



US009271288B2

(12) **United States Patent**  
**Chen et al.**

(10) **Patent No.:** **US 9,271,288 B2**

(45) **Date of Patent:** **Feb. 23, 2016**

(54) **RESOURCE ALLOCATION FOR ENHANCED PHYSICAL DOWNLINK CONTROL CHANNEL (EPDCCH)**

72/042; H04W 72/044; H04W 72/0446; H04W 72/08; H04W 72/082; H04L 5/0048; H04L 5/0053; H04L 5/0051

See application file for complete search history.

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

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2011/0170496 A1 7/2011 Fong et al.  
2011/0273992 A1 11/2011 Zhang et al.  
2012/0020323 A1 1/2012 Noh et al.  
2012/0281646 A1 11/2012 Liao et al.  
2013/0039284 A1\* 2/2013 Marinier ..... H04L 5/001  
370/329  
2013/0044692 A1\* 2/2013 Nory ..... H04L 25/0228  
370/329  
2013/0194931 A1\* 8/2013 Lee ..... H04L 5/0053  
370/241

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 298 days.

(Continued)

(21) Appl. No.: **13/759,410**

OTHER PUBLICATIONS

(22) Filed: **Feb. 5, 2013**

(65) **Prior Publication Data**

US 2013/0201975 A1 Aug. 8, 2013

Ericsson et al., "Discussion on design principles for additional carrier types", 3GPP Draft; R1-112925, 3rd Generation Partnership Project (3GPP), Mobile Competence Centre ; 650, Route Des Lucioles ; F-06921 Sophia-Antipolis Cedex ; France, vol. RAN WG1, no. Zhuhai; Oct. 10, 2011, Oct. 4, 2011, XP050538135.

(Continued)

**Related U.S. Application Data**

(60) Provisional application No. 61/596,036, filed on Feb. 7, 2012.

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(51) **Int. Cl.**  
**H04W 72/04** (2009.01)  
**H04L 5/00** (2006.01)  
**H04L 1/18** (2006.01)

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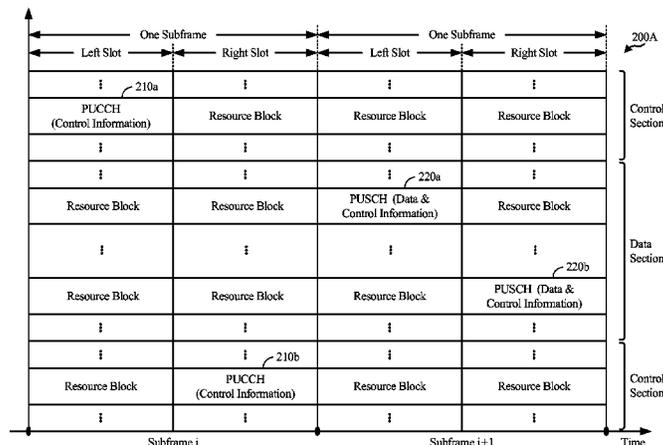
(52) **U.S. Cl.**  
CPC ..... **H04W 72/0446** (2013.01); **H04L 5/0048** (2013.01); **H04L 5/0051** (2013.01); **H04L 5/0053** (2013.01); **H04L 1/1893** (2013.01); **H04L 5/0023** (2013.01); **H04L 5/0092** (2013.01)

(57) **ABSTRACT**

Certain aspects of the present disclosure provide techniques for systems that support DMRS-based transmissions, that may allow such systems to at least partially utilize resources in the center six RBs of subframes 0 and 5 for DMRS-based transmissions (e.g., EPDCCH), while avoiding collision with Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS) or Physical Broadcast Channel (PBCH).

(58) **Field of Classification Search**  
CPC ..... H04W 72/00; H04W 72/02; H04W 72/04; H04W 72/0406; H04W 72/0413; H04W

**51 Claims, 8 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

2014/0286288 A1\* 9/2014 Park ..... H04W 72/14  
370/329  
2014/0334416 A1\* 11/2014 Ko ..... H04L 5/0053  
370/329

OTHER PUBLICATIONS

Huawei et al., "Additional carrier types a motivations and issues", 3GPP Draft; R1-112893, 3rd Generation Partnership Project (3GPP), Mobile Competence Centre ; 650, Route Des Lucioles ; F-06921 Sophia-Antipolis Cedex ; France, vol. RAN WG1, no. Zhuhai; Oct. 10, 2011, Oct. 4, 2011, XP050538107.

International Search Report and Written Opinion—PCT/US2013/024808—ISA/EPO—Apr. 23, 2013.  
Panasonic: "Channels and signals for additional carrier type", 3GPP Draft; R1-120220, 3rd Generation Partnership Project (3GPP), Mobile Competence Centre ; 650, Route Des Lucioles ; F-06921 Sophia-Antipolis Cedex ; France, vol. RAN WG1, no. Dresden, Germany; Feb. 6, 2012-Feb. 10, 2012, Jan. 31, 2012, XP050562777.  
Samsung: "Avoidance of DMRS collision with PSS and SSS", 3GPP Draft; R1-110088, 3rd Generation Partnership Project (3GPP), Mobile Competence Centre ; 650, Route Des Lucioles ; F-06921 Sophia-Antipolis Cedex ; France, vol. RAN WG1, no. Dublin, Ireland; Jan. 17, 2011, Jan. 11, 2011, XP050490058.  
Bhat P., et al., "LTE-advanced: An Operator Perspective," IEEE Communications Magazine, LTE-Advanced and 4G Wireless Communications, Feb. 2012, pp. 104-114.

\* cited by examiner

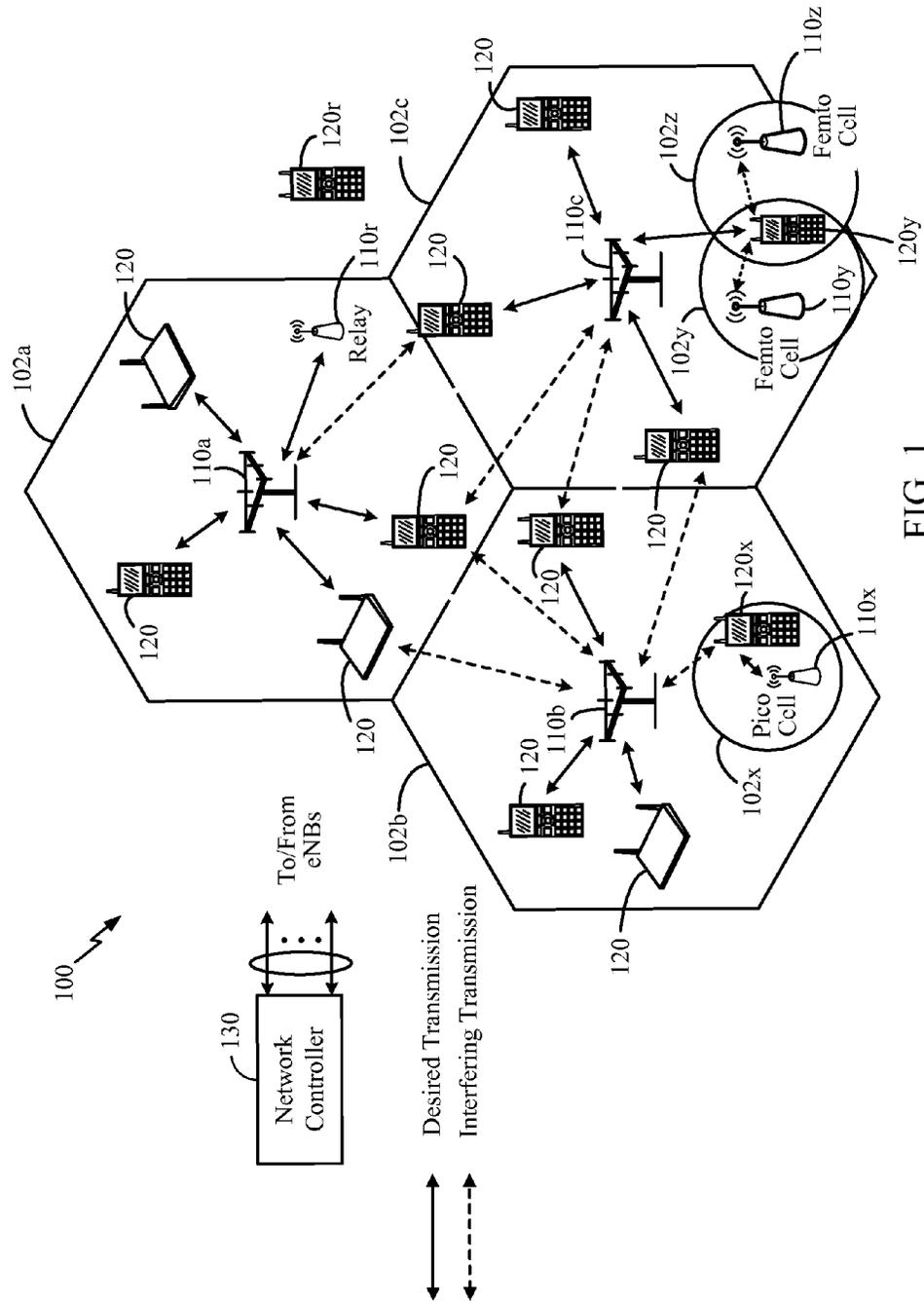


FIG. 1

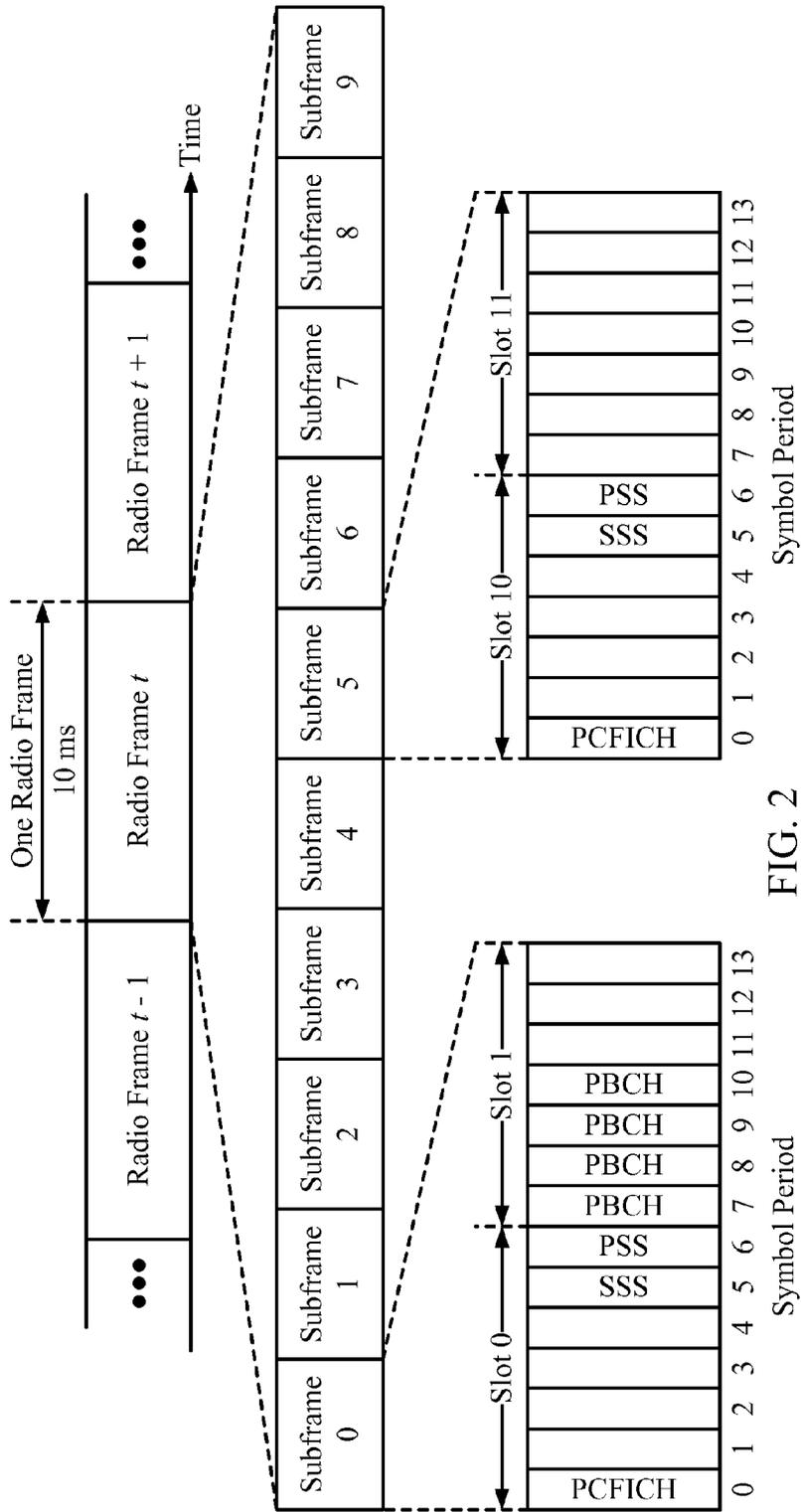


FIG. 2

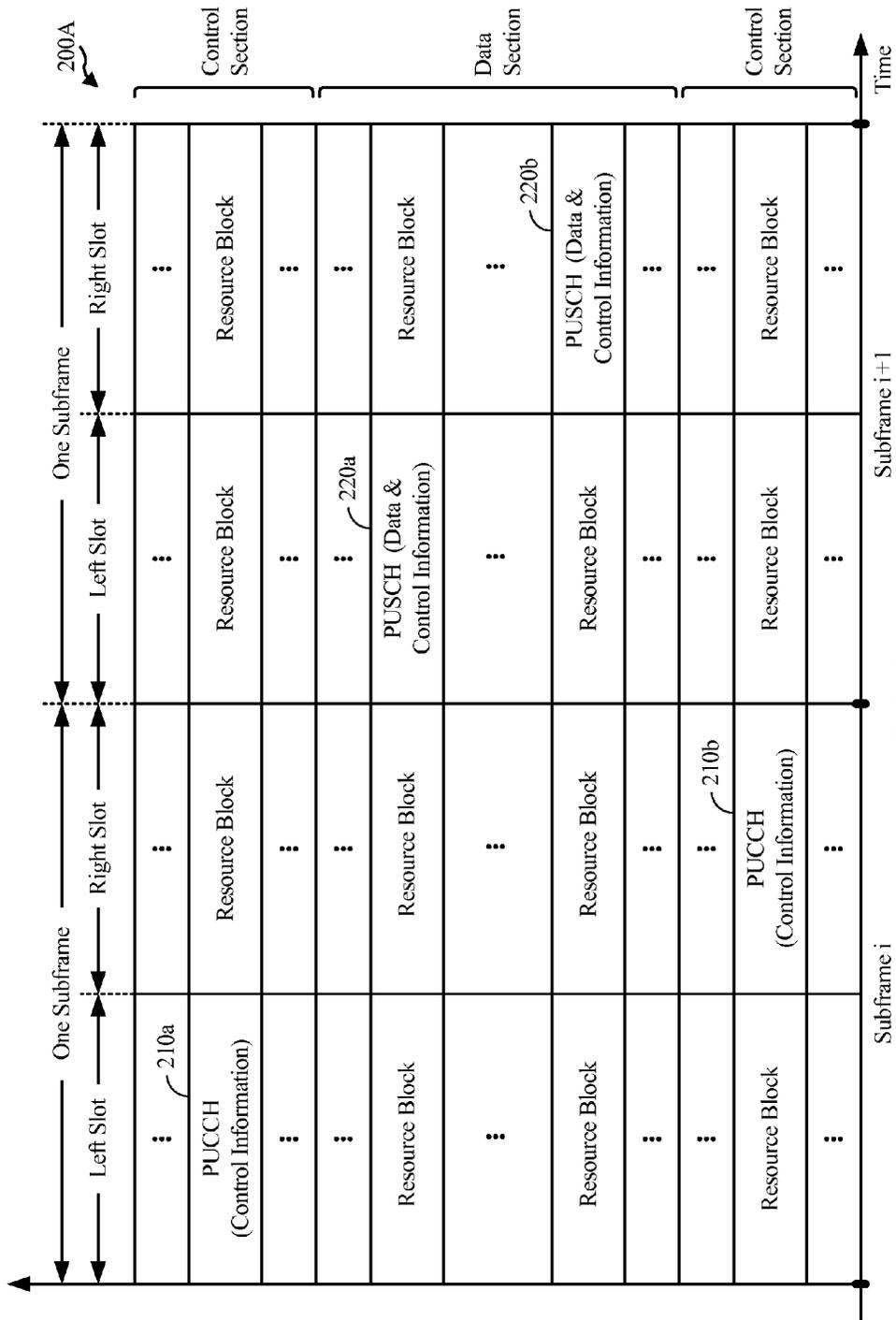


FIG. 2A

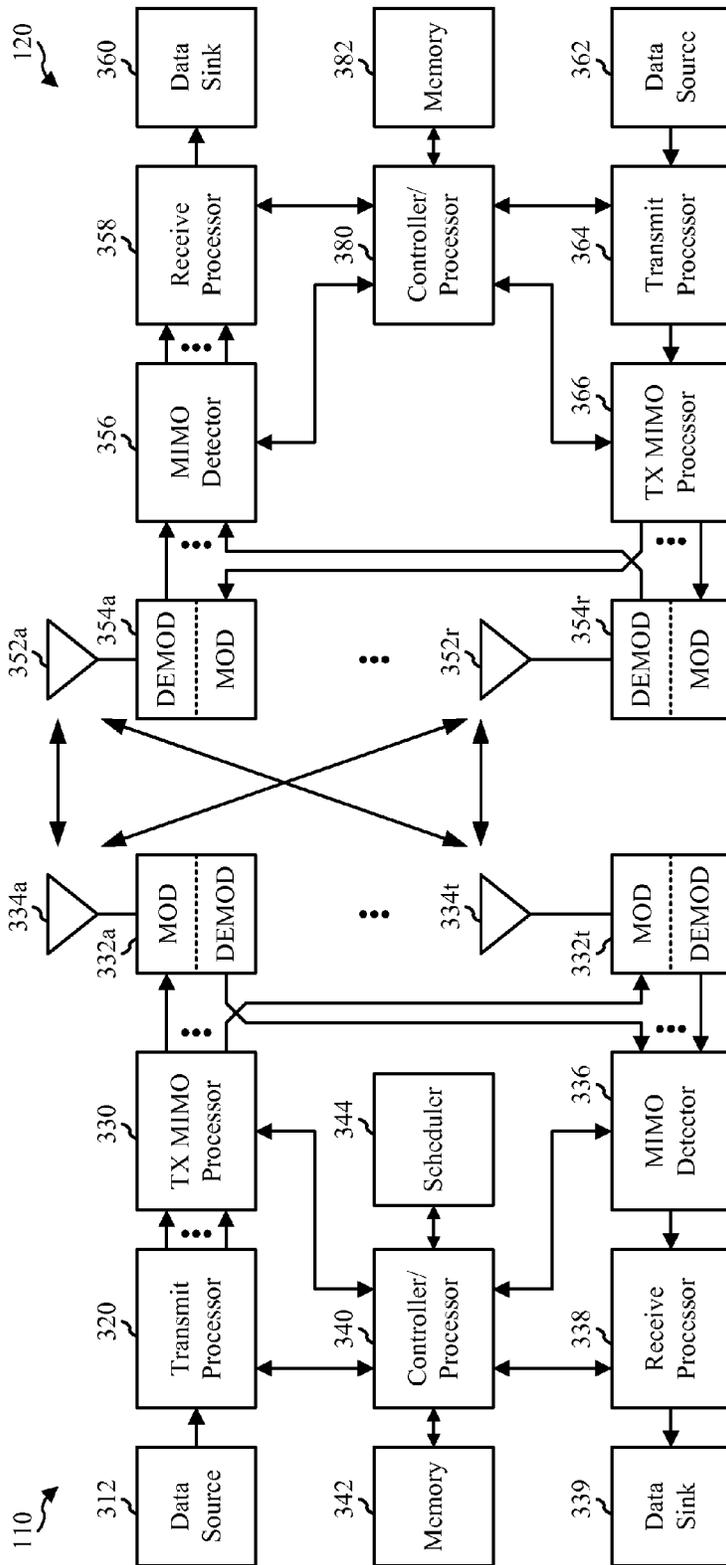


FIG. 3

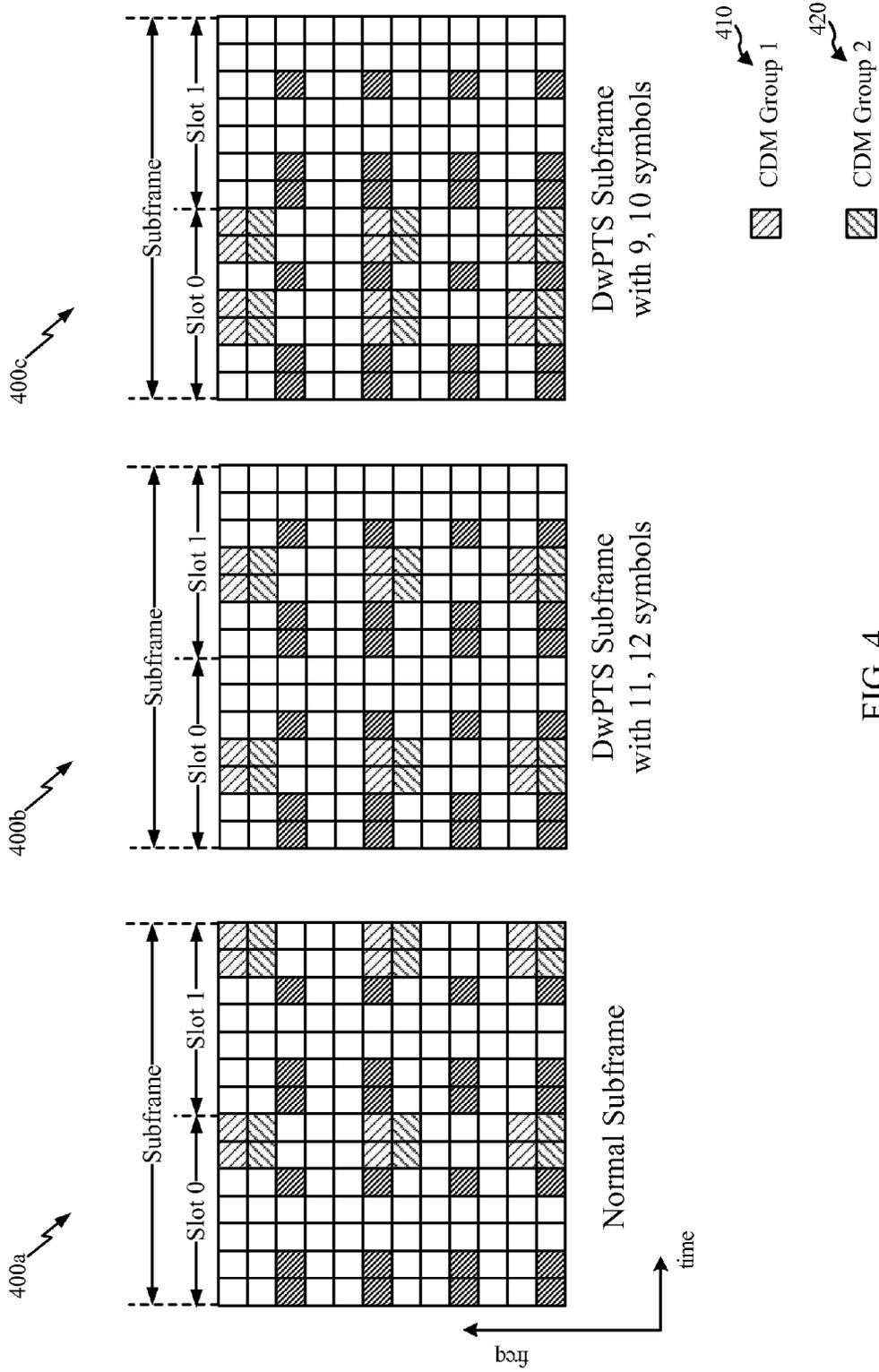


FIG. 4

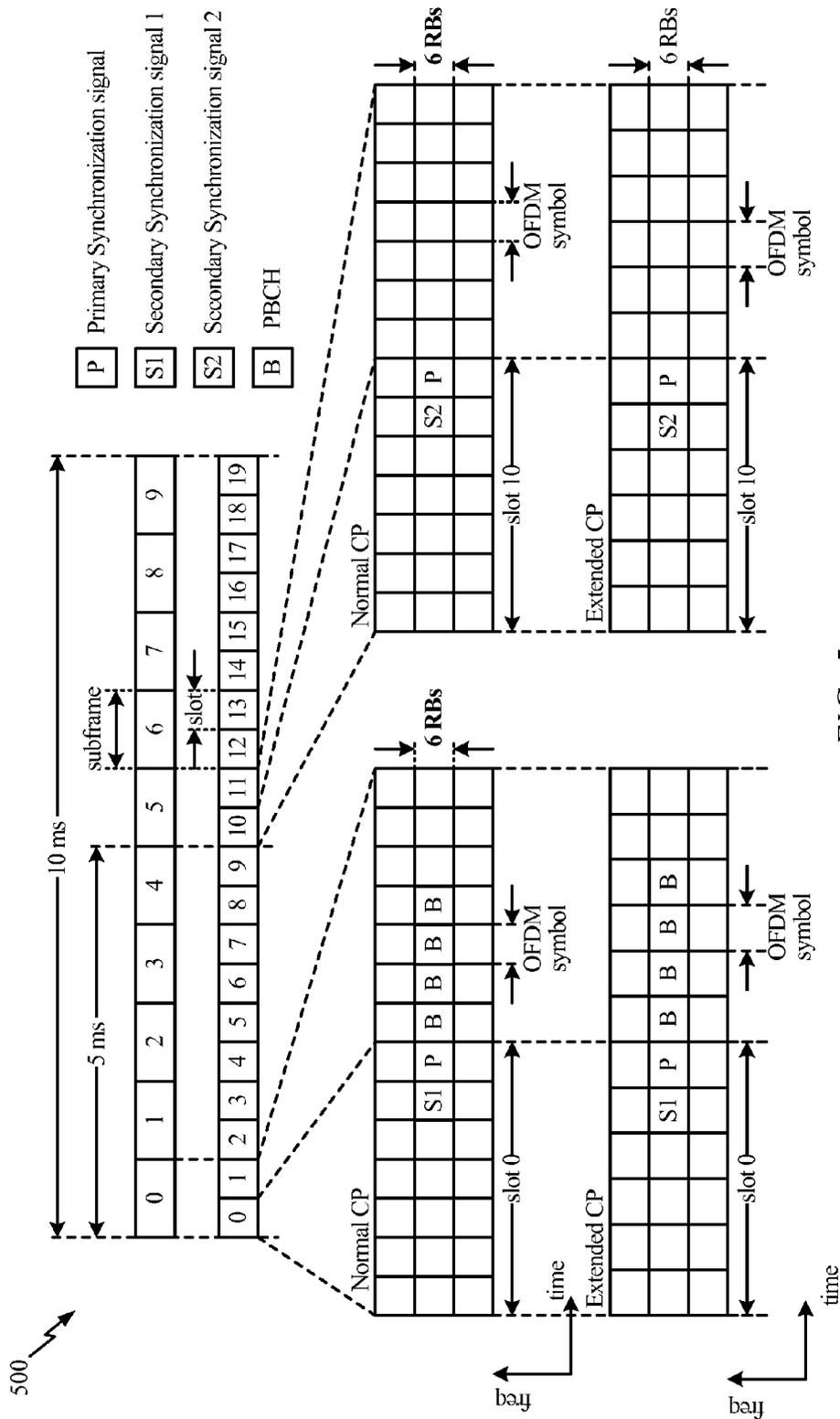


FIG. 5

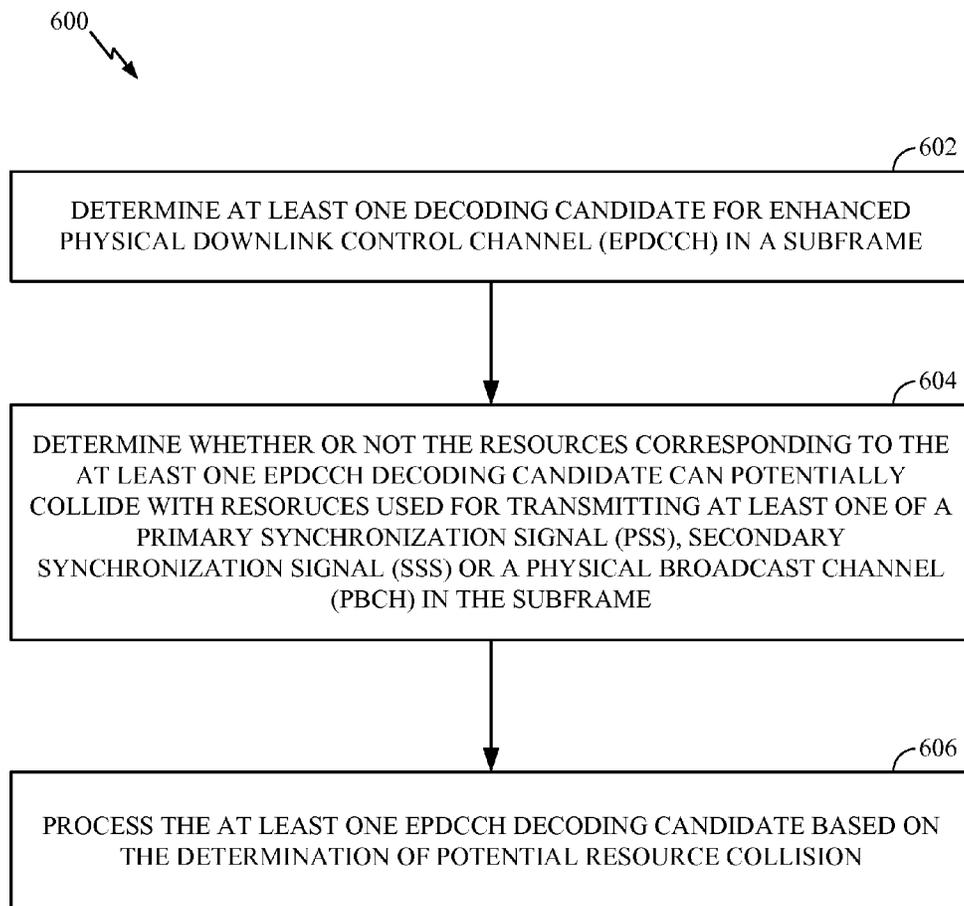


FIG. 6

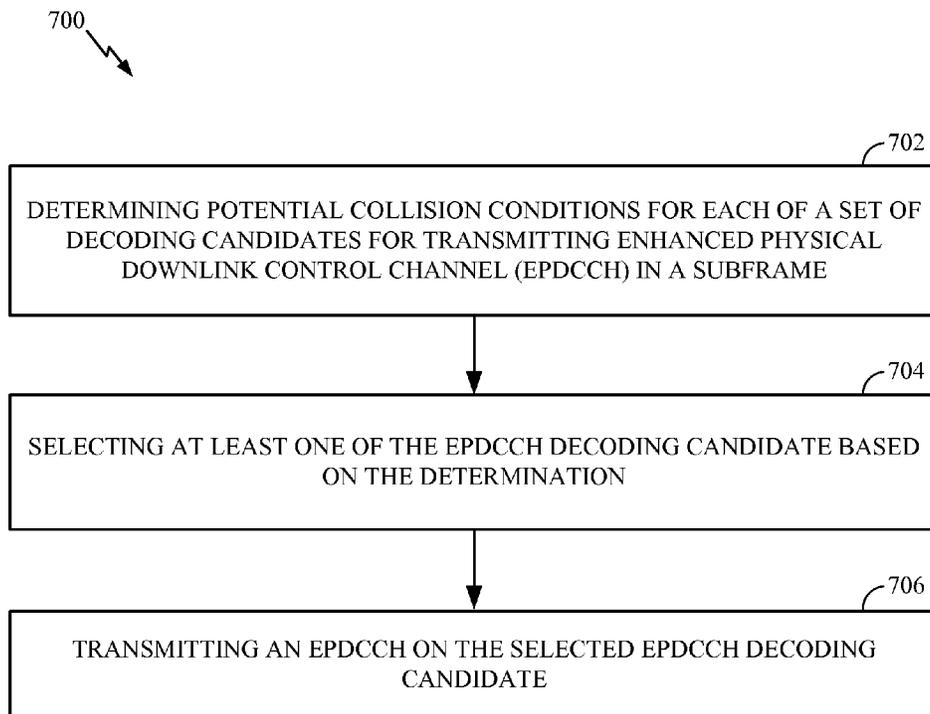


FIG. 7

**RESOURCE ALLOCATION FOR ENHANCED  
PHYSICAL DOWNLINK CONTROL  
CHANNEL (EPDCCH)**

CLAIM OF PRIORITY UNDER 35 U.S.C. §119

The present Application for Patent claims priority to U.S. Provisional Application No. 61/596,036, entitled "INTER-ACTION OF EPDCCH WITH PBCH/PSS/SSS IN LTE-A," filed Feb. 7, 2012, and assigned to the assignee hereof and hereby expressly incorporated by reference herein.

BACKGROUND

I. Field

Certain aspects of the disclosure generally relate to wireless communications and, more particularly, to techniques for allocating resources for Enhanced Physical Downlink Control Channel (EPDCCH).

II. Background

Wireless communication networks are widely deployed to provide various communication services such as voice, video, packet data, messaging, broadcast, etc. These wireless networks may be multiple-access networks capable of supporting multiple users by sharing the available network resources. Examples of such multiple-access networks include Code Division Multiple Access (CDMA) networks, Time Division Multiple Access (TDMA) networks, Frequency Division Multiple Access (FDMA) networks, Orthogonal FDMA (OFDMA) networks and Single-Carrier FDMA (SC-FDMA) networks.

A wireless communication network may include a number of base stations that can support communication for a number of user equipments (UEs). A UE may communicate with a base station via the downlink and uplink. The downlink (or forward link) refers to the communication link from the base station to the UE, and the uplink (or reverse link) refers to the communication link from the UE to the base station.

A base station may transmit data and control information on the downlink to a UE and/or may receive data and control information on the uplink from the UE. On the downlink, a transmission from the base station may observe interference due to transmissions from neighbor base stations. On the uplink, a transmission from the UE may cause interference to transmissions from other UEs communicating with the neighbor base stations. The interference may degrade performance on both the downlink and uplink.

SUMMARY

Certain aspects of the present disclosure provide a method of wireless communications by a User Equipment (UE). The method generally includes determining at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, determining whether or not the resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe, and processing the at least one EPDCCH decoding candidate based on the determination of potential resource collision.

Certain aspects of the present disclosure provide an apparatus for wireless communications. The apparatus generally includes means for determining at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, means for determining whether or not

the resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe, and means for processing the at least one EPDCCH decoding candidate based on the determination of potential resource collision.

Certain aspects of the present disclosure provide an apparatus for wireless communications. The apparatus generally includes at least one processor and a memory coupled to the at least one processor. The at least one processor is generally configured to determine at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, determine whether or not the resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe, and process the at least one EPDCCH decoding candidate based on the determination of potential resource collision.

Certain aspects of the present disclosure provide a computer program product for wireless communications. The computer program product generally includes a computer-readable medium comprising code for determining at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, determining whether or not the resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe, and processing the at least one EPDCCH decoding candidate based on the determination of potential resource collision.

Certain aspects of the present disclosure provide a method for wireless communications by a Base Station (BS). The method generally includes determining potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, selecting at least one EPDCCH decoding candidate from the set based on the determination, and transmitting an EPDCCH on the selected EPDCCH decoding candidate.

Certain aspects of the present disclosure provide an apparatus for wireless communications. The apparatus generally includes means for determining potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, means for selecting at least one EPDCCH decoding candidate from the set based on the determination, and means for transmitting an EPDCCH on the selected EPDCCH decoding candidate.

Certain aspects of the present disclosure provide an apparatus for wireless communications. The apparatus generally includes at least one processor and a memory coupled to the at least one processor. The at least one processor is generally configured to determine potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, select at least one EPDCCH decoding candidate from the set based on the determination, and transmit an EPDCCH on the selected EPDCCH decoding candidate.

Certain aspects of the present disclosure provide a computer program product for wireless communications. The computer program product generally includes a computer-

readable medium comprising code for determining potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe, selecting at least one EPDCCH decoding candidate from the set based on the determination, and transmitting an EPDCCH on the selected EPDCCH decoding candidate.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram conceptually illustrating an example of a wireless communications network in accordance with certain aspects of the present disclosure.

FIG. 2 is a block diagram conceptually illustrating an example of a frame structure in a wireless communications network in accordance with certain aspects of the present disclosure.

FIG. 2A shows an example format for the uplink in Long Term Evolution (LTE) in accordance with certain aspects of the present disclosure.

FIG. 3 shows a block diagram conceptually illustrating an example of a Node B in communication with a user equipment device (UE) in a wireless communications network in accordance with certain aspects of the present disclosure.

FIG. 4 illustrates DMRS patterns as defined in Rel-10 for the normal cyclic prefix case, in accordance with certain aspects of the present disclosure.

FIG. 5 illustrates resource configuration for PSS, SSS and PBCH in an LTE frame, in accordance with certain aspects of the present disclosure.

FIG. 6 illustrates example operations that may be performed by a User Equipment (UE) for monitoring and decoding EPDCCH, in accordance with certain aspects of the present disclosure.

FIG. 7 illustrates example operations that may be performed by a Base Station (BS) for transmitting EPDCCH, in accordance with certain aspects of the present disclosure.

### DETAILED DESCRIPTION

The techniques described herein may be used for various wireless communication networks such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA and other networks. The terms “network” and “system” are often used interchangeably. A CDMA network may implement a radio technology such as Universal Terrestrial Radio Access (UTRA), cdma2000, etc. UTRA includes Wideband CDMA (WCDMA) and other variants of CDMA. cdma2000 covers IS-2000, IS-95 and IS-856 standards. A TDMA network may implement a radio technology such as Global System for Mobile Communications (GSM). An OFDMA network may implement a radio technology such as Evolved UTRA (E-UTRA), Ultra Mobile Broadband (UMB), IEEE 802.11 (Wi-Fi), IEEE 802.16 (WiMAX), IEEE 802.20, Flash-OFDM®, etc. UTRA and E-UTRA are part of Universal Mobile Telecommunication System (UMTS). 3GPP Long Term Evolution (LTE) and LTE-Advanced (LTE-A) are new releases of UMTS that use E-UTRA. UTRA, E-UTRA, UMTS, LTE, LTE-A and GSM are described in documents from an organization named “3rd Generation Partnership Project” (3GPP). cdma2000 and UMB are described in documents from an organization named “3rd Generation Partnership Project 2” (3GPP2). The techniques described herein may be used for the wireless networks and radio technologies mentioned above as well as other wireless networks and radio technologies. For clarity,

certain aspects of the techniques are described below for LTE/LTE-A, and LTE/LTE-A terminology is used in much of the description below.

### Example Wireless Network

FIG. 1 shows a wireless communication network 100, which may be an LTE network. The wireless network 100 may include a number of evolved Node Bs (eNBs) 110 and other network entities. An eNB may be a station that communicates with user equipment devices (UEs) and may also be referred to as a base station, a Node B, an access point, etc. Each eNB 110 may provide communication coverage for a particular geographic area. In 3GPP, the term “cell” can refer to a coverage area of an eNB and/or an eNB subsystem serving this coverage area, depending on the context in which the term is used.

An eNB may provide communication coverage for a macro cell, a pico cell, a femto cell, and/or other types of cell. A macro cell may cover a relatively large geographic area (e.g., several kilometers in radius) and may allow unrestricted access by UEs with service subscription. A pico cell may cover a relatively small geographic area and may allow unrestricted access by UEs with service subscription. A femto cell may cover a relatively small geographic area (e.g., a home) and may allow restricted access by UEs having association with the femto cell (e.g., UEs in a Closed Subscriber Group (CSG), UEs for users in the home, etc.). An eNB for a macro cell may be referred to as a macro eNB (i.e., a macro base station). An eNB for a pico cell may be referred to as a pico eNB (i.e., a pico base station). An eNB for a femto cell may be referred to as a femto eNB (i.e., a femto base station) or a home eNB. In the example shown in FIG. 1, eNBs 110a, 110b, and 110c may be macro eNBs for macro cells 102a, 102b, and 102c, respectively. eNB 110x may be a pico eNB for a pico cell 102x. eNBs 110y and 110z may be femto eNBs for femto cells 102y and 102z, respectively. An eNB may support one or multiple (e.g., three) cells.

The wireless network 100 may also include relay stations. A relay station is a station that receives a transmission of data and/or other information from an upstream station (e.g., an eNB or a UE) and sends a transmission of the data and/or other information to a downstream station (e.g., a UE or an eNB). A relay station may also be a UE (e.g. UE relay station) that relays transmissions for other UEs. In the example shown in FIG. 1, a relay station 110r may communicate with eNB 110a and a UE 120r in order to facilitate communication between eNB 110a and UE 120r. A relay station may also be referred to as a relay eNB, a relay, etc.

The wireless network 100 may be a heterogeneous network (HetNet) that includes eNBs of different types, e.g., macro eNBs, pico eNBs, femto eNBs, relays, etc. These different types of eNBs may have different transmit power levels, different coverage areas, and different impact on interference in the wireless network 100. For example, macro eNBs may have a high transmit power level (e.g., 20 watts) whereas pico eNBs, femto eNBs, and relays may have a lower transmit power level (e.g., 1 watt).

The wireless network 100 may support synchronous or asynchronous operation. For synchronous operation, the eNBs may have similar frame timing, and transmissions from different eNBs may be approximately aligned in time. For asynchronous operation, the eNBs may have different frame timing, and transmissions from different eNBs may not be aligned in time. The techniques described herein may be used for both synchronous and asynchronous operation.

A network controller **130** may couple to a set of eNBs and provide coordination and control for these eNBs. The network controller **130** may communicate with eNBs **110** via a backhaul. The eNBs **110** may also communicate with one another, e.g., directly or indirectly via wireless or wireline backhaul.

The UEs **120** (e.g., **120x**, **120y**) may be dispersed throughout the wireless network **100**, and each UE may be stationary or mobile. A UE may also be referred to as a terminal, a mobile station, a subscriber unit, a station, etc. A UE may be a cellular phone, a smart phone, a personal digital assistant (PDA), a wireless modem, a wireless communication device, a handheld device, a laptop/notebook computer, a cordless phone, a wireless local loop (WLL) station, a tablet, etc. A UE may be able to communicate with macro eNBs, pico eNBs, femto eNBs, relays, etc. In FIG. 1, a solid line with double arrows indicates desired transmissions between a UE and a serving eNB, which is an eNB designated to serve the UE on the downlink and/or uplink. A dashed line with double arrows indicates interfering transmissions between a UE and an eNB. For certain aspects, the UE may comprise an LTE Release 10 UE.

LTE utilizes orthogonal frequency division multiplexing (OFDM) on the downlink and single-carrier frequency division multiplexing (SC-FDM) on the uplink. OFDM and SC-FDM partition the system bandwidth into multiple (K) orthogonal subcarriers, which are also commonly referred to as tones, bins, etc. Each subcarrier may be modulated with data. In general, modulation symbols are sent in the frequency domain with OFDM and in the time domain with SC-FDM. The spacing between adjacent subcarriers may be fixed, and the total number of subcarriers (K) may be dependent on the system bandwidth. For example, K may be equal to 128, 256, 512, 1024, or 2048 for system bandwidth of 1.25, 2.5, 5, 10, or 20 megahertz (MHz), respectively. The system bandwidth may also be partitioned into subbands. For example, a subband may cover 1.08 MHz, and there may be 1, 2, 4, 8, or 16 subbands for system bandwidth of 1.25, 2.5, 5, 10, or 20 MHz, respectively.

FIG. 2 shows a frame structure used in LTE. The transmission timeline for the downlink may be partitioned into units of radio frames. Each radio frame may have a predetermined duration (e.g., 10 milliseconds (ms)) and may be partitioned into 10 subframes with indices of 0 through 9. Each subframe may include two slots. Each radio frame may thus include 20 slots with indices of 0 through 19. Each slot may include L symbol periods, e.g., L=7 symbol periods for a normal cyclic prefix (as shown in FIG. 2) or L=6 symbol periods for an extended cyclic prefix. The 2L symbol periods in each subframe may be assigned indices of 0 through 2L-1. The available time frequency resources may be partitioned into resource blocks. Each resource block may cover N subcarriers (e.g., 12 subcarriers) in one slot.

In LTE, an eNB may send a primary synchronization signal (PSS) and a secondary synchronization signal (SSS) for each cell in the eNB. The primary and secondary synchronization signals may be sent in symbol periods 6 and 5, respectively, in each of subframes 0 and 5 of each radio frame with the normal cyclic prefix, as shown in FIG. 2. The synchronization signals may be used by UEs for cell detection and acquisition. The eNB may send a Physical Broadcast Channel (PBCH) in symbol periods 0 to 3 in slot 1 of subframe 0. The PBCH may carry certain system information.

The eNB may send a Physical Control Format Indicator Channel (PCFICH) in the first symbol period of each subframe, as shown in FIG. 2. The PCFICH may convey the number of symbol periods (M) used for control channels,

where M may be equal to 1, 2, or 3 and may change from subframe to subframe. M may also be equal to 4 for a small system bandwidth, e.g., with less than 10 resource blocks. The eNB may send a Physical HARQ Indicator Channel (PHICH) and a Physical Downlink Control Channel (PDCCH) in the first M symbol periods of each subframe (not shown in FIG. 2). The PHICH may carry information to support hybrid automatic repeat request (HARQ). The PDCCH may carry information on resource allocation for UEs and control information for downlink channels. The eNB may send a Physical Downlink Shared Channel (PDSCH) in the remaining symbol periods of each subframe. The PDSCH may carry data for UEs scheduled for data transmission on the downlink. The various signals and channels in LTE are described in 3GPP TS 36.211, entitled "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation," which is publicly available.

The eNB may send the PSS, SSS, and PBCH in the center 1.08 MHz of the system bandwidth used by the eNB. The eNB may send the PCFICH and PHICH across the entire system bandwidth in each symbol period in which these channels are sent. The eNB may send the PDCCH to groups of UEs in certain portions of the system bandwidth. The eNB may send the PDSCH to specific UEs in specific portions of the system bandwidth. The eNB may send the PSS, SSS, PBCH, PCFICH, and PHICH in a broadcast manner to all UEs, may send the PDCCH in a unicast manner to specific UEs and may also send the PDSCH in a unicast manner to specific UEs.

A number of resource elements may be available in each symbol period. Each resource element may cover one subcarrier in one symbol period and may be used to send one modulation symbol, which may be a real or complex value. Resource elements not used for a reference signal in each symbol period may be arranged into resource element groups (REGs). Each REG may include four resource elements in one symbol period. The PCFICH may occupy four REGs, which may be spaced approximately equally across frequency, in symbol period 0. The PHICH may occupy three REGs, which may be spread across frequency, in one or more configurable symbol periods. For example, the three REGs for the PHICH may all belong in symbol period 0 or may be spread in symbol periods 0, 1, and 2. The PDCCH may occupy 9, 18, 32, or 64 REGs, which may be selected from the available REGs, in the first M symbol periods. Only certain combinations of REGs may be allowed for the PDCCH.

A UE may know the specific REGs used for the PHICH and the PCFICH. The UE may search different combinations of REGs for the PDCCH. The number of combinations to search is typically less than the number of allowed combinations for the PDCCH. An eNB may send the PDCCH to the UE in any of the combinations that the UE will search.

FIG. 2A shows an exemplary format **200A** for the uplink in LTE. The available resource blocks for the uplink may be partitioned into a data section and a control section. The control section may be formed at the two edges of the system bandwidth and may have a configurable size. The resource blocks in the control section may be assigned to UEs for transmission of control information. The data section may include all resource blocks not included in the control section. The design in FIG. 2A results in the data section including contiguous subcarriers, which may allow a single UE to be assigned all of the contiguous subcarriers in the data section.

A UE may be assigned resource blocks in the control section to transmit control information to an eNB. The UE may also be assigned resource blocks in the data section to transmit data to the eNB. The UE may transmit control infor-

mation in a Physical Uplink Control Channel (PUCCH) **210a**, **210b** on the assigned resource blocks in the control section. The UE may transmit only data or both data and control information in a Physical Uplink Shared Channel (PUSCH) **220a**, **220b** on the assigned resource blocks in the data section. An uplink transmission may span both slots of a sub-frame and may hop across frequency as shown in FIG. 2A.

A UE may be within the coverage of multiple eNBs. One of these eNBs may be selected to serve the UE. The serving eNB may be selected based on various criteria such as received power, pathloss, signal-to-noise ratio (SNR), etc.

A UE may operate in a dominant interference scenario in which the UE may observe high interference from one or more interfering eNBs. A dominant interference scenario may occur due to restricted association. For example, in FIG. 1, UE **120y** may be close to femto eNB **110y** and may have high received power for eNB **110y**. However, UE **120y** may not be able to access femto eNB **110y** due to restricted association and may then connect to macro eNB **110c** with lower received power (as shown in FIG. 1) or to femto eNB **110z** also with lower received power (not shown in FIG. 1). UE **120y** may then observe high interference from femto eNB **110y** on the downlink and may also cause high interference to eNB **110y** on the uplink.

A dominant interference scenario may also occur due to range extension, which is a scenario in which a UE connects to an eNB with lower pathloss and lower SNR among all eNBs detected by the UE. For example, in FIG. 1, UE **120x** may detect macro eNB **110b** and pico eNB **110x** and may have lower received power for eNB **110x** than eNB **110b**. Nevertheless, it may be desirable for UE **120x** to connect to pico eNB **110x** if the pathloss for eNB **110x** is lower than the pathloss for macro eNB **110b**. This may result in less interference to the wireless network for a given data rate for UE **120x**.

According to certain aspects, communication in a dominant interference scenario may be supported by having different eNBs operate on different frequency bands. A frequency band is a range of frequencies that may be used for communication and may be given by (i) a center frequency and a bandwidth or (ii) a lower frequency and an upper frequency. A frequency band may also be referred to as a band, a frequency channel, etc. The frequency bands for different eNBs may be selected such that a UE can communicate with a weaker eNB in a dominant interference scenario while allowing a strong eNB to communicate with its UEs. An eNB may be classified as a “weak” eNB or a “strong” eNB based on the received power of signals from the eNB received at a UE (and not based on the transmit power level of the eNB).

FIG. 3 is a block diagram of a design of a base station or an eNB **110** and a UE **120**, which may be one of the base stations/eNBs and one of the UEs in FIG. 1. For a restricted association scenario, the eNB **110** may be macro eNB **110c** in FIG. 1, and the UE **120** may be UE **120y**. The eNB **110** may also be a base station of some other type. The eNB **110** may be equipped with T antennas **334a** through **334t**, and the UE **120** may be equipped with R antennas **352a** through **352r**, where in general  $T \geq 1$  and  $R \geq 1$ .

At the eNB **110**, a transmit processor **320** may receive data from a data source **312** and control information from a controller/processor **340**. The control information may be for the PBCH, PCFICH, PHICH, PDCCH, etc. The data may be for the PDSCH, etc. The transmit processor **320** may process (e.g., encode and symbol map) the data and control information to obtain data symbols and control symbols, respectively. The transmit processor **320** may also generate reference sym-

bols, e.g., for the PSS, SSS, and cell-specific reference signal. A transmit (TX) multiple-input multiple-output (MIMO) processor **330** may perform spatial processing (e.g., precoding) on the data symbols, the control symbols, and/or the reference symbols, if applicable, and may provide T output symbol streams to T modulators (MODs) **332a** through **332t**. Each modulator **332** may process a respective output symbol stream (e.g., for OFDM, etc.) to obtain an output sample stream. Each modulator **332** may further process (e.g., convert to analog, amplify, filter, and upconvert) the output sample stream to obtain a downlink signal. T downlink signals from modulators **332a** through **332t** may be transmitted via T antennas **334a** through **334t**, respectively.

At the UE **120**, antennas **352a** through **352r** may receive the downlink signals from the eNB **110** and may provide received signals to demodulators (DEMODs) **354a** through **354r**, respectively. Each demodulator **354** may condition (e.g., filter, amplify, downconvert, and digitize) a respective received signal to obtain input samples. Each demodulator **354** may further process the input samples (e.g., for OFDM, etc.) to obtain received symbols. A MIMO detector **356** may obtain received symbols from all R demodulators **354a** through **354r**, perform MIMO detection on the received symbols, if applicable, and provide detected symbols. A receive processor **358** may process (e.g., demodulate, deinterleave, and decode) the detected symbols, provide decoded data for the UE **120** to a data sink **360**, and provide decoded control information to a controller/processor **380**.

On the uplink, at the UE **120**, a transmit processor **364** may receive and process data (e.g., for the PUSCH) from a data source **362** and control information (e.g., for the PUCCH) from the controller/processor **380**. The transmit processor **364** may also generate reference symbols for a reference signal. The symbols from transmit processor **364** may be precoded by a TX MIMO processor **366** if applicable, further processed by modulators **354a** through **354r** (e.g., for SC-FDM, etc.), and transmitted to the eNB **110**. At the eNB **110**, the uplink signals from the UE **120** may be received by the antennas **334**, processed by the demodulators **332**, detected by a MIMO detector **336** if applicable, and further processed by a receive processor **338** to obtain decoded data and control information sent by the UE **120**. The receive processor **338** may provide the decoded data to a data sink **339** and the decoded control information to the controller/processor **340**.

The controllers/processors **340** and **380** may direct the operation at the eNB **110** and the UE **120**, respectively. The controller/processor **340**, receive processor **338**, and/or other processors and modules at the eNB **110** may perform or direct operations **800** in FIG. 8 and/or other processes for the techniques described herein. The memories **342** and **382** may store data and program codes for the eNB **110** and the UE **120**, respectively. A scheduler **344** may schedule UEs for data transmission on the downlink and/or uplink. eNB **110** may transmit static resource partitioning information (SPRI) **390** to UE **120**. UE **120** may transmit sounding reference signals (SRS) **392** to eNB **110**.

#### Example Resource Allocation for EPDCCH

In existing wireless communications systems (e.g., so called “legacy” LTE Rel-8/9/10 systems), PDCCH is located in the first several symbols of an LTE subframe. The PDCCH is generally distributed across the entire bandwidth of the subframe and is time division multiplexed with PDSCH. In other words, the subframe is effectively divided into a control region and a data region, and the PDCCH occupies the first several symbols of the control region.

An enhanced PDCCH (EPDCCH) may be defined, for example, in non-legacy systems (e.g., Rel-12) which may complement or replace the legacy PDCCH. Unlike the legacy PDCCH which occupies the control region of the subframe in which it is transmitted, the EPDCCH generally occupies the data region of the subframe, similar to the legacy PDSCH. In other words, an EPDCCH region may be defined that occupies the conventional/legacy PDSCH region. The EPDCCH region may consist of multiple contiguous or non-contiguous Resource Blocks (RBs) and may occupy a subset of OFDM symbols within those RBs.

The EPDCCH may have several advantages over the legacy PDCCH. For example, the EPDCCH may help increase control channel capacity (e.g., and may add to the capacity of the legacy PDCCH), support frequency-domain Inter-Cell Interference Cancellation (ICIC), achieve improved spatial reuse of control channel resource, support beamforming and/or diversity, operate on a New Carrier Type (NCT) and in Multicast-Broadcast Single Frequency Network (MBSFN) subframes, and/or coexist on a same carrier as legacy UEs.

According to certain aspects, UE-specific demodulation reference signals (DMRSs) may be used for downlink channel estimation for coherent demodulation of the PDSCH/EPDCCH. According to certain aspects, to provide good channel estimation for the PDSCH/EPDCCH, each RB carrying the PDSCH/EPDCCH may include sufficient DMRS for good channel estimation within the RB.

FIG. 4 illustrates example DMRS patterns 400a-c, as defined in Rel-10 for the normal cyclic prefix case, that may be used in accordance with certain aspects of the present disclosure.

As illustrated, resource elements (REs) 410 and 420 are allocated for DMRS transmissions. In the illustrated example, REs 410 are used for CDM Group 1 and REs 420 are used for CDM Group 2. As shown in FIG. 4, the DMRS occupies the sixth and seventh symbols of each of the first and second slots of the subframe.

DMRS pattern 400a shows a DMRS pattern for a normal subframe. As used herein, the term normal subframe is a relative term, referring to a subframe that does not have a Downlink Pilot Time Slot (DwPTS), a special downlink timeslot that typically occurs in certain subframes (e.g., the 2<sup>nd</sup> or 7<sup>th</sup> subframe in a radio frame, depending on a subframe configuration) when LTE is operated in Time Division Duplex (TDD). The length of DwPTS subframes is variable, to allow for different DownLink-UpLink switching periods to be configured.

DMRS pattern 400b shows an example DMRS pattern for a DwPTS subframe with 11 or 12 symbols. As shown in this example, the DMRS occupies the third and fourth symbols of each of the first and second slots of the subframe. DMRS pattern 400c shows a DMRS pattern for a DwPTS subframe with 9, 10 symbols. As shown in this example, the DMRS occupies the third, fourth, sixth and seventh symbols of the, first slot of the subframe.

In legacy systems (e.g., Rel-8/9/10), the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS) are generally transmitted in the center six RBs only in subframes 0 and 5 (e.g., as shown in FIG. 2). The Primary Broadcast Channel (PBCH) is also generally transmitted in the center six RBs but only in subframe 0.

FIG. 5 illustrates an example resource configuration 500 for PSS, SSS and PBCH in an LTE frame, in accordance with certain aspects of the present disclosure. As shown in FIG. 5, an LTE frame of 10 ms long is typically divided in to ten subframes each 1 ms long. Each subframe may further be

divided in to two slots slot 0 and slot 1. As shown, PSS and SSS are typically transmitted every 5 ms in subframes 0 and 5. The PSS and SSS are transmitted back to back in the last two symbols of the first slot in the subframes 0 and 5. Typically SSS is transmitted before PSS.

According to certain aspects of the present disclosure, as shown in FIG. 5, in order to differentiate the 10 ms boundary, the two SSS signals, SSS1 (subframe 0) and SSS2 (subframe 5) may have different arrangements. The PSS arrangement, however, may be fixed. PBCH is transmitted every 10 ms in the first four symbols of the second slot of subframe 0. According to certain aspects, the above defined PSS/SSS/PBCH configuration is used for FDD transmission.

According to certain aspects, for TDD transmissions, the SSS may be transmitted in the last symbol of subframes 0 and 5, and the PSS may be transmitted in the third symbol of subframes 1 and 6.

Referring back to FIG. 4, according to certain aspects, since the DMRS may use at least some of the same resources (e.g., symbols and/or REs) allocated to PSS and SSS, the transmission of PSS and SSS can potentially collide with DM-RS in subframes 0 and 5 when transmitted in the center six RBs. For example, since PSS and SSS may be transmitted in the last two symbols of slot 1 (refer FIG. 5), they may potentially collide with DMRS which (as noted in FIG. 4) may be allocated on the same two symbols.

According to current specifications (e.g., current LTE specifications), for subframes in the center six RBs having PSS, SSS and/or PBCH, DMRS-based EPDCCH is not supported. Thus, in subframes containing PSS, SSS or PBCH, a UE cannot expect to receive DMRS-based PDSCH or EPDCCH. For example, even if the UE supports DMRS-based EPDCCH, it may not expect to receive DMRS PRBs overlapping with PSS, SSS, or PBCH. Thus, such a UE may drop DMRS in subframes in which it collides with PSS, SSS or PBCH. This may lead to performance issues for PDSCH and/or EPDCCH.

For a legacy carrier type (e.g., Rel-8), not being able to use resources from the center six RBs in subframes 0 and 5 for DMRS-based PDSCH or EPDCCH may not of great concern, since Cell-Specific Reference Signal (CRS) based PDSCH and legacy PDCCH may still utilize these resources. For example, the REs not used by PSS, SSS or PBCH may be used by CRS based PDSCH.

However, certain legacy and non-legacy systems may only support DMRS-based transmissions with no support for CRS based transmissions. For example, according to certain aspects, non-legacy systems (e.g., Rel-12) may define a New carrier type (NCT). The NCT may be standalone or an extension carrier, for example, designed to achieve enhanced spectral efficiency, improve support for heterogeneous networks, and/or improve energy efficiency. The NCT may be “bandwidth agnostic” from the physical layer perspective, with at least reduced or eliminated legacy control signaling and/or CRS at least one the downlink (e.g., for Time Division Duplex (TDD), on the downlink subframes on a carrier). Thus, according to certain aspects, the NCT may not support CRS based PDSCH or PDCCH, and may only support DMRS-based PDSCH and EPDCCH.

This may be a serious concern, since the entire downlink subframe (e.g., subframes 0 and 5) in the data region for the center six RBs may be empty (except for PSS, SSS, and PBCH)—in the cases where DMRS-based PDSCH or EPDCCH cannot be transmitted. This may lead to a significant waste of resources. This issue may be even more pronounced when a control transmission completely relies on EPDCCH (i.e., with no reliance on PDCCH). In addition, for a narrow

band operation, such as where the system supports only the center 6 RBs (e.g., from a UE's perspective), the UE can never be scheduled for a corresponding uplink, since the subframes cannot carry EPDCCH. For a larger bandwidth, UL may be scheduled with EPDCCH not colliding with PSS/SSS/PBCH.

As noted above, the NCT may be associated with a backward compatible carrier (as an extension) or may be a standalone carrier. According to certain aspects, for Frequency Division Duplex (FDD), a downlink carrier of the new type may be linked with a legacy uplink carrier. For TDD, a carrier may contain downlink subframes of the new type and legacy uplink subframes.

One possible solution to the collision problem for systems with larger bandwidths that only support DMRS-based transmissions, is to not allocate DMRS or DMRS-based transmissions (e.g., EPDCCH) in the center six RBs. According to certain aspects, the EPDCCH may come from RBS other than the center six RBs. However, this solution may not work for systems with narrow bandwidth. In addition, the resource wastage issue still persists.

Certain aspects of the present disclosure, however, provide techniques for systems that support only DMRS-based transmissions, for at least partially utilizing resources in the center six RBs of subframes 0 and 5 for DMRS-based transmissions (e.g., EPDCCH), while avoiding collision with PSS, SSS or PBCH.

According to certain aspects, the DMRS pattern (e.g., as noted in FIG. 4) may be re-defined to avoid collisions with PSS, SSS or PBCH. According to certain aspects, the DMRS pattern may be moved from the sixth and seventh symbols in the first slot to the second and third symbols in the first slot. In an alternative aspect, the DMRS pattern may be moved to the third and fourth symbols in the first slot.

According to certain aspects, a punctured DMRS pattern may be used. The punctured DMRS pattern may allow DMRS-based EPDCCH transmission in the center six RBs in subframes 0 and 5, but only based on the DMRS in the sixth and the seventh symbols in the second slot.

According to certain aspects, the PSS or SSS may be punctured by EPDCCH (in other words, resources that would have otherwise been used for PSS or SSS may be used for EPDCCH). According to certain aspects, EPDCCH may be allowed for transmission in some of the center six RBs used by the PSS or SSS, wherein EPDCCH will override the PSS and SSS in these RBs. According to certain aspects, the PSS and/or SSS may rely on the remaining RBs.

According to certain aspects, the pattern for PSS, SSS and PBCH (e.g., as shown in FIG. 5) may be re-designed, for example, at least for NCTs. According to certain aspects, the resource allocation for the PSS, SSS and/or PBCH may be re-defined to avoid collision with DMRS and DMRS-based transmissions (e.g., EPDCCH). For example, the PBCH may be moved to the first four symbols in the first slot. The PSS and SSS may be moved to the third and fourth symbols in the second slot. According to certain aspects, the different placements of PSS and SSS in the backward compatible carriers and the new carriers may help in early detection of the new type of carriers by the UE. In addition, the new placement may also prevent legacy UEs from accessing the new carrier.

According to certain aspects, cross-carrier scheduling may be employed. According to certain aspects, a carrier with EPDCCH issues may be cross-carrier scheduled by another carrier. For example, a 1.4 MHz carrier may be cross-carrier scheduled by another carrier of 5 MHz, when both carriers are configured for a UE. However, it may be noted that although

PDSCH. For downlink PDSCH, one or more of the above discussed techniques may have to be used. In addition, the center six RBs are still wasted.

FIG. 6 illustrates example operations 600 that may be performed by a User Equipment (UE) for monitoring and decoding EPDCCH, in accordance with certain aspects of the present disclosure. Operations 600 may begin, at 602, by determining at least one decoding candidate for EPDCCH in a subframe. At 604, the UE may determine whether or not the resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of PSS, SSS or PBCH in the subframe. At 606, the UE may process the at least one EPDCCH decoding candidate based on the determination of potential resource collision.

According to certain aspects, the UE may receive a configuration of EPDCCH resources and determine the at least one EPDCCH decoding candidate based on the received configuration. Further, the UE may determine the resources corresponding to the at least one EPDCCH decoding candidate based on the received configuration.

According to certain aspects, the UE may determine validity of the at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision. According to certain aspects, the UE may declare the at least one EPDCCH decoding candidate as a valid candidate if the resources corresponding to the candidate do not potentially collide with the resources used by at least one of the PSS, SSS, or PBCH. According to certain aspects, processing the EPDCCH candidate may include monitoring and decoding the EPDCCH candidate-only if it is determined to be a valid candidate.

According to certain aspects, the UE may declare the EPDCCH candidate as an invalid candidate if the resources corresponding to the candidate potentially collide with the resources used by at least one of the PSS, SSS or PBCH. According to certain aspects, processing the EPDCCH candidate may include not monitoring for a particular candidate if it is determined to an invalid candidate.

According to certain aspects, determining if the resources corresponding to the EPDCCH candidate can potentially collide with resources used for transmitting at least one of the PSS, SSS or PBCH may include determining if the candidate and at least one of the PSS, SSS or PBCH use a same resource based on a comparison of the resources corresponding to the EPDCCH decoding candidate and the resources used for transmitting at least one of the PSS, SSS or PBCH.

According to certain aspects, determining if the resources corresponding to the EPDCCH candidate can potentially collide with resources used for transmitting at least one of the PSS, SSS or PBCH may include determining if the EPDCCH candidate and at least one of the PSS, SSS or PBCH use a same physical resource block (PRB) pair, based on a comparison of a set of PRB pairs associated with EPDCCH resources and a set of PRB pairs used for transmitting at least one of the PSS, SSS or PBCH.

According to certain aspects, the resources corresponding to at least one EPDCCH decoding candidate includes at least one PRB pair of a set of PRB pairs used for transmission of at least one of the PSS, SSS or PBCH. According to certain aspects, the at least one PRB pair is assigned such that resources in the at least one PRB pair assigned to at least one of the PSS, SSS or PBCH are not assigned for EPDCCH transmission, and resources in the at least one PRB pair not assigned to at least one of the PSS, SSS or PBCH are assigned for EPDCCH transmission.

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According to certain aspects the at least one EPDCCH decoding candidate is based on a DMRS, and the resources corresponding to the candidate includes resources used by the DMRS. According to certain aspects, in a subframe comprising of two slots, the DMRS is located in at least one symbol not occupied by at least one of the PSS or SSS in a same slot as the at least one of the PSS or SSS. According to certain aspects, the DMRS is located only in symbols not occupied by at least one of the PSS or SSS. According to certain aspects, the DMRS is located at least in one symbol originally occupied by at least one of PSS or SSS of a legacy type.

According to certain aspects, the at least one EPDCCH decoding candidate scheduling a transmission on a first carrier is transmitted on a second carrier different from the first carrier.

FIG. 7 illustrates example operations 700 that may be performed by a Base Station (BS) for transmitting EPDCCH, in accordance with certain aspects of the present disclosure. Operations 700 may begin, at 702, with the BS determining potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe. At 704, the BS may select at least one of the EPDCCH decoding candidates based on the determination. At 706, the BS transmits an EPDCCH on the selected EPDCCH decoding candidate.

According to certain aspects, the BS selects at least one decoding candidate if resources corresponding to the candidate do not collide with the resources used for transmitting at least one of the PSS, SSS, or PBCH in the subframe. In certain aspects, the BS determining the potential collision conditions may include determining if the EPDCCH decoding candidate and at least one of the PSS, SSS or PBCH use a same resource based on a comparison of the resources corresponding to the EPDCCH decoding candidate and the resources used for transmitting at least one of the PSS, SSS or PBCH.

According to certain aspects, determining the potential collision conditions may include determining if the EPDCCH decoding candidate and at least one of the PSS, SSS or PBCH use a same PRB pair, based on a comparison of a set of PRB pairs associated with EPDCCH resources and a set of PRB pairs used for transmitting at least one of the PSS, SSS or PBCH.

In certain aspects, the resources corresponding to the at least one EPDCCH decoding candidate includes at least one PRB pair of a set of PRB pairs used for transmission of at least one of the PSS, SSS or PBCH. In an aspect the at least one PRB pair is scheduled such that resources in the at least one PRB pair assigned to at least one of the PSS, SSS or PBCH are not assigned for EPDCCH transmission, and resources in the at least one PRB pair not assigned to at least one of the PSS, SSS or PBCH are assigned for EPDCCH transmission.

According to certain aspects, the at least one EPDCCH decoding candidate is based on DMRS, and resources corresponding to the at least one EPDCCH decoding candidate comprise resources used by the DMRS. In an aspect, in a subframe comprising of two slots, the DMRS is located in at least one symbol not occupied by at least one of the PSS or SSS in a same slot as the at least one of the PSS or SSS. In an aspect the DMRS is located only in symbols not occupied by at least one of the PSS or SSS. In an aspect, the DMRS is located at least in one symbol originally occupied by at least one of PSS or SSS of a legacy type.

According to certain aspects, the resources corresponding to each EPDCCH decoding candidate includes at least one PRB. In an aspect, resources used for transmitting at least one of the PSS, SSS or PBCH includes at least one PRB.

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Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits and algorithm steps described in connection with the disclosure herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

The various illustrative logical blocks, modules, and circuits described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The steps of a method or algorithm described in connection with the disclosure herein may be embodied directly in hardware, in a software/firmware module executed by a processor, or in a combination of the two. A software/firmware module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and/or write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal. Generally, where there are operations illustrated in Figures, those operations may have corresponding counterpart means-plus-function components with similar numbering.

In one or more exemplary designs, the functions described may be implemented in hardware, software/firmware or combinations thereof. If implemented in software/firmware, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a general purpose or special purpose com-

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puter. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code means in the form of instructions or data structures and that can be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

The previous description of the disclosure is provided to enable any person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the spirit or scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein, but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

What is claimed is:

1. A method for wireless communication by a User Equipment, comprising:
  - determining at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe;
  - determining whether or not resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), a Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe;
  - determining validity of the at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision; and
  - processing the at least one EPDCCH decoding candidate based on the determination of the potential resource collision.
2. The method of claim 1, further comprising:
  - receiving a configuration of EPDCCH resources; and
  - determining the at least one EPDCCH decoding candidate based on the received configuration.
3. The method of claim 2, further comprising:
  - determining the resources corresponding to the at least one EPDCCH decoding candidate based on the received configuration.
4. The method of claim 1, wherein determining the validity of the at least one EPDCCH decoding candidate comprises:
  - declaring the at least one EPDCCH decoding candidate as a valid candidate if the resources corresponding to the at least one EPDCCH decoding candidate do not potentially collide with the resources used by the at least one of the PSS, SSS or PBCH.

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5. The method of claim 4, wherein processing the at least one EPDCCH decoding candidate comprises:
  - monitoring and decoding the at least one EPDCCH decoding candidate if the at least one EPDCCH decoding candidate is determined to be valid.
6. The method of claim 1, wherein determining the validity of the at least one EPDCCH decoding candidate comprises:
  - declaring the at least one EPDCCH decoding candidate as an invalid candidate if the resources corresponding to the at least one EPDCCH decoding candidate potentially collide with the resources used by at least one of the PSS, SSS or PBCH.
7. The method of claim 6, wherein processing the at least one EPDCCH decoding candidate comprises:
  - skipping monitoring the at least one EPDCCH decoding candidate if the at least one EPDCCH decoding candidate is determined to be invalid.
8. The method of claim 1, wherein determining if the resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of the PSS, SSS or PBCH comprises:
  - determining if the at least one EPDCCH decoding candidate and the at least one of the PSS, SSS or PBCH use a same resource based on a comparison of the resources corresponding to the at least one EPDCCH decoding candidate and the resources used for transmitting the at least one of the PSS, SSS or PBCH.
9. The method of claim 1, wherein determining if the resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of the PSS, SSS or PBCH comprises:
  - determining if the at least one EPDCCH decoding candidate and the at least one of the PSS, SSS or PBCH use a same physical resource block (PRB) pair, based on a comparison of a set of PRB pairs associated with EPDCCH resources and a set of PRB pairs used for transmitting at least one of the PSS, SSS or PBCH.
10. The method of claim 1, wherein the resources corresponding to the at least one EPDCCH decoding candidate includes at least one physical resource block (PRB) pair of a set of PRB pairs used for transmission of at least one of the PSS, SSS or PBCH such that:
  - resources in the at least one PRB pair assigned to at least one of the PSS, SSS or PBCH are not assigned for EPDCCH transmission; and
  - resources in the at least one PRB pair not assigned to at least one of the PSS, SSS or PBCH are assigned for EPDCCH transmission.
11. The method of claim 1, wherein the at least one EPDCCH decoding candidate is based on a demodulation reference signal (DMRS), and the resources corresponding to the at least one EPDCCH decoding candidate comprise resources used by the DMRS.
12. The method of claim 11, wherein in a subframe comprising of two slots, the DMRS is located in at least one symbol not occupied by at least one of the PSS or SSS in a same slot as the at least one of the PSS or SSS.
13. The method of claim 11, wherein the DMRS is located only in symbols not occupied by at least one of the PSS or SSS.
14. The method of claim 11, wherein the DMRS is located at least in one symbol originally occupied by at least one of PSS or SSS of a legacy type.
15. The method of claim 1, wherein the at least one EPDCCH decoding candidate scheduling a transmission on a first carrier is transmitted on a second carrier different from the first carrier.

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16. The method of claim 1, wherein the resources corresponding to the at least one EPDCCH decoding candidate includes at least one Physical Resource Block Pair.

17. The method of claim 1, wherein the resources used for transmitting the at least one of the PSS, SSS or PBCH includes at least one Physical Resource Block Pair.

18. An apparatus for wireless communication, comprising:  
means for determining at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe;

means for determining whether or not resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), a Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe;

means for determining validity of the at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision; and

means for processing the at least one EPDCCH decoding candidate based on the determination of potential resource collision.

19. The apparatus of claim 18, wherein the means for determining the validity of the at least one EPDCCH decoding candidate is configured to:

declare the at least one EPDCCH decoding candidate as a valid candidate if the resources corresponding to the at least one EPDCCH decoding candidate do not potentially collide with the resources used by the at least one of the PSS, SSS or PBCH.

20. The apparatus of claim 19, wherein the means for processing the at least one EPDCCH decoding candidate is configured to:

monitor and decode the at least one EPDCCH decoding candidate if the at least one EPDCCH decoding candidate is determined to be valid.

21. The apparatus of claim 18, wherein the means for determining the validity of the at least one EPDCCH decoding candidate is configured to:

declare the at least one EPDCCH decoding candidate as an invalid candidate if the resources corresponding to the at least one EPDCCH decoding candidate potentially collide with the resources used by the at least one of the PSS, SSS or PBCH.

22. The apparatus of claim 21, wherein the means for processing the at least one EPDCCH decoding candidate is configured to:

skip monitoring the at least one EPDCCH decoding candidate if the at least one EPDCCH decoding candidate is determined to be invalid.

23. The apparatus of claim 18, wherein the at least one EPDCCH decoding candidate is based on a demodulation reference signal (DMRS), and the resources corresponding to the at least one EPDCCH decoding candidate comprise resources used by the DMRS.

24. The apparatus of claim 23, wherein in a subframe comprising of two slots, the DMRS is located in at least one symbol not occupied by at least one of the PSS or SSS in a same slot as the at least one of the PSS or SSS.

25. The apparatus of claim 23, wherein the DMRS is located only in symbols not occupied by at least one of the PSS or SSS.

26. The apparatus of claim 23, wherein the DMRS is located at least in one symbol originally occupied by at least one of PSS or SSS of a legacy type.

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27. The apparatus of claim 18, wherein the at least one EPDCCH decoding candidate scheduling a transmission on a first carrier is transmitted on a second carrier different from the first carrier.

28. An apparatus for wireless communication, comprising:  
at least one processor configured to:

determine at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe;

determine whether or not resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), a Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe;

determine validity of the at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision; and

process the at least one EPDCCH decoding candidate based on the determination of potential resource collision; and

a memory coupled to the at least one processor.

29. A computer program product for wireless communication, comprising:

a non-transitory computer-readable medium comprising code for:

determining at least one decoding candidate for Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe;

determining whether or not resources corresponding to the at least one EPDCCH decoding candidate can potentially collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), a Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe;

determining validity of the at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision; and

processing the at least one EPDCCH decoding candidate based on the determination of potential resource collision.

30. A method for wireless communications by a Base Station (BS), comprising:

determining potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe;

determining validity of at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision;

selecting the at least one EPDCCH decoding candidate from the set based on the validity determination; and transmitting an EPDCCH on the selected EPDCCH decoding candidate.

31. The method of claim 30, wherein the selecting comprises selecting the at least one EPDCCH decoding candidate if the at least one EPDCCH decoding candidate is determined to be valid, wherein the at least one EPDCCH decoding candidate is declared as a valid candidate if resources corresponding to the candidate do not collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), a Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe.

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**32.** The method of claim **31**, wherein the determining the potential collision conditions comprises:

determining if the at least one EPDCCH decoding candidate and the at least one of the PSS, SSS or PBCH use a same resource based on a comparison of the resources corresponding to the EPDCCH decoding candidate and the resources used for transmitting the at least one of the PSS, SSS or PBCH.

**33.** The method of claim **31**, wherein the determining the potential collision conditions comprises:

determining if the at least one EPDCCH decoding candidate and the at least one of the PSS, SSS or PBCH use a same physical resource block (PRB) pair, based on a comparison of a set of PRB pairs associated with EPDCCH resources and a set of PRB pairs used for transmitting at least one of the PSS, SSS or PBCH.

**34.** The method of claim **31**, wherein the resources corresponding to the at least one EPDCCH decoding candidate includes at least one physical resource block (PRB) pair of a set of PRB pairs used for transmission of at least one of the PSS, SSS or PBCH such that:

resources in the at least one PRB pair assigned to at least one of the PSS, SSS or PBCH are not assigned for EPDCCH transmission; and

resources in the at least one PRB pair not assigned to at least one of the PSS, SSS or PBCH are assigned for EPDCCH transmission.

**35.** The method of claim **30**, wherein the at least one EPDCCH decoding candidate is based on a demodulation reference signal (DMRS), and resources corresponding to the at least one EPDCCH decoding candidate comprise resources used by the DMRS.

**36.** The method of claim **35**, wherein in a subframe comprising of two slots, the DMRS is located in at least one symbol not occupied by at least one of Primary Synchronization Signal (PSS) or Secondary Synchronization Signal (SSS) in a same slot as the at least one of the PSS or SSS.

**37.** The method of claim **35**, wherein the DMRS is located only in symbols not occupied by at least one of Primary Synchronization Signal (PSS) or Secondary Synchronization Signal (SSS).

**38.** The method of claim **35**, wherein the DMRS is located at least in one symbol originally occupied by at least one of Primary Synchronization Signal (PSS) or Secondary Synchronization Signal (SSS) of a legacy type.

**39.** The method of claim **30**, wherein resources corresponding to each EPDCCH decoding candidate includes at least one Physical Resource Block Pair.

**40.** The method of claim **30**, wherein resources used for transmitting at least one of the PSS, SSS or PBCH includes at least one Physical Resource Block Pair.

**41.** An apparatus for wireless communications, comprising:

means for determining potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe;

means for determining validity of at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision;

means for selecting the at least one EPDCCH decoding candidate from the set based on the validity determination; and

means for transmitting an EPDCCH on the selected EPDCCH decoding candidate.

**42.** The apparatus of claim **41**, wherein the means for selecting is configured to select the at least one EPDCCH

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decoding candidate if the at least one EPDCCH decoding candidate is determined to be valid, wherein the at least one EPDCCH decoding candidate is declared as a valid candidate if resources corresponding to the candidate do not collide with resources used for transmitting at least one of a Primary Synchronization Signal (PSS), a Secondary Synchronization Signal (SSS) or a Physical Broadcast Channel (PBCH) in the subframe.

**43.** The apparatus of claim **42**, wherein the means for determining the potential collision conditions is configured to:

determine if the at least one EPDCCH decoding candidate and the at least one of the PSS, SSS or PBCH use a same resource based on a comparison of the resources corresponding to the EPDCCH decoding candidate and the resources used for transmitting at least one of the PSS, SSS or PBCH.

**44.** The apparatus of claim **42**, wherein the means for determining the potential collision conditions is configured to:

determine if the at least one EPDCCH decoding candidate and the at least one of the PSS, SSS or PBCH use a same physical resource block (PRB) pair, based on a comparison of a set of PRB pairs associated with EPDCCH resources and a set of PRB pairs used for transmitting at least one of the PSS, SSS or PBCH.

**45.** The apparatus of claim **42**, wherein the resources corresponding to the at least one EPDCCH decoding candidate includes at least one physical resource block (PRB) pair of a set of PRB pairs used for transmission of at least one of the PSS, SSS or PBCH such that:

resources in the at least one PRB pair assigned to at least one of the PSS, SSS or PBCH are not assigned for EPDCCH transmission; and

resources in the at least one PRB pair not assigned to at least one of the PSS, SSS or PBCH are assigned for EPDCCH transmission.

**46.** The apparatus of claim **41**, wherein the at least one EPDCCH decoding candidate is based on a demodulation reference signal (DMRS), and resources corresponding to the at least one EPDCCH decoding candidate comprise resources used by the DMRS.

**47.** The apparatus of claim **46**, wherein in a subframe comprising of two slots, the DMRS is located in at least one symbol not occupied by at least one of Primary Synchronization Signal (PSS) or Secondary Synchronization Signal (SSS) in a same slot as the at least one of the PSS or SSS.

**48.** The apparatus of claim **46**, wherein the DMRS is located only in symbols not occupied by at least one of Primary Synchronization Signal (PSS) or Secondary Synchronization Signal (SSS).

**49.** The apparatus of claim **46**, wherein the DMRS is located at least in one symbol originally occupied by at least one of Primary Synchronization Signal (PSS) or Secondary Synchronization Signal (SSS) of a legacy type.

**50.** An apparatus for wireless communications, comprising:

at least one processor configured to:

determine potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe;

determine validity of at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision;

select the at least one EPDCCH decoding candidate from the set based on the validity determination; and transmit an EPDCCH on the selected EPDCCH decoding candidate; and

a memory coupled to the at least one processor. 5

51. A computer program product for wireless communications, comprising:

a non-transitory computer-readable medium comprising code for:

determining potential collision conditions for each of a set of decoding candidates for transmitting Enhanced Physical Downlink Control Channel (EPDCCH) in a subframe; 10

determining validity of at least one EPDCCH decoding candidate based, at least in part, on the determination of the potential resource collision; 15

selecting the at least one EPDCCH decoding candidate from the set based on the validity determination; and transmitting an EPDCCH on the selected EPDCCH decoding candidate. 20

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