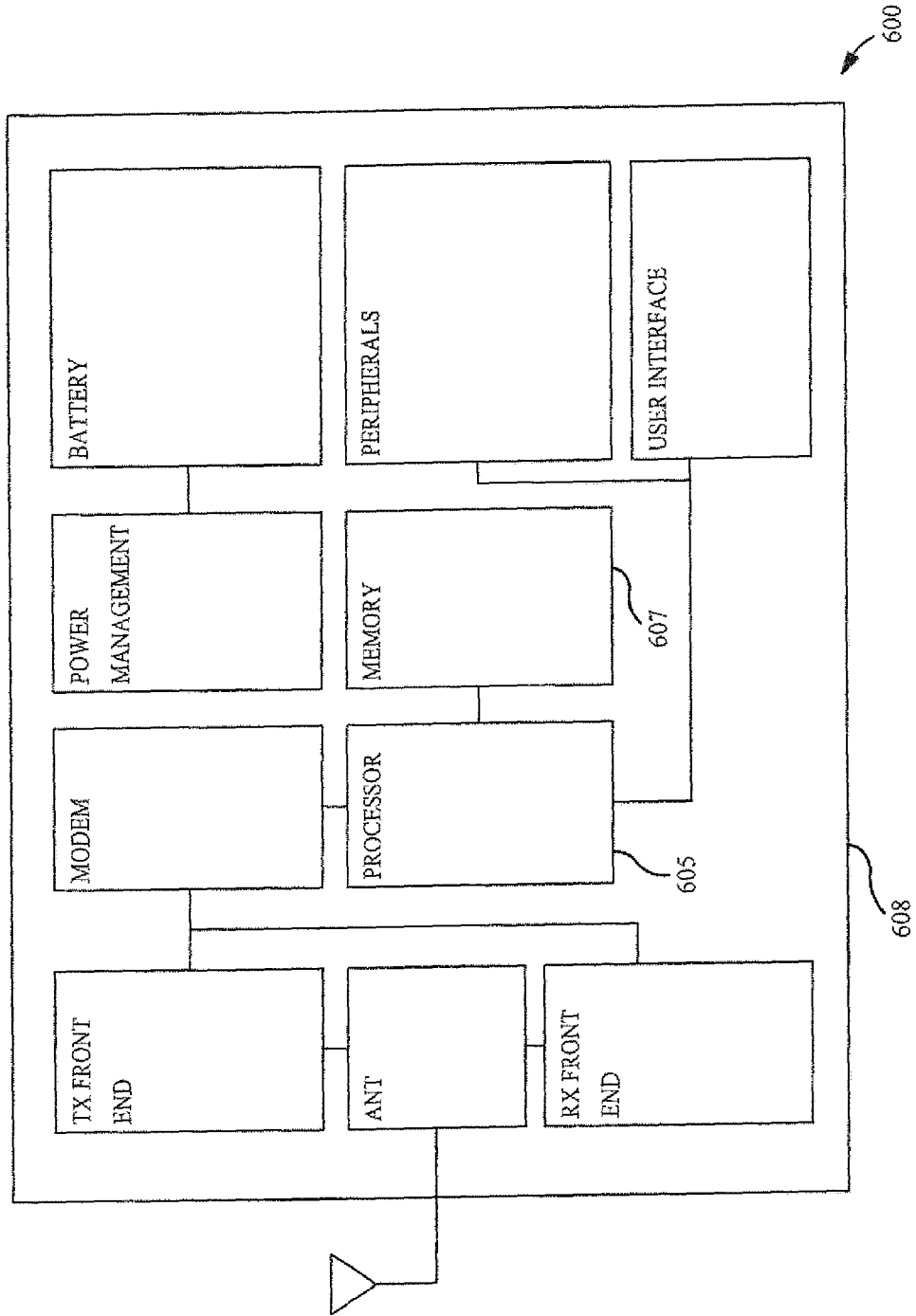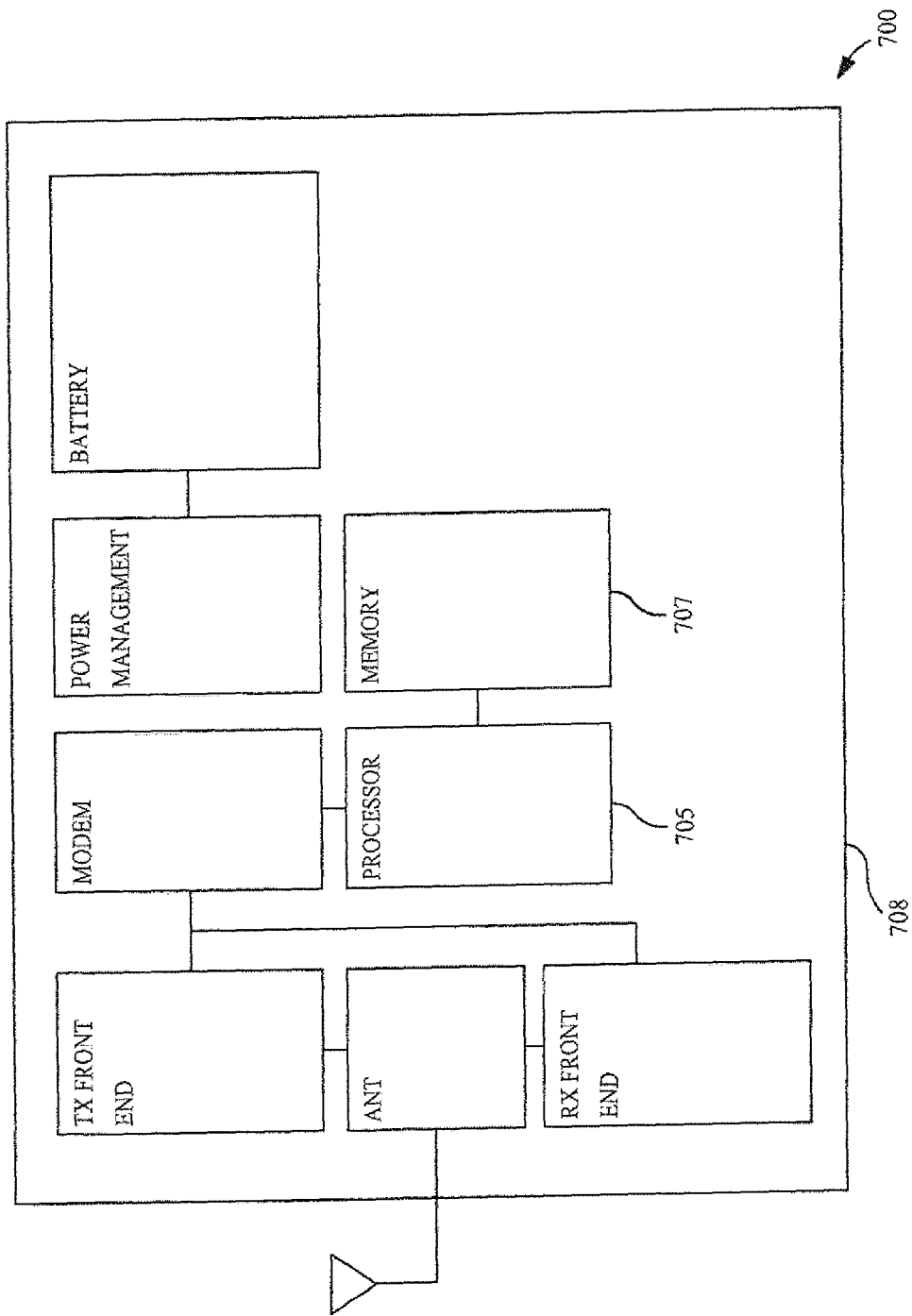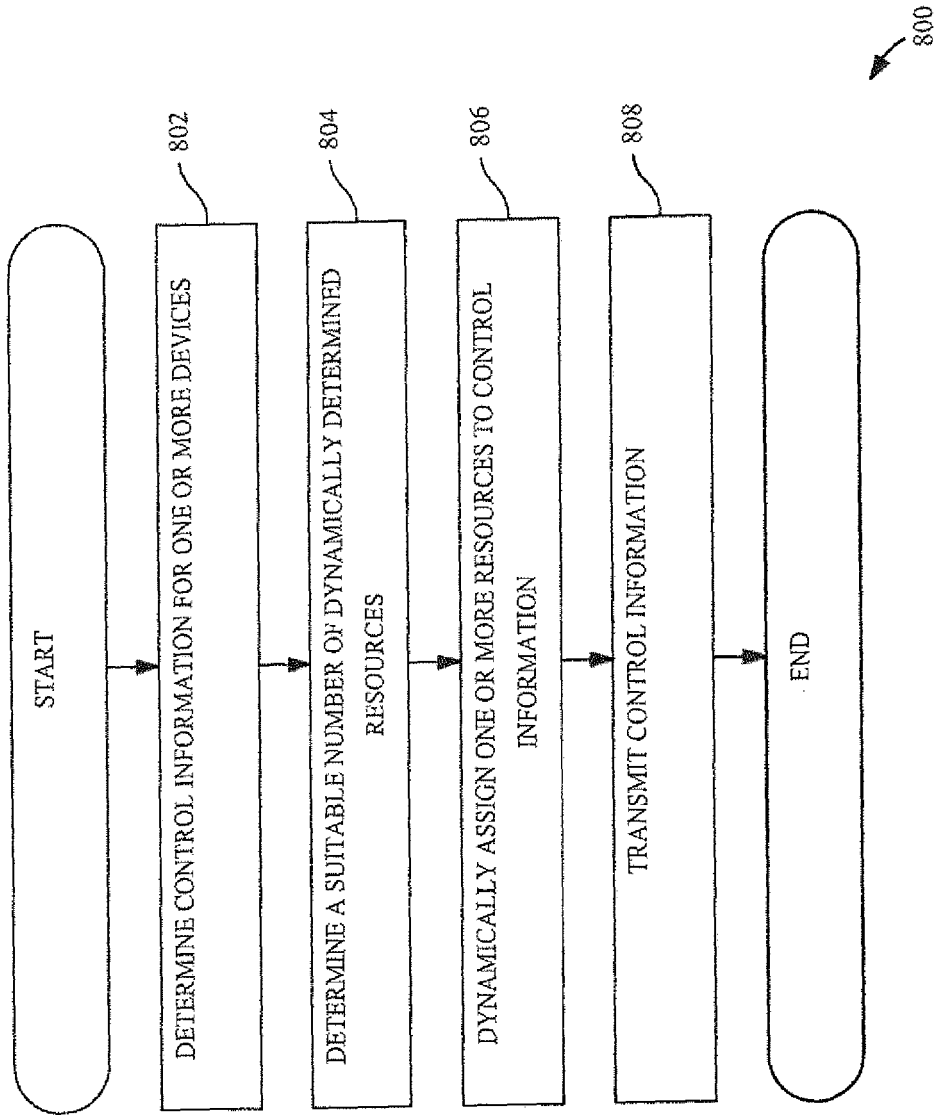
FIG. 8

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 55712112 **[0001]**
- US 61557329 **[0001]**

- WO 2011137383 A1 **[0007]**

Non-patent literature cited in the description

- Coordinated multipoint operation for LTE physical layer aspects (Release 11). *3GPP TR 36.819 Technical Specification Group Radio Access Network,* September 2011 **[0022]**
- Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 11). *3GPP TS 36.300,* September 2011 **[0024]**

- Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures. *3GPP TS 36.213 Technical Specification Group Radio Access Network,* March 2012 **[0024] [0025]**
- Physical Channels and Modulation (Release 10). *3GPP TS 36.211 Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA),* March 2011 **[0031]**