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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 September 2006 (21.09.2006)

PCT

(10) International Publication Number
WO 2006/099577 A1

(51) International Patent Classification:
H04J 11/00 (2006.01)

(21) International Application Number:
PCT/US2006/009757

(22) International Filing Date: 16 March 2006 (16.03.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/662,634 16 March 2005 (16.03.2005) US
11/129,140 13 May 2005 (13.05.2005) US

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

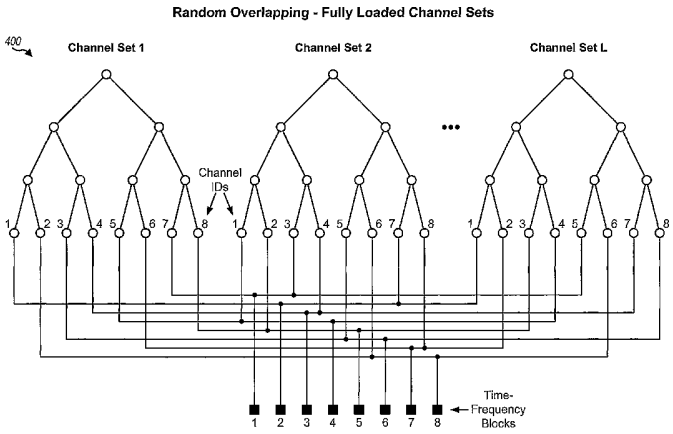
(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:
— *with international search report*

[Continued on next page]

(54) **Title:** CHANNEL STRUCTURES FOR A QUASI-ORTHOGONAL MULTIPLE-ACCESS COMMUNICATION SYSTEM



(57) **Abstract:** A channel structure has at least two channel sets. Each channel set contains multiple channels and is associated with a specific mapping of the channels to the system resources available for data transmission. Each channel set may be defined based on a channel tree having a hierarchical structure. To achieve intra-cell interference diversity, the channel-to-resource mapping for each channel set is pseudo-random with respect to the mapping for each remaining channel set. In each scheduling interval, terminals are scheduled for transmission on the forward and/or reverse link. The scheduled terminals are assigned channels from the channel sets. Multiple terminals may use the same system resources and their overlapping transmissions may be separated in the spatial domain. For example, beamforming may be performed to send multiple overlapping transmissions on the forward link, and receiver spatial processing may be performed to separate out multiple overlapping transmissions received on the reverse link.

WO 2006/099577 A1

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

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CHANNEL STRUCTURES FOR A QUASI-ORTHOGONAL MULTIPLE-ACCESS COMMUNICATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Patent Application Serial No. 60/662,634, filed March 16, 2005, which is expressly incorporated herein by reference in its entirety.

BACKGROUND

I. Field

[0002] The present disclosure relates generally to communication, and more specifically to data transmission in a multiple-access communication system.

II. Background

[0003] A multiple-access system can concurrently communicate with multiple terminals on the forward and reverse links. The forward link (or downlink) refers to the communication link from the base stations to the terminals, and the reverse link (or uplink) refers to the communication link from the terminals to the base stations. Multiple terminals may simultaneously transmit data on the reverse link and/or receive data on the forward link. This is often achieved by multiplexing the multiple data transmissions on each link to be orthogonal to one another in time, frequency and/or code domain. Complete orthogonality among the multiple data transmissions is typically not achieved in most instances due to various factors such as channel conditions, receiver imperfections, and so on. Nevertheless, the orthogonal multiplexing ensures that the data transmission for each terminal minimally interferes with the data transmissions for the other terminals.

[0004] The number of terminals that may communicate with the multiple-access system at any given moment is typically limited by the number of physical channels available for data transmission, which in turn is limited by the available system resources. For example, the number of physical channels is determined by the number of available orthogonal code sequences in a code division multiple access (CDMA) system, the number of available frequency subbands in a frequency division multiple

access (FDMA) system, the number of available time slots in a time division multiple access (TDMA) system, and so on. In many instances, it is desirable to allow more terminals to simultaneously communicate with the system in order to improve system capacity. There is therefore a need in the art for techniques to support simultaneous transmissions for more terminals in a multiple-access system.

SUMMARY

[0005] Techniques for assigning system resources in a manner to control intra-cell interference and to achieve higher system capacity are described herein. In an embodiment, a channel structure with at least two channel sets is defined. Each channel set contains multiple channels and is associated with a specific mapping of the channels to the system resources available for data transmission. Each channel set may be defined based on a channel tree having a hierarchical structure. For example, the channel tree may include multiple "base" channels and multiple "composite" channels. The base channels may be mapped to the available system resources (e.g., using frequency hopping). Each composite channel may be associated with at least two base channels. For the channel tree, each channel that is assigned to a terminal restricts at least one other channel from being assigned. Various channel structures having different interference characteristics may be formed by partitioning the channel tree in different manners and/or using different channel-to-resource mappings for the channel sets, as described below. For example, intra-cell interference diversity may be achieved by defining the mapping for each channel set to be pseudo-random with respect to the mapping for each remaining channel set.

[0006] In each scheduling interval, terminals are scheduled for transmission on the forward and/or reverse link. The scheduled terminals are assigned channels from the channel sets. The scheduling and/or channel assignment may be based on pertinent information for the terminals such as their channel estimates, signal-to-noise-and-interference ratio (SNR) estimates, quality of service (QoS) requirements, handoff status, and so on. Multiple terminals may use the same system resources and their overlapping transmissions may be separated in the spatial domain. For the forward link (FL), data for overlapping terminals is spatially processed (e.g., for beamforming) based on their FL channel estimates and then transmitted from multiple antennas. For the

reverse link (RL), multiple transmissions from overlapping terminals are received via the multiple antennas. The received symbols for the overlapping terminals are then spatially processed based on their RL channel estimates to recover the transmission from each terminal.

[0007] Various aspects and embodiments of the invention are described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 shows a system with multiple base stations and multiple terminals.

[0009] FIG. 2 shows a mapping of a physical channel to time-frequency blocks.

[0010] FIG. 3 shows a binary channel tree.

[0011] FIGS. 4, 5 and 6 show three channel structures for random overlapping with fully loaded, partially loaded, and sequentially loaded channel sets, respectively.

[0012] FIG. 7 shows a channel structure for common overlapping.

[0013] FIG. 8 shows a channel structure for random and common overlapping.

[0014] FIG. 9 shows a channel structure with random overlapping channel subsets.

[0015] FIG. 10 shows a process for assigning system resources.

[0016] FIG. 11 shows a block diagram of a base station and two terminals.

DETAILED DESCRIPTION

[0017] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment or design described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments or designs.

[0018] The channel structures described herein may be used for various multiple-access communication systems such as (1) a CDMA system that transmits data for different users using different orthogonal code sequences, (2) an FDMA system that transmits data for different users on different frequency subbands, (3) a TDMA system that transmits data for different users in different time slots, (4) a spatial division multiple access (SDMA) system that transmits data for different users on different spatial channels, (5) an orthogonal frequency division multiple access (OFDMA) system that transmits data for different users on different frequency subbands, and so

on. An OFDMA system utilizes orthogonal frequency division multiplexing (OFDM), which is a multi-carrier modulation technique that partitions the overall system bandwidth into multiple (K) orthogonal frequency subbands. These subbands are also called tones, subcarriers, bins, frequency channels, and so on. Each subband is associated with a respective subcarrier that may be modulated with data.

[0019] The channel structures described herein may also be used for time division duplexed (TDD) and frequency division duplexed (FDD) systems, for the forward and reverse links, with or without frequency hopping (FH), and so on. For clarity, the channel structures are described below for a specific quasi-orthogonal multiple-access system that utilizes a combination of SDMA and OFDMA. This system is called a quasi-orthogonal division access (QODA) system.

[0020] **FIG. 1** shows a QODA system 100 with multiple base stations 110 and multiple terminals 120. A base station is generally a fixed station that communicates with the terminals and may also be called an access point, a Node B, or some other terminology. Each base station 110 provides communication coverage for a particular geographic area 102. The term "cell" can refer to a base station and/or its coverage area depending on the context in which the term is used. To improve system capacity, the base station coverage area may be partitioned into multiple smaller areas (e.g., three smaller areas 104a, 104b, and 104c) that normally overlap at the edges. Each smaller area is served by a respective base transceiver subsystem (BTS). The term "sector" can refer to a BTS and/or its coverage area depending on the context in which the term is used. For a sectorized cell, the BTSs for all sectors of that cell are typically co-located within the base station for the cell. For simplicity, in the following description, the term "base station" is used generically for both a fixed station that serves a cell and a fixed station that serves a sector. A serving sector is a sector with which a terminal communicates.

[0021] A terminal may be fixed or mobile and may also be called a mobile station, a wireless device, a user equipment, or some other terminology. The terms "terminal" and "user" are used interchangeably herein. Each terminal 120 may communicate with zero, one, or multiple base stations at any given moment. A terminal communicates with multiple sectors of the same cell for "softer" handoff and with multiple cells for "soft" handoff.

[0022] Each base station 110 is equipped with multiple antennas that may be used for data transmission and reception. Each terminal may be equipped with one or multiple antennas for data transmission and reception. The multiple antennas at each base station represent the multiple-input (MI) for forward link transmissions and the multiple-output (MO) for reverse link transmissions. If multiple terminals are selected for simultaneous transmission, then the multiple antennas for the selected terminals collectively represent the multiple-output for forward link transmissions and the multiple-input for reverse link transmissions.

[0023] The QODA system may define physical channels to facilitate allocation and use of the available system resources. A physical channel is a means for sending data at a physical layer and may also be called a channel, a traffic channel, a transmission channel, a data channel, and so on. The physical channels may be defined for any type of system resources such as subbands, time intervals, code sequences, and so on.

[0024] **FIG. 2** shows an exemplary partitioning of the available system resources (time and frequency) into time-frequency blocks. A time-frequency block may also be called a transmission unit or by some other terminology. Each time-frequency block corresponds to a specific subband set in a specific time slot. A subband set may include one or multiple subbands, which may be contiguous or distributed across the system bandwidth. A time slot may span one or multiple symbol periods. N time-frequency blocks are available in each time slot, where $N > 1$.

[0025] FIG. 2 also shows an exemplary mapping of a physical channel to the available system resources in the QODA system. The physical channel is mapped to a specific sequence of time-frequency blocks. The time-frequency blocks for the physical channel may hop across frequency in different time slots to achieve frequency diversity, as shown in FIG. 2. The physical channel may be associated with a frequency hopping (FH) pattern that indicates one or more specific time-frequency blocks (e.g., two time-frequency blocks for the example in FIG. 2) to use for the physical channel in each time slot. The physical channel may be mapped to time-frequency blocks in consecutive time slots (as shown in FIG. 2) or non-consecutive time slots.

[0026] The QODA system may define physical channels having different transmission capacities in order to efficiently assign system resources to terminals. The

QODA system may also utilize a channel structure that facilitates both the mapping of physical channels to system resources and the assignment of physical channels to users.

[0027] **FIG. 3** shows a binary channel tree 300 that may be used to define physical channels. In channel tree 300, each node represents a physical channel that is assigned a unique channel identifier (ID). Channel tree 300 has six tiers of physical channels. The 32 physical channels at the bottom tier 1 are assigned channel IDs of 1 through 32, the 16 physical channels at tier 2 are assigned channel IDs of 33 through 48, the eight physical channels at tier 3 are assigned channel IDs of 49 through 56, the four physical channels at tier 4 are assigned channel IDs of 57 through 60, the two physical channels at tier 5 are assigned channel IDs of 61 and 62, and the single physical channel at the top tier 6 is assigned a channel ID of 63. The 32 base physical channels (or simply, the base channels) at the bottom tier 1 are associated with the smallest assignment of system resources. Each base channel is associated with a specific sequence of time-frequency blocks, e.g., as shown in FIG. 2. The 32 base channels are orthogonal to one another so that no two base channels use the same time-frequency block (i.e., the same subband set in the same time slot). The 31 composite physical channels (or simply, the composite channels) above the base channels are each associated with multiple base channels.

[0028] Channel tree 300 has a hierarchical structure. Each physical channel at each tier (except for the bottom tier 1) is composed of two "children" physical channels in the next lower tier. For example, physical channel 49 at tier 3 is composed of physical channels 33 and 34 at tier 2 and is also composed of physical channels 1 through 4 at tier 1. The time-frequency blocks for each physical channel are composed of the time-frequency blocks for all children physical channels. Each physical channel (except for physical channel 63 at the top tier 6) is also a subset of another physical channel. For example, physical channel 1 is a subset of physical channel 33, which is a subset of physical channel 49, and so on.

[0029] The channel tree structure places certain restrictions on the use of the physical channels for an orthogonal system. For each physical channel that is assigned, all physical channels that are subsets of the assigned physical channel and all physical channels for which the assigned physical channel is a subset are restricted. The restricted physical channels are not available for use concurrently with the assigned physical channel so that no two physical channels use the same system resource at the

same time. For example, if physical channel 49 is assigned, then physical channels 1 through 4, 33, 34, 57, 61 and 63 are restricted and are not used concurrently with physical channel 49 if orthogonality is desired. Each physical channel that is assigned thus restricts at least one other physical channel from being assigned.

[0030] FIG. 3 shows an exemplary channel tree that may be used to define physical channels. Other channel trees may also be used, and this is within the scope of the invention. For example, non-binary channel trees containing physical channels that are associated with more than two physical channels in one or more lower tiers may also be used. In general, a channel tree may have any number of base channels, any number of composite channels, and any mapping of composite channels to base channels.

[0031] In the QODA system, the transmissions for different users on each link are sent on different time-frequency blocks whenever possible in order to maintain orthogonality among these transmissions. To increase system capacity, multiple users may use the same time-frequency block whenever the available time-frequency blocks are insufficient to serve all users. As used herein, "overlapping" refers to multiple transmissions sent on the same time-frequency block, "overlapping transmissions" refer to transmissions sent on the same time-frequency block, and "overlapping users" and "overlapping terminals" are users using the same time-frequency block. The overlapping of users may be achieved with the following schemes:

1. Randomly overlap users in each time slot to randomize the interference observed by each user and to maximize intra-cell interference diversity.
2. Overlap multiple users on the same time-frequency blocks throughout a transmission.
3. Divide users into groups, maintain orthogonality among the users in the same group, and randomly overlap the users in different groups.
4. Divide users into groups, randomly overlap the users in each group, and maintain orthogonality among the users in different groups.
5. Overlap handoff users with non-handoff users in neighboring sectors.

[0032] Intra-cell interference refers to interference observed by a user from other users within the same cell. Intra-cell interference can come from (1) multiple users in the same sector using the same time-frequency block via SDMA and (2) users in other

sectors of the same cell. Intra-cell interference has a large impact on performance for SDMA and may be controlled using the overlapping schemes described herein.

[0033] Scheme 1 can provide maximum intra-cell interference diversity for the users. Scheme 2 is advantageous if multiple transmissions on the same time-frequency blocks can be separated using receiver spatial processing techniques. Scheme 3 is a compromise of schemes 1 and 2, where spatially correlated users may be placed in the same group so that they can maintain orthogonality with each other and achieve interference diversity from users in the other groups. Scheme 4 can support users with different requirements. The overlapping schemes may be implemented with various channel structures, as described below.

[0034] In an embodiment, a channel structure is defined by duplicating a channel tree to obtain L instances or copies of the channel tree, where $L > 1$, and forming a channel set for each of the L channel tree instances. There is a one-to-one mapping between channel set and channel tree instance. Each channel set is associated with a specific mapping of base channels to time-frequency blocks. For random overlapping, the channel-to-resource mapping for each channel set is pseudo-random with respect to the mapping for each of the other $L-1$ channel sets. For example, each channel set may be associated with a different set of frequency hopping patterns. The base channels in each channel set are orthogonal to one another and are pseudo-random with respect to the base channels in each of the other $L-1$ channel sets.

[0035] **FIG. 4** shows a channel structure 400 for random overlapping with fully loaded channel sets. In this example, L channel sets are formed with L instances of a channel tree having eight base channels. The base channels are given channel IDs of 1 through 8. Each channel set is assigned a different set of frequency hopping patterns. The frequency hopping patterns for each channel set are orthogonal to one another and are pseudo-random with respect to the frequency hopping patterns for each of the other $L-1$ channel sets. Each base channel in each channel set is assigned one of the frequency hopping patterns for that channel set. The frequency hopping pattern for each base channel indicates the time-frequency block (if any) to use in each time slot.

[0036] For channel structure 400, all of the physical channels in each channel set are usable for transmission. A physical channel may or may not be used for transmission in a given time slot depending on whether or not (1) the physical channel is mapped to a

time-frequency block in that time slot, (2) the physical channel is assigned to a user, and (3) a transmission is sent on the time-frequency block for/by the assigned user.

[0037] FIG. 4 also shows eight time-frequency blocks and the mapping of the eight base channels in each channel set to the eight time-frequency blocks in a specific time slot *t*. For example, base channel 7 in channel set 1, base channel 3 in channel set 2, and so on, and base channel 5 in channel set L are all mapped to time-frequency block 1 in time slot *t*. The mapping of the base channels to time-frequency blocks is different for another time slot and is determined by the frequency hopping patterns assigned to the base channels.

[0038] For channel structure 400, all base channels in the L channel sets may be assigned to different users and used for data transmission. If all of the base channels are assigned, then there are L overlapping users for each frequency-time block, and each user observes interference from $L-1$ other users. However, each user observes interference from different groups of $L-1$ users in different time slots due to the use of pseudo-random frequency hopping patterns for the L channel sets.

[0039] Channel structure 400 supports overlapping schemes 1 and 3. For scheme 1, the users may be randomly assigned with physical channels in the L channel sets. A user may be assigned physical channels from different channel sets in different time slots (e.g., based on the availability of the physical channels) but is not assigned multiple physical channels from different channel sets in the same time slot (to avoid self interference). For scheme 3, the users are placed in groups, each group is associated with one channel set, and all users in each group are assigned physical channels in the associated channel set. A user may be assigned different physical channels in the associated channel set in different time slots but is typically not moved to another group, e.g., unless the channel and/or operating conditions change.

[0040] Overlapping the users improves system capacity but also results in higher intra-cell interference. A tradeoff between system capacity and interference may be made by overlapping the users on a fraction of the system bandwidth.

[0041] **FIG. 5** shows a channel structure 500 for random overlapping with partially loaded channel sets. In this example, L channel sets are formed with L instances of a channel tree having eight base channels, and each channel set is associated with a different set of frequency hopping patterns, as described above for FIG. 4. For channel

structure 500, each channel set has six usable base channels 1 through 6 and two non-usable base channels 7 and 8. The usable physical channels are indicated by unfilled circles, and the non-usable physical channels are indicated by crossed-out circles ⊗. A usable physical channel may be assigned to a user and used for transmission. A non-usable physical channel cannot be assigned and cannot be used for transmission.

[0042] FIG. 5 also shows eight time-frequency blocks and the mapping of the six usable base channels in each channel set to the eight time-frequency blocks in a specific time slot *t*. For example, base channel 3 in channel set 2, and so on, and base channel 5 in channel set L are all mapped to time-frequency block 1 in time slot *t*. The mapping of the usable base channels to time-frequency blocks is different for different time slots. With partial loading, each channel set does not use a fraction of the system bandwidth. All of the usable base channels observe the same intra-cell interference level through random frequency hopping. For the example shown in FIG. 5, each channel set is partially loaded and only uses 75% of the available time-frequency blocks. For this example, each base channel in each channel set overlaps with 1.5 other base channels on average.

[0043] Channel structure 500 also supports overlapping schemes 1 and 3. For scheme 1, the users may be randomly assigned the usable physical channels in the L channel sets. For scheme 3, the users are placed in groups, and the users in each group are assigned usable physical channels in the associated channel set.

[0044] FIG. 5 shows an embodiment in which all L channel sets have the same loading factor, which is 0.75 in this example. In another embodiment, each channel set is associated with a reuse factor that determines the loading level for that channel set. Different channel sets may be associated with different reuse factors. For example, channel set 1 may be associated with a reuse factor of 1.0 and all eight base channels in this channel set are usable, channel set 2 may be associated with a reuse factor of 0.75 and six base channels are usable, channel set 3 may be associated with a reuse factor of 0.5 and four base channels are usable, and so on. Different reuse factors for different channel sets result in different levels of overlapping across the channel sets, which can provide different QoS levels. For the example given above with channel sets 1, 2 and 3 having reuse factors of 1.0, 0.75 and 0.5, respectively, each base channel in channel set 1 overlaps with 1.25 other base channels on average, each base channel in channel set 2

overlaps with 1.5 other base channels on average, and each base channel in channel set 3 overlaps with 1.75 other base channels on average.

[0045] **FIG. 6** shows a channel structure 600 for random overlapping with sequentially loaded channel sets. In this example, L channel sets are formed with L instances of a channel tree having eight base channels, and each channel set is assigned a different set of frequency hopping patterns, as described above for FIG. 4. For channel structure 600, the L channel sets are used in sequential order based on system loading. Thus, the physical channels in channel set 1 are assigned to users first, then the physical channels in channel set 2 are assigned to users next, if and as needed, and so on, and the physical channels in channel set L are assigned to users last, again if and as needed. Any number of channel sets may be in use at any given moment depending on the system loading. Channel set j is used only if channel sets 1 through $j-1$ are insufficient to serve the users. For the example shown in FIG. 6, all of the base channels in channel sets 1 through $L-1$ as well as base channels 1 and 2 in channel set L are assigned to the users, and only base channels 3 through 8 in channel set L are not used and are shown by darkened circles.

[0046] For channel structure 600, each channel set is fully used (if possible) before the next channel set is used. Channel structure 600 can also provide different QoS levels. For example, channel sets 1 and 2 may be fully used and only base channels 1 and 2 in channel set 3 may be used. In this case, each base channel in channel set 3 overlaps with two other base channels, and each base channel in channel sets 1 and 2 overlaps with only 1.25 other base channels on average. Sequential loading may also be used for channel structure 500 in FIG. 5.

[0047] Common overlapping may be achieved by duplicating a channel tree to obtain L instances of the channel tree, forming a channel set for each of the L channel tree instances, and using the same mapping of base channels to time-frequency blocks for all L channel sets. For example, a single set of frequency hopping patterns may be used for all L channel sets. For each channel set, each base channel in the channel set is assigned a different frequency hopping pattern, and all base channels in the channel set are orthogonal to one another. However, base channels x in all L channel sets use the same frequency hopping pattern. Base channels x (plural) include base channel x for channel set 1 through base channel x for channel set L, where $x \in \{1, ..., N\}$.

[0048] **FIG. 7** shows a channel structure 700 for common overlapping. In this example, L channel sets are formed with L instances of a channel tree having eight base channels, and all L channel sets use the same set of frequency hopping patterns. Thus, base channels x for all L channel sets are mapped to the same sequence of time-frequency blocks. For the example in FIG. 7, in time slot t, base channels 7 for all channel sets are mapped to time-frequency block 1, base channels 1 for all channel sets are mapped to time-frequency block 2, and so on. The mapping of the base channels to time-frequency blocks is different for another time slot.

[0049] For channel structure 700, the users assigned with different base channels in the same channel set are orthogonal to one another. A user assigned with base channel x in one channel set continuously observes interference from other users assigned with base channels x in the other channel sets. Up to L users can exclusively reuse the same sequence of time-frequency blocks.

[0050] For common overlapping, base channels x in the L channel sets may be assigned to spatially compatible users, which are users that can be separated using receiver spatial processing techniques. Users that are not spatially compatible may be assigned different physical channels in the same channel set and would then be orthogonal to one another.

[0051] **FIG. 8** shows a channel structure 800 for both random and common overlapping. In this example, L channel sets are formed with L instances of a channel tree having eight base channels. Random overlapping is used for a first channel subset containing base channels 1 through 4. Common overlapping is used for a second channel subset containing base channels 5 through 8. Each channel set is associated with (1) a different set of frequency hopping patterns for the first channel subset and (2) a common set of frequency hopping patterns for the second channel subset. For each channel set, the eight base channels are orthogonal to one another. Base channels 1 for the L channel sets are associated with different frequency hopping patterns and are pseudo-random with respect to each other. The same is also true for base channels 2, 3 and 4. Base channels 5 for the L channel sets are associated with the same frequency hopping pattern and share the same sequence of time-frequency blocks. The same is also true for base channels 6, 7 and 8.

[0052] For channel structure 800, spatially compatible users may be assigned physical channels in the second channel subset. Other users may be assigned physical channels in the first channel subset.

[0053] **FIG. 9** shows a channel structure 900 with multiple random overlapping channel subsets. In this example, L channel sets are formed with L instances of a channel tree having eight base channels. Random overlapping is used for a first channel subset containing base channels 1 through 4. Random overlapping is also used for a second channel subset containing base channels 5 through 8. Each channel set is associated with two sets of frequency hopping patterns for the two channel subsets. The base channels in the first channel subset for each channel set are pseudo-random with respect to the base channels in the first channel subset for each of the other $L-1$ channel sets. The same is also true for the second channel subset.

[0054] Channel structure 900 supports overlapping scheme 4. For scheme 4, the users are placed in two groups, each group is associated with one channel subset, and all users in each group are assigned physical channels in the associated channel subset. A user that is assigned a physical channel in the first channel subset in one channel set would observe (1) no interference from other users assigned with physical channels in the same channel subset of the same channel set, (2) no interference from other users assigned with physical channels in the other channel subset for all L channel sets, and (3) random interference from other users assigned with physical channels in the same channel subset for the other $L-1$ channel sets.

[0055] Exemplary channel structures have been described above in FIGS. 4 through 9. Other channel structures may also be defined based on the description provided herein. In general, a channel structure may have any number of channel sets, any number of channel subsets, any percentage of physical channels for each channel subset, any reuse factor for each channel set/subset, and any type and combination of overlapping (e.g., random and/or common) across the channel sets.

[0056] The channel structure for the QODA system may be defined once and thereafter remain static. Alternatively, the channel structure may be adaptively defined based on the composition of the users in the system and may be signaled to the users.

[0057] The random overlapping schemes shown in FIGS. 4, 5, 6, 8 and 9 rely on statistical multiplexing to obtain the average intra-cell interference behavior. The

common overlapping schemes shown in FIGS. 7 and 8 allow for direct control of intra-cell interference. With common overlapping, each user observes interference from only other users using the same time-frequency blocks. The intra-cell interference may be controlled by properly assigning physical channels to users.

[0058] In general, users may be assigned physical channels based on various factors such as spatial compatibility, received SNR, QoS requirements, handoff status, and so on. For common overlapping, base channels x in the L channel sets may be assigned to spatially compatible users that can be separated using receiver spatial processing techniques. For both random and common overlapping, users may be assigned physical channels based on their received SNRs. For example, better performance may be achieved by overlapping a low SNR user with a high SNR user. The low SNR user may be able to form a beam null toward the high SNR user, and the high SNR user may be able to ignore the interference from the low SNR user. For the channel structures shown in FIGS. 4 through 6, low SNR users may be assigned physical channels in channel set 1, and high SNR users may be assigned physical channels in channel set 2. Users with high QoS requirements may be assigned (1) common overlapping physical channels with no other users sharing these physical channels or (2) random overlapping physical channels that share time-frequency blocks with low SNR users. The high QoS users may be users that cannot tolerate delay jitter due to an incremental redundancy transmission scheme such as HARQ.

[0059] The QODA system can support handoff users in various manners. A handoff user may be a soft handoff user or a softer handoff user. A soft handoff user is a user that communicates with multiple cells and may be handed off from a serving cell to a handoff cell. A softer handoff user is a user that communicates with multiple sectors within the same cell and may be handed off from a serving sector to a handoff sector. A handoff user typically achieves low SNRs at both sectors/cells.

[0060] In an embodiment, handoff users are assigned physical channels in the same manner as non-handoff users. The handoff users can overlap with non-handoff users gracefully without causing excessive interference via use of receiver spatial processing techniques. For a softer handoff user, the serving and handoff sectors each attempt to detect the transmission from the user using receiver spatial processing techniques. The detected symbols from both sectors are then combined, demodulated, and decoded to

obtain decoded data for the user. For a soft handoff user, the serving and handoff cells each attempt to detect, demodulate, and decode the transmission from the user. The cell that correctly decodes the data for the user provides the decoded data for the user.

[0061] In another embodiment, handoff users are assigned physical channels in a shared channel subset that is reserved for these users. The shared channel subset is used by neighboring sectors/cells. The base channels in the shared channel subset are orthogonal to one another and are also orthogonal to all other physical channels used by the neighboring sectors/cells. A handoff user may be assigned a physical channel in the shared channel subset and would then be orthogonal to all other users in the neighboring sectors/cells. A network entity may coordinate the handoff users and may assign physical channels in the shared channel subset to these users. The physical channels in the shared channel subset may also be partitioned into multiple shared channel groups. These channel groups may be assigned to different sectors within a cell or to different cells. Each sector/cell may then assign the physical channels in its shared channel group to its handoff users.

[0062] In yet another embodiment, handoff is achieved by using one copy of the channel set in each sector of a cell and processing all received signals from multiple sectors jointly. Given an L-sector cell, L channel sets may be formed with L copies of a channel tree, e.g., as illustrated in FIG. 4, where each channel set may be used by one sector. The intra-cell interference may be separated using receiver spatial processing techniques.

[0063] The channel structures described herein have various features, including:

1. Orthogonality among system resources assigned to the same user;
2. Orthogonality among resources assigned to users that are not well separated;
3. Interference diversity for overlapping users;
4. Flexible tradeoff between intra-cell interference level and resource reuse factor;
5. Support of common overlapping for users that are well separated; and
6. Support of softer handoff.

[0064] For the forward link, a base station can transmit a pilot from all of its antennas on a sufficient number of subbands and symbol periods to provide good channel estimation performance for the forward link. The pilot transmissions from the base station antennas may be orthogonalized in time, frequency, code and/or some other

domain to allow the terminals to distinguish each base station antenna. For example, the pilot transmission from each base station antenna may be generated with a different orthogonal sequence, e.g., a Walsh code or an OVSF code. Each terminal can estimate the forward link channel response from the base station antennas to the terminal antenna(s) based on the pilot transmissions from the base station.

[0065] For the reverse link, each terminal may transmit a pilot from all or a subset of its antenna(s) to allow the base station to estimate the reverse link channel response from the terminal antenna(s) to the base station antennas. The performance of all users, and especially overlapping users and handoff users, is dependent on the quality of the RL channel estimates for the users. For overlapping and handoff users, the RL channel estimates are used for receiver spatial processing to separate out the transmissions from multiple users on the same time-frequency block. Channel estimation errors cause residual errors (or crosstalk) in the separation of the multiple transmissions. The residual errors represent a noise floor that can potentially degrade SNR.

[0066] An exemplary pilot design that can support overlapping and handoff users and provide good channel estimation performance is described below. In an embodiment, the L channel sets are associated with L different orthogonal pilot patterns, one pilot pattern for each channel set. Each pilot pattern is a sequence of P values, where $P > 1$, and is denoted as $\{w_\ell\} = [w_{\ell,1}, w_{\ell,2}, ..., w_{\ell,P}]$, for $\ell = 1, ..., L$. For example, pilot sequence ℓ may be defined as $w_{\ell,i} = e^{-j2\pi \cdot (\ell-1)\cdot(i-1)/P}$, for $i = 1, ..., P$. Other orthogonal sequences or codes may also be used for the pilot patterns.

[0067] The pilots transmitted by users in one sector act as interference to the pilots transmitted by users in other sectors of the same cell. To reduce intra-cell pilot interference, the sectors in the same cell may be assigned different scrambling patterns, one scrambling pattern for each sector. Each sector-specific scrambling pattern is a sequence of P values and is denoted as $\{x_s\} = [x_{s,1}, x_{s,2}, ..., x_{s,P}]$, for $s = 1, ..., S$, where S is the number of sectors in the cell. The S sector-specific scrambling patterns are selected to provide good channel estimation performance under various channel and operating conditions. These scrambling patterns may be obtained, e.g., based on a search of a large number of possible scrambling patterns. For example, an exhaustive search of 10,000 sequences may yield a few "good" scrambling sequences where the channel estimation floor is well below the interference from other sources.

[0068] To randomize inter-cell pilot interference, neighboring cells may be assigned different scrambling patterns, one scrambling pattern for each cell. Each cell-specific scrambling pattern is a sequence of P values and is denoted as $\{y_c\} = [y_{c,1}, y_{c,2}, ..., y_{c,P}]$, for $c = 1, 2, ...$ The cell-specific scrambling patterns are selected to differ substantially for neighboring cells (e.g., to have good cross-correlation property so that an interfering pilot appears as random as possible) and to provide good channel estimation performance. Optimization of a large number of cell scrambling sequences may be quite complex as the number of neighboring cells increases. Random sequences typically provide good performance.

[0069] An overall pilot pattern for a user assigned with a physical channel in channel set ℓ and communicating with sector s in cell c may be denoted as $\{p_{\ell,s,c}\} = [p_{\ell,s,c,1}, p_{\ell,s,c,2}, ..., p_{\ell,s,c,P}]$, where $p_{\ell,s,c,i} = w_{\ell,i} \cdot x_{s,i} \cdot y_{c,i}$ for $i = 1, ..., P$. The sector-specific scrambling may be used if more than one channel set is used by the sectors and may be omitted otherwise. The sector-specific scrambling pattern $\{x_s\}$ may be a sequence of all ones if sector-specific scrambling is not used. Similarly, the cell-specific scrambling pattern $\{y_c\}$ may be a sequence of all ones if cell-specific scrambling is not used.

[0070] Each user forms an overall pilot pattern $\{p_{\ell,s,c}\}$ based on the pilot pattern $\{w_\ell\}$ associated with the assigned physical channel, the scrambling pattern $\{x_s\}$ for its sector, and the scrambling pattern $\{y_c\}$ for its cell. Since each channel set is associated with one pilot pattern, a channel assignment conveys both the assigned physical channel and the pilot pattern. Each user may transmit a pilot on a portion of each time-frequency block for the assigned physical channel using its overall pilot pattern $\{p_{\ell,s,c}\}$. The pilots from all users sharing a given time-frequency block in the same sector are orthogonal to one another because of the orthogonal pilot patterns used by these users. If sector-specific scrambling is used, then the pilots from users in each sector are pseudo-random with respect to the pilots from users in other sectors of the same cell. If cell-specific scrambling is used, then the pilots from users in each cell are pseudo-random with respect to the pilots from users in neighboring cells. A sector can process the pilot transmission from a user, remove both the cell-specific scrambling and the sector-specific scrambling, and match (e.g., multiply and accumulate) the pilot pattern

for that user to obtain a reverse link channel response estimate for the user. The orthogonal pilot patterns allow the sector to differentiate the channel responses of overlapping users using the same time-frequency block.

[0071] A user may transmit a pilot on one or more subbands and in a sufficient number of symbol periods in each time-frequency block used by the assigned physical channel. The rate of pilot transmission is determined by the coherence time and the coherence bandwidth of the communication link. For example, the user may transmit a pilot on one cluster of subbands and symbol periods in each time-frequency block or on multiple clusters that are distributed throughout (e.g., at the four corners) of the time-frequency block.

[0072] A user may be equipped with (1) a single antenna that may be used for both data transmission and reception, (2) a single transmit antenna and multiple receive antennas, or (3) multiple transmit and receive antennas. For case (3), the user may transmit a pilot in a manner to allow the sector to estimate the channel response for each transmit antenna. A user with N transmit antennas may be treated in similar manner as N users with a single antenna.

[0073] In an embodiment, a handoff user is assigned a pilot pattern that is orthogonal to the pilot patterns used by non-handoff users in order to improve channel estimation performance for the handoff user. The handoff user typically has weaker signals to the serving and handoff sectors and may also be less tolerant to interference from other users. A subset of pilot patterns may be reserved for handoff users. This reserved subset is used by all sectors of the same cell, e.g., in similar manner as the shared channel subset described above. Each pilot pattern in the reserved subset may be assigned to one handoff user. The pilot from each handoff user would then be orthogonal to the pilots from other users in the same cell.

[0074] The channel structures described herein facilitate both the mapping of physical channels to system resources and the assignment of physical channels to users. The channel structures may be used for both the forward and reverse links. The same or different system resources may be available for data transmission on the forward and reverse links. The same or different channel structures may be used for the forward and reverse links. For simplicity, portions of the description herein assume that the same

system resources are available for both links and that the same channel structure is used for both links.

[0075] **FIG. 10** shows a process 1000 for assigning system resources and transmitting data in the QODA system. Initially, a channel structure with at least two channel sets is defined, with each channel set containing multiple physical channels and associated with a specific mapping of the physical channels to the available system resources (block 1010). Block 1010 may be implicitly performed for a static channel structure and explicitly performed for an adaptive/ dynamic channel structure. The mapping for each channel set is pseudo-random with respect to the mapping for each of the remaining channel sets for at least a subset of the physical channels. Each channel set may be defined based on a channel tree having a hierarchical structure, as described above.

[0076] In each scheduling interval, information that is pertinent for scheduling and/or channel assignment is obtained (block 1012). The pertinent information may include, e.g., channel estimates, SNR estimates, QoS requirements, handoff status, and so on. Terminals are scheduled for transmission on the forward and/or reverse link (block 1014). The scheduled terminals are assigned physical channels from the channel sets (block 1016). The scheduling and/or channel assignment may be based on the collected information for the terminals. For example, the channel estimates, SNR estimates, and/or QoS requirements may be used to arrange the terminals into group, to overlap spatially compatible terminals, to isolate handoff terminals, and so on. A handoff terminal may be assigned a physical channel that is orthogonal to the physical channels for non-handoff users in the same cell and may further be assigned a pilot pattern that is orthogonal to the pilot patterns for the non-handoff users. Channel assignments are formed and sent to the scheduled terminals.

[0077] For the forward link, data for overlapping terminals are spatially processed (e.g., for beamforming) based on their FL channel estimates, as described below (block 1018), and then transmitted from multiple base station antennas (block 1020). For the reverse link, multiple transmissions from overlapping terminals are received via the multiple base station antennas (block 1022). The received symbols for the overlapping terminals are spatially processed (e.g., for spatial matched filtering) based on their RL channel estimates to recover the transmission from each terminal (block 1024).

[0078] On the forward link, a base station may transmit data to multiple users in each time-frequency block via multiple antennas. The base station may steer each FL transmission toward a target user based on the channel estimate for that user. For simplicity, the following description is for one time-frequency block, the base station is assumed to have multiple (T) antennas, and each terminal is assumed to have a single antenna.

[0079] A multiple-input single-output (MISO) channel is formed between the T antennas at the base station and the single antenna at a terminal u. The MISO channel may be characterized by a $T \times 1$ channel response vector $\underline{\mathbf{h}}_{fl,u}(k,t)$, which may be expressed as:

$$\underline{\mathbf{h}}_{fl,u}(k,t) = [\, h_{u,1}(k,t) \;\; h_{u,2}(k,t) \;\; \ldots \;\; h_{u,T}(k,t)]^{T} \;, \qquad \text{Eq (1)}$$

where $h_{u,j}(k,t)$, for $j = 1, \ldots, T$, is the complex channel gain from base station antenna j to the terminal antenna for subband k in time slot t, and "^{T}" denotes a transpose.

[0080] The base station may transmit data to up to L terminals on the same time-frequency block using the L channel sets. In general, the number of terminals that may be transmitted to on the same time-frequency block is limited by the number of antennas at the base station, so that $L \leq T$. For simplicity, the following description assumes that the base station transmits to L terminals on each time-frequency block.

[0081] An FL multiple-input multiple-output (MIMO) channel is formed between the T base station antennas and the L antennas at the L terminals. The FL MIMO channel may be characterized by a $T \times L$ channel response matrix $\underline{\mathbf{H}}_{fl}(k,t)$, which may be expressed as:

$$\underline{\mathbf{H}}_{fl}(k,t) = [\, \underline{\mathbf{h}}_{fl,1}(k,t) \;\; \underline{\mathbf{h}}_{fl,2}(k,t) \;\; \ldots \;\; \underline{\mathbf{h}}_{fl,L}(k,t)] \;. \qquad \text{Eq (2)}$$

Each column of $\underline{\mathbf{H}}_{fl}(k,t)$ corresponds to an FL channel response vector for one terminal.

[0082] The base station may perform transmitter spatial processing (or beamforming) for the data transmissions to the L terminals, as follows:

$$\underline{\mathbf{x}}_{fl}(k,t,n) = \underline{\mathbf{H}}^{*}_{fl}(k,t) \cdot \underline{\mathbf{s}}_{fl}(k,t,n) \;, \qquad \text{Eq (3)}$$

where $\underline{\mathbf{s}}_{fl}(k,t,n)$ is an $\mathrm{L}\times 1$ vector with L data symbols to be sent to the L terminals on subband k in symbol period n of time slot t;

$\underline{\mathbf{x}}_{fl}(k,t,n)$ is a $\mathrm{T}\times 1$ vector with T transmit symbols to be sent from the T base station antennas on subband k in symbol period n of time slot t; and

" * " denotes a conjugate.

For simplicity, the scaling for the data symbols transmitted to the L terminals is omitted in equation (3). Time slot t may span one or multiple symbol periods. For simplicity, the channel response is assumed to be constant over time slot t and is not a function of symbol period n. The channel response matrix $\underline{\mathbf{H}}_{fl}(k,t)$ is dependent on the specific set of terminals assigned to subband k in time slot t. The terminals overlapping each time-frequency block may be selected such that their channel response vectors are spatially decorrelated, e.g., are as orthogonal to one another as possible. The beamforming may also be performed in other manners, e.g., based on zero-forcing (ZF), maximal ratio combining (MRC), minimum mean square error (MMSE), or some other techniques.

[0083] For the reverse link, the base station may receive RL transmissions from up to L terminals on each time-frequency block via the T antennas. In general, the number of terminals that may transmit on the same time-frequency block is limited by the number of antennas at the base station, which determines the base station's ability to separate out the RL transmissions, so that $\mathrm{L}\le\mathrm{T}$. For simplicity, the following description assumes that the base station receives transmissions from L terminals on each time-frequency block.

[0084] A single-input multiple-output (SIMO) channel is formed between the single antenna at each terminal and the T antennas at the base station. The SIMO channel for each terminal may be characterized by a $\mathrm{T}\times 1$ channel response vector $\underline{\mathbf{h}}_{rl,u}(k,t)$ having the form shown in equation (1). An RL MIMO channel is formed between the L antennas at the L terminals and the T base station antennas. The RL MIMO channel may be characterized by a $\mathrm{T}\times\mathrm{L}$ channel response matrix $\underline{\mathbf{H}}_{rl}(k,t)$, which may be expressed as:

$$\underline{\mathbf{H}}_{rl}(k,t)=[\,\underline{\mathbf{h}}_{rl,1}(k,t)\;\;\underline{\mathbf{h}}_{rl,2}(k,t)\;\ldots\;\underline{\mathbf{h}}_{rl,\mathrm{L}}(k,t)\,]\;. \qquad \text{Eq (4)}$$

Each column of $\underline{\mathbf{H}}_{rl}(k,t)$ corresponds to an RL channel response vector for one terminal. The channel response matrix $\underline{\mathbf{H}}_{rl}(k,t)$ is dependent on the specific set of terminals assigned to subband k in time slot t.

[0085] The base station obtains received symbols from the T antennas for the RL transmissions from the L terminals, which may be expressed as:

$$\underline{\mathbf{r}}(k,t,n) = \underline{\mathbf{H}}_{rl}(k,t) \cdot \underline{\mathbf{s}}_{rl}(k,t,n) + \underline{\mathbf{n}}(k,t,n) , \qquad \text{Eq (5)}$$

where $\underline{\mathbf{s}}_{rl}(k,t,n)$ is an $L \times 1$ vector with L data symbols sent by the L terminals on subband k in symbol period n of time slot t;

$\underline{\mathbf{r}}(k,t,n)$ is a $T \times 1$ vector with T received symbols obtained via the T base station antennas for subband k in symbol period n of time slot t; and

$\underline{\mathbf{n}}(k,t,n)$ is a noise vector for subband k in symbol period n of time slot t.

For simplicity, the noise may be assumed to be additive white Gaussian noise (AWGN) with a zero mean vector and a covariance matrix of $\underline{\varphi}_{nn} = \sigma^2 \cdot \underline{\mathbf{I}}$, where σ^2 is the variance of the noise and $\underline{\mathbf{I}}$ is the identity matrix.

[0086] The base station may use various receiver spatial processing techniques to separate out the RL transmissions sent by the L terminals on the same time-frequency block. These receiver spatial processing techniques include a zero-forcing (ZF) technique, a minimum mean square error (MMSE) technique, a maximal ratio combining (MRC) technique, and so on. The base station may derive a spatial filter matrix based on the ZF, MMSE, or MRC technique, as follows:

$$\underline{\mathbf{M}}_{zf}(k,t) = [\underline{\mathbf{H}}_{rl}^{H}(k,t) \cdot \underline{\mathbf{H}}_{rl}(k,t)]^{-1} \cdot \underline{\mathbf{H}}_{rl}^{H}(k,t) , \qquad \text{Eq (6)}$$

$$\underline{\mathbf{M}}_{mmse}(k,t) = \underline{\mathbf{D}}_{mmse}(k,t) \cdot [\underline{\mathbf{H}}_{rl}^{H}(k,t) \cdot \underline{\mathbf{H}}_{rl}(k,t) + \sigma^2 \cdot \underline{\mathbf{I}}]^{-1} \cdot \underline{\mathbf{H}}_{rl}^{H}(k,t) , \qquad \text{Eq (7)}$$

$$\underline{\mathbf{M}}_{mrc}(k,t) = \underline{\mathbf{D}}_{mrc}(k,t) \cdot \underline{\mathbf{H}}_{rl}^{H}(k,t) , \qquad \text{Eq (8)}$$

where $\underline{\mathbf{D}}_{mmse}(k,t) = \text{diag}\{[\underline{\mathbf{H}}_{rl}^{H}(k,t) \cdot \underline{\mathbf{H}}_{rl}(k,t) + \sigma^2 \cdot \underline{\mathbf{I}}]^{-1} \cdot \underline{\mathbf{H}}_{rl}^{H}(k,t) \cdot \underline{\mathbf{H}}_{rl}(k,t)\}^{-1}$; and

$\underline{\mathbf{D}}_{mrc}(k,t) = \text{diag}\,[\underline{\mathbf{H}}_{rl}^{H}(k,t) \cdot \underline{\mathbf{H}}_{rl}(k,t)]^{-1}$.

The base station derives an estimate of $\underline{\mathbf{H}}_{rl}(k,t)$ based on the pilots transmitted by the L terminals. For simplicity, equations (6) through (8) assume no channel estimation error.

[0087] The base station may perform receiver spatial processing as follows:

$$\begin{aligned}\hat{\underline{\mathbf{s}}}_{rl}(k,t,n) &= \underline{\mathbf{M}}(k,t)\cdot\underline{\mathbf{r}}(k,t,n) \ , \\ &= \underline{\mathbf{s}}_{rl}(k,t,n)+\tilde{\underline{\mathbf{n}}}(k,t,n) \ ,\end{aligned} \qquad \text{Eq (9)}$$

where $\underline{\mathbf{M}}(k,t)$ may be equal to $\underline{\mathbf{M}}_{zf}(k,t)$, $\underline{\mathbf{M}}_{mmse}(k,t)$, or $\underline{\mathbf{M}}_{mrc}(k,t)$;

$\hat{\underline{\mathbf{s}}}_{rl}(k,t,n)$ is an $L\times 1$ vector with L detected symbols for subband k in symbol period n of time slot t; and

$\tilde{\underline{\mathbf{n}}}(k,t,n)$ is the noise after the receiver spatial processing.

A detected symbol is an estimate of a transmitted data symbol.

[0088] For simplicity, the description above assumes that each terminal is equipped with a single antenna. A terminal equipped with multiple (R) antennas may receive multiple FL transmissions on the same time-frequency block via the R antennas and may also send multiple RL transmissions on the same time-frequency block from these R antennas. Matrix $\underline{\mathbf{H}}_{fl}(k,t)$ would contain a column for each terminal antenna used to receive an FL transmission. Matrix $\underline{\mathbf{H}}_{rl}(k,t)$ would contain a column for each terminal antenna used to send an RL transmission.

[0089] **FIG. 11** shows an embodiment of base station 110 and two terminals 120x and 120y in QODA system 100. Base station 110 is equipped with multiple (T) antennas 1128a through 1128t, terminal 120x is equipped with a single antenna 1152x, and terminal 120y is equipped with multiple (R) antennas 1152a through 1152r.

[0090] On the forward link, at base station 110, a data/pilot processor 1120 receives traffic data from a data source 1112 for all scheduled terminals and signaling (e.g., channel assignments) from a controller 1130. Data/pilot processor 1120 encodes, interleaves, and symbol maps the traffic data and signaling to generate data symbols and further generates pilot symbols for the forward link. As used herein, a data symbol is a modulation symbol for traffic/packet data, a pilot symbol is a symbol for pilot (which is data that is known *a priori* by both the transmitter and receiver), a modulation symbol is a complex value for a point in a signal constellation for a modulation scheme (e.g., M-

PSK or M-QAM), and a symbol is any complex value. A transmit (TX) spatial processor 1122 performs spatial processing on the data symbols (e.g., as shown in equation (3)), multiplexes in the pilot symbols, and provides transmit symbols to transmitter units (TMTR) 1126a through 1126t. Each transmitter unit 1126 processes its transmit symbols (e.g., for OFDM) and generates an FL modulated signal. The FL modulated signals from transmitter units 1126a through 1126t are transmitted from antennas 1128a through 1128t, respectively.

[0091] At each terminal 120, one or multiple antennas 1152 receive the transmitted FL modulated signals, and each antenna provides a received signal to a respective receiver unit (RCVR) 1154. Each receiver unit 1154 performs processing complementary to the processing performed by transmitter units 1126 and provides received symbols. For each terminal, a channel estimator 1178 derives an FL channel estimate based on the pilot received from base station 110. For multi-antenna terminal 120y, a receive (RX) spatial processor 1160y performs receiver spatial processing on the received symbols with the FL channel estimate and provides detected symbols. An RX data processor 1170 symbol demaps, deinterleaves, and decodes the received or detected symbols, provides decoded data to a data sink 1172, and provides detected signaling (e.g., for a channel assignment) to a controller 1180.

[0092] On the reverse link, traffic data from a data source 1188 and signaling (e.g., ACK/NAK) to be sent by each terminal 120 are processed by a data/pilot processor 1190, further processed by a TX spatial processor 1192 if multiple antennas are present, conditioned by transmitter unit(s) 1154, and transmitted from antenna(s) 1152. At base station 110, the transmitted RL modulated signals from terminals 120 are received by antennas 1128 and conditioned by receiver units 1126 to obtain received symbols. A channel estimator 1136 derives an RL channel estimate for each terminal 120 based on the pilot received from that terminal. An RX spatial processor 1140 performs receiver spatial processing on the received symbols with the RL channel estimates for all the terminals (e.g., as shown in equation (9)) and provides detected symbols. An RX data processor 1142 then symbol demaps, deinterleaves, and decodes the detected symbols, provides decoded data to a data sink 1144, and provides detected signaling to controller 1130.

[0093] Controllers 1130, 1180x and 1180y control the operation of various processing units at base station 110 and terminals 120x and 120y, respectively. Memory units 1132, 1182x and 1182y store data and program codes used by controllers 1130, 1180x and 1180y, respectively. A scheduler 1134 schedules terminals for data transmission on the forward and reverse links and assigns physical channels to the scheduled terminals. Scheduler 1134 or some other network entity may assign physical channels and pilot patterns to handoff users. Controller 1130 may form and send channel assignments for the scheduled terminals.

[0094] The techniques described herein may be implemented by various means. For example, these techniques may be implemented in hardware, software, or a combination thereof. For a hardware implementation, the processing units used to schedule terminals, assign channels, and perform spatial processing may be implemented within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field programmable gate arrays (FPGAs), processors, controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described herein, or a combination thereof.

[0095] For a software implementation, the transmission techniques may be implemented with modules (e.g., procedures, functions, and so on) that perform the functions described herein. The software codes may be stored in a memory unit (e.g., memory unit 1132, 1182x or 1182y in FIG. 11) and executed by a processor (e.g., controller 1130, 1180x or 1180y). The memory unit may be implemented within the processor or external to the processor.

[0096] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0097] WHAT IS CLAIMED IS:

CLAIMS

1. An apparatus comprising:

a scheduler operative to schedule a plurality of terminals for data transmission and to assign the plurality of terminals with channels in at least two channel sets, wherein each channel set comprises a plurality of channels and is associated with a specific mapping of the plurality of channels to system resources available for data transmission, and wherein the mapping for each channel set is pseudo-random with respect to the mapping for each remaining one of the at least two channel sets for at least a subset of the plurality of channels; and

a controller operative to form channel assignments for the plurality of terminals.

2. The apparatus of claim 1, wherein each channel set is defined based on a channel tree having a hierarchical structure for the plurality of channels.

3. The apparatus of claim 2, wherein the channel tree comprises a plurality of base channels and a plurality of composite channels, wherein the plurality of base channels are mapped to the available system resources, and wherein each composite channel is associated with at least two base channels and is mapped to system resources used for the at least two base channels.

4. The apparatus of claim 2, wherein each channel in the channel tree that is assigned to a terminal restricts at least one other channel in the channel tree from being assigned.

5. The apparatus of claim 1, wherein the plurality of channels in each channel tree are mapped to the available system resources using frequency hopping.

6. The apparatus of claim 1, wherein the mapping for each channel set is pseudo-random with respect to the mapping for each remaining one of the at least two channel sets for the plurality of channels

7. The apparatus of claim 1, wherein the plurality of channels in each channel set are mapped to a subset of the available system resources in each time slot.

8. The apparatus of claim 1, wherein the scheduler is operative to select the at least two channel sets in a sequential order and to assign the plurality of channels in each selected channel set to at least one of the plurality of terminals.

9. The apparatus of claim 1, wherein the mapping for each channel set is common with respect to the mapping for each remaining one of the at least two channel sets for at least one of the plurality of channels.

10. The apparatus of claim 1, wherein each channel set comprises a plurality of channel subsets that are associated with a plurality of subsets of the available system resources, and wherein overlapping channel subsets for the at least two channel sets are associated with different pseudo-random mappings of channels to system resources.

11. The apparatus of claim 1, wherein the scheduler is operative to assign a handoff terminal with a channel that is orthogonal to channels for non-handoff terminals.

12. The apparatus of claim 1, wherein the at least two channel sets are associated with at least two orthogonal pilot patterns, one pilot pattern for each channel set, and wherein pilots for the plurality of channels in each channel set are generated with the pilot pattern associated with the channel set.

13. The apparatus of claim 1, wherein the scheduler is operative to assign a handoff terminal with a pilot pattern that is orthogonal to pilot patterns for non-handoff terminals.

14. The apparatus of claim 1, wherein the scheduler is operative to select terminals for overlapping transmissions based on channel estimates, signal-to-noise-

and-interference ratio (SNR) estimates, quality of service (QoS) requirements, or a combination thereof.

15. The apparatus of claim 1, further comprising:

a spatial processor operative to spatially process data for overlapping terminals based on channel estimates for the terminals; and

a plurality of transmitter units operative to transmit the spatially processed data via a plurality of antennas to the overlapping terminals.

16. The apparatus of claim 1, further comprising:

a plurality of receiver units operative to receive a plurality of transmissions from overlapping terminals via a plurality of antennas; and

a spatial processor operative to perform receiver spatial processing on received symbols from the plurality of antennas based on channel estimates for the overlapping terminals to recover the plurality of transmissions.

17. A method of assigning system resources in a communication system, comprising:

scheduling a plurality of terminals for data transmission; and

assigning the plurality of terminals with channels in at least two channel sets, wherein each channel set comprises a plurality of channels and is associated with a specific mapping of the plurality of channels to system resources available for data transmission, and wherein the mapping for each channel set is pseudo-random with respect to the mapping for each remaining one of the at least two channel sets for at least a subset of the plurality of channels.

18. The method of claim 17, further comprising:

defining the mapping for each channel set to be common with respect to the mapping for each remaining one of the at least two channel sets for at least one of the plurality of channels.

19. The method of claim 17, further comprising:

assigning a handoff terminal with a channel that is orthogonal to channels for non-handoff terminals.

20. The method of claim 17, further comprising:

selecting terminals for overlapping transmissions based on channel estimates, signal-to-noise-and-interference ratio (SNR) estimates, quality of service (QoS) requirements, or a combination thereof.

21. The method of claim 17, further comprising:

receiving a plurality of transmissions from overlapping terminals via a plurality of antennas; and

performing receiver spatial processing on received symbols from the plurality of antennas based on channel estimates for the overlapping terminals to recover the plurality of transmissions.

22. An apparatus comprising:

means for scheduling a plurality of terminals for data transmission; and

means for assigning the plurality of terminals with channels in at least two channel sets, wherein each channel set comprises a plurality of channels and is associated with a specific mapping of the plurality of channels to system resources available for data transmission, and wherein the mapping for each channel set is pseudo-random with respect to the mapping for each remaining one of the at least two channel sets for at least a subset of the plurality of channels.

23. The apparatus of claim 22, further comprising:

means for defining the mapping for each channel set to be common with respect to the mapping for each remaining one of the at least two channel sets for at least one of the plurality of channels.

24. The apparatus of claim 22, further comprising:

means for receiving a plurality of transmissions from overlapping terminals via a plurality of antennas; and

means for performing receiver spatial processing on received symbols from the plurality of antennas based on channel estimates for the overlapping terminals to recover the plurality of transmissions.

25. An apparatus comprising:

a controller operative to receive an assignment of a channel to use for data transmission and to determine a mapping of the channel to system resources available for data transmission, wherein the channel is selected from among at least two channel sets, wherein each channel set comprises a plurality of channels and is associated with a specific mapping of the plurality of channels to the system resources available for data transmission, and wherein the mapping for each channel set is pseudo-random with respect to the mapping for each remaining one of the at least two channel sets for at least a subset of the plurality of channels; and

a processor operative to process data for transmission on system resources mapped to the channel.

26. The apparatus of claim 25, wherein the channel is mapped to the available system resources based on a frequency hopping pattern.

27. The apparatus of claim 25, wherein the controller is further operative to determine a pilot pattern associated with the channel, and wherein the processor is further operative to generate a pilot based on the pilot pattern.

28. The apparatus of claim 25, wherein the controller is further operative to receive a second assignment of a second channel to use for receiving data and to determine a mapping of the second channel to system resources available for receiving data, and wherein the processor is further operative to process data received on system resources mapped to the second channel.

29. An apparatus comprising:

means for receiving an assignment of a channel to use for data transmission, wherein the channel is selected from among at least two channel sets, wherein each

channel set comprises a plurality of channels and is associated with a specific mapping of the plurality of channels to system resources available for data transmission, and wherein the mapping for each channel set is pseudo-random with respect to the mapping for each remaining one of the at least two channel sets for at least a subset of the plurality of channels;

means for determining a mapping of the channel to the system resources available for data transmission; and

means for transmitting data on system resources mapped to the channel.

30. The apparatus of claim 29, further comprising:

means for determining a pilot pattern associated with the channel; and

means for generating a pilot based on the pilot pattern.

31. The apparatus of claim 29, further comprising:

means for receiving a second assignment of a second channel to use for receiving data;

means for determining a mapping of the second channel to system resources available for receiving data; and

means for receiving data on system resources mapped to the second channel.

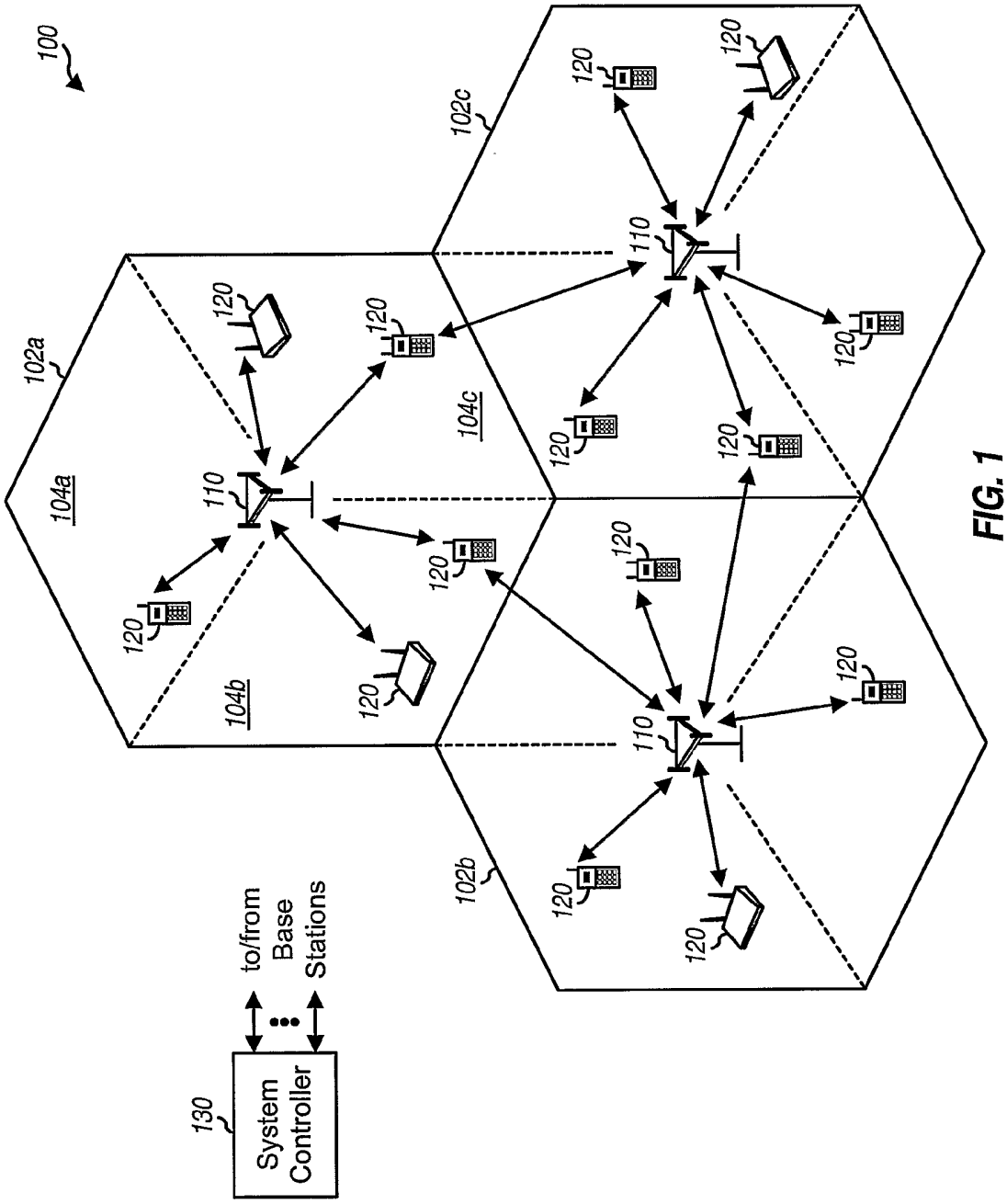
100
102a
102b
102c
104a
104b
104c
110
120
130
System Controller
to/from Base Stations

FIG. 1

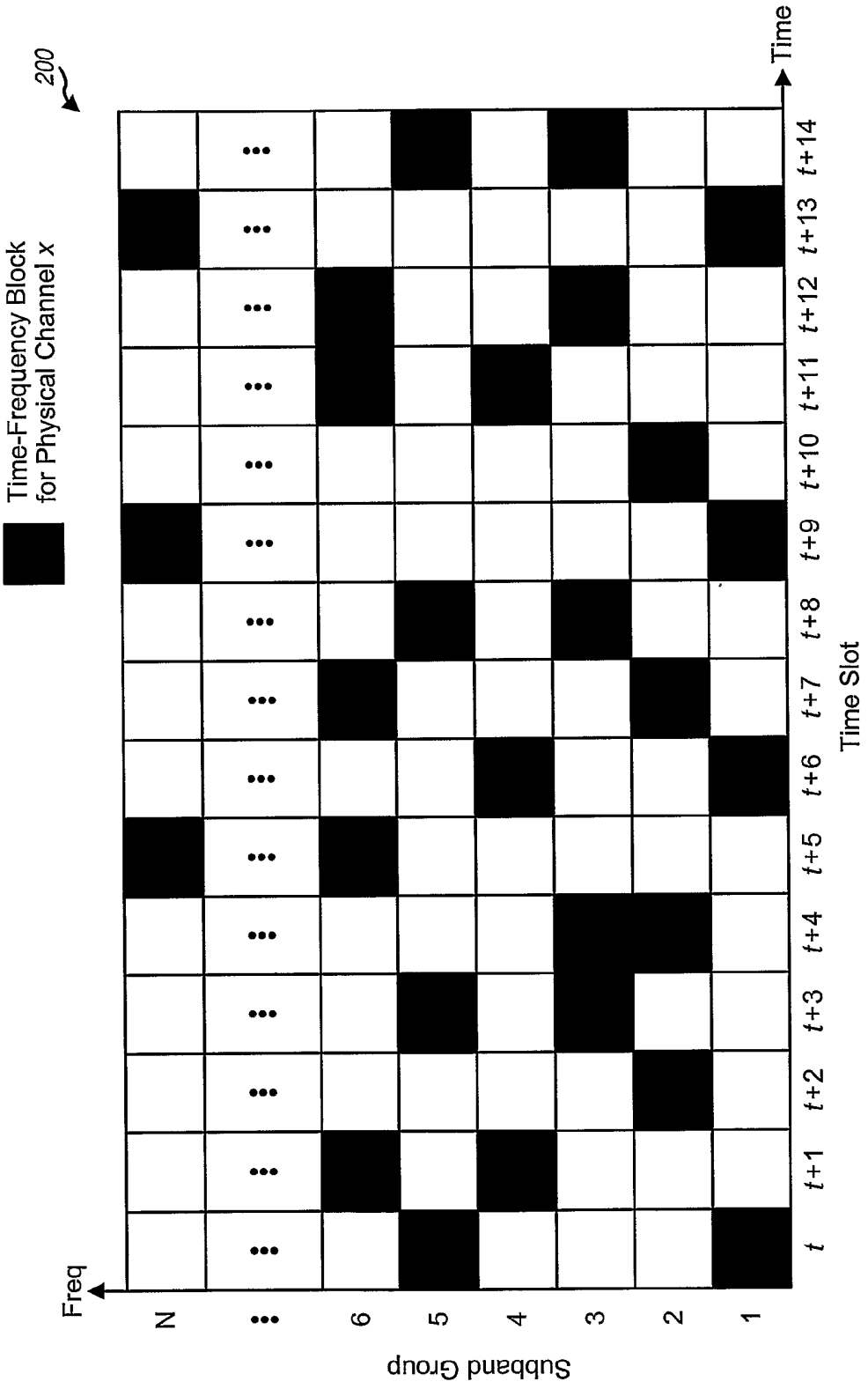
200
Time-Frequency Block
for Physical Channel x
Time
Freq
Time Slot
Subband Group
t
t+1
t+2
t+3
t+4
t+5
t+6
t+7
t+8
t+9
t+10
t+11
t+12
t+13
t+14
N
6
5
4
3
2
1

FIG. 2

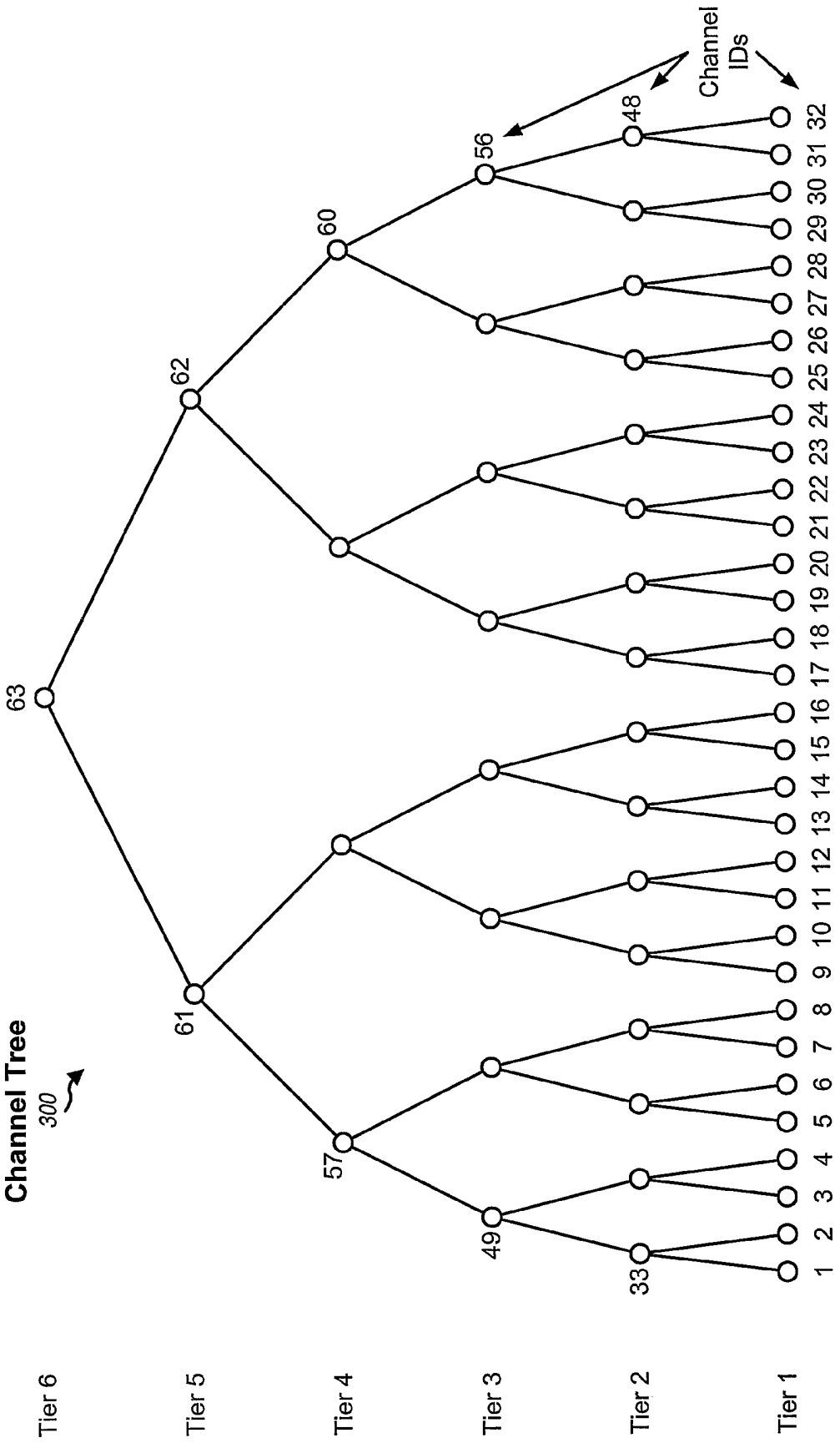
Channel Tree
300
Tier 6
Tier 5
Tier 4
Tier 3
Tier 2
Tier 1
63
62
61
60
57
56
49
48
33
Channel IDs
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

FIG. 3

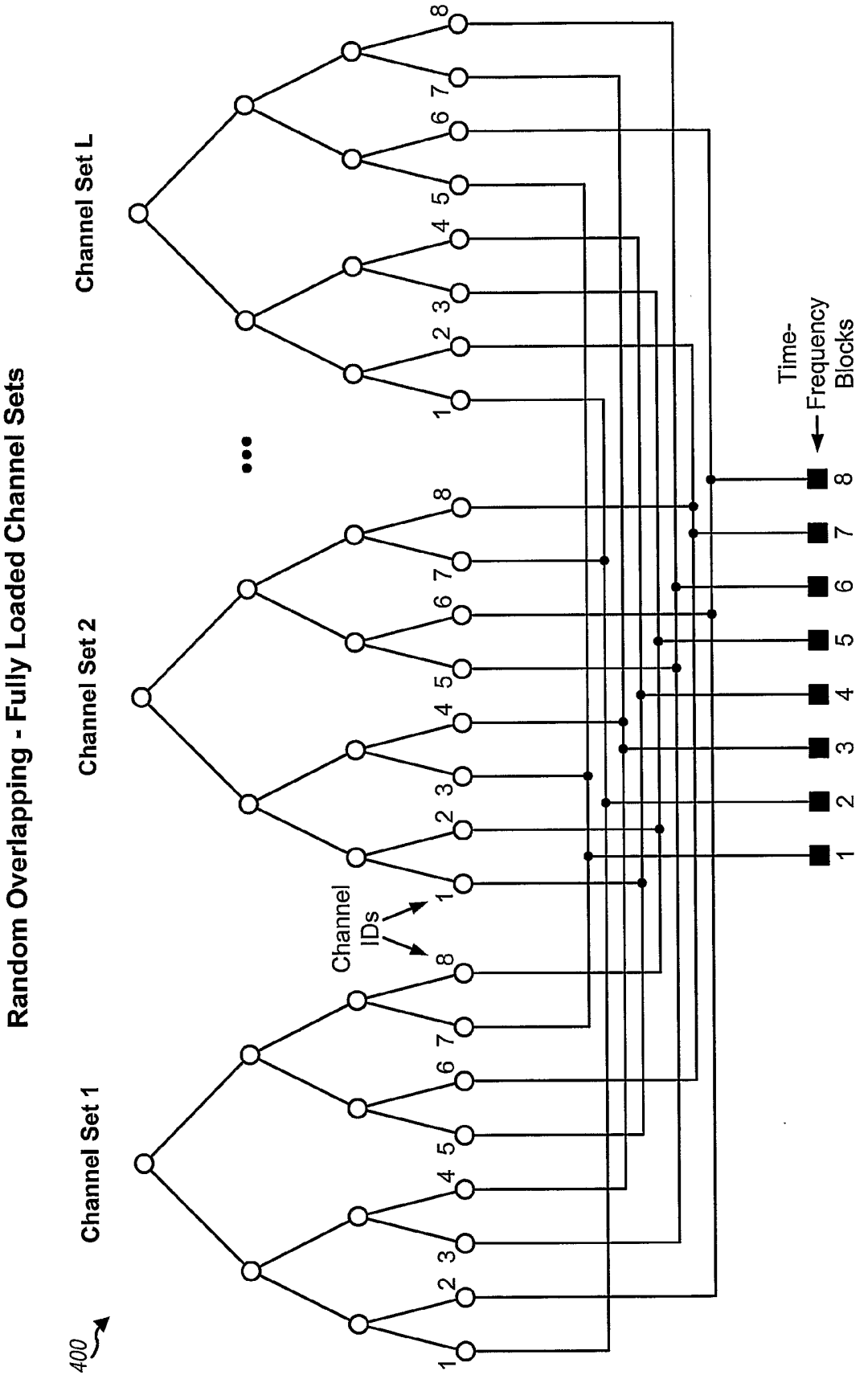
Random Overlapping - Fully Loaded Channel Sets
400
Channel Set 1
Channel Set 2
Channel Set L
Channel IDs
Time-Frequency Blocks
1 2 3 4 5 6 7 8

FIG. 4

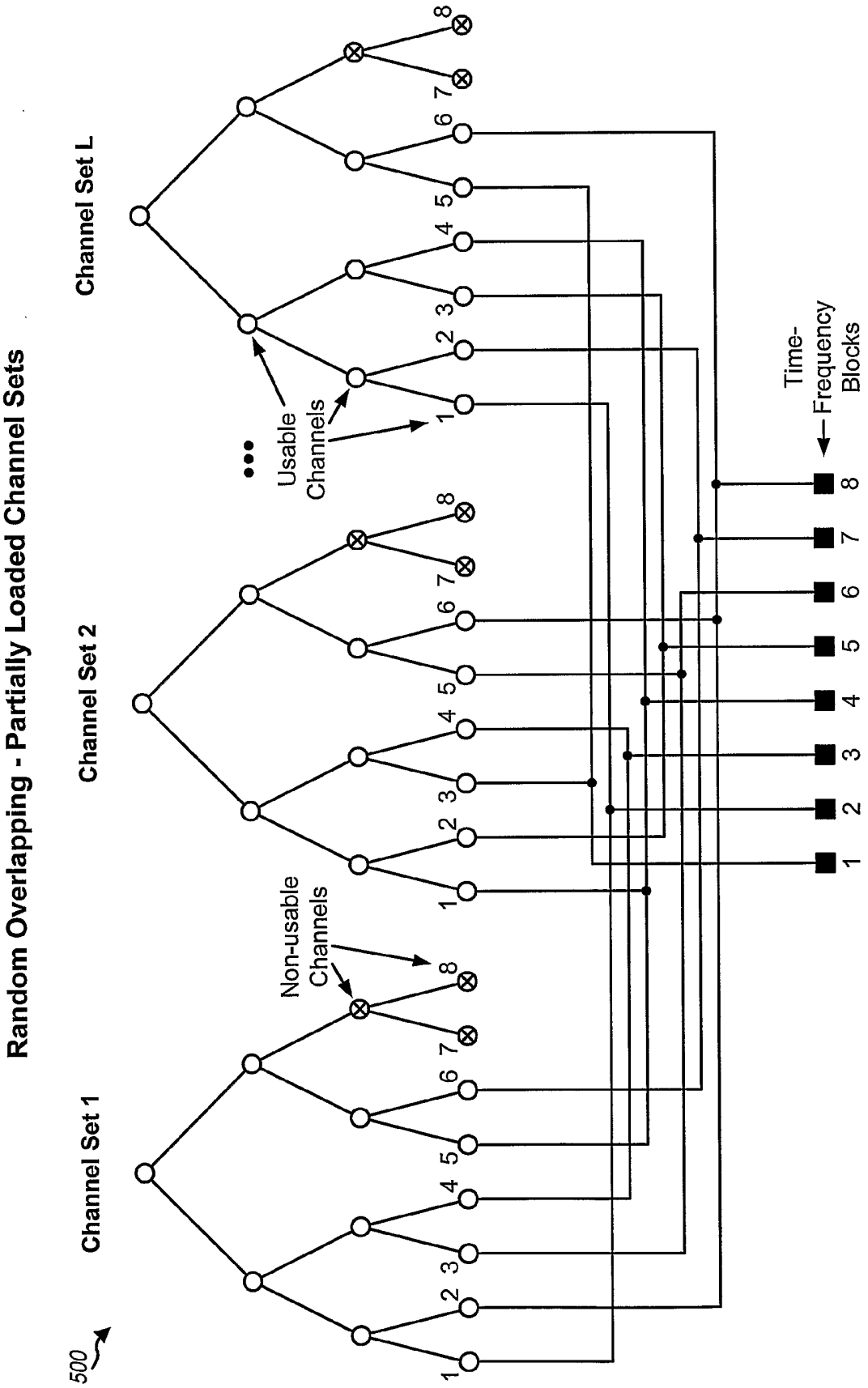
Random Overlapping - Partially Loaded Channel Sets
500
Channel Set 1
Channel Set 2
Channel Set L
Non-usable Channels
Usable Channels
Time-Frequency Blocks
1 2 3 4 5 6 7 8

FIG. 5

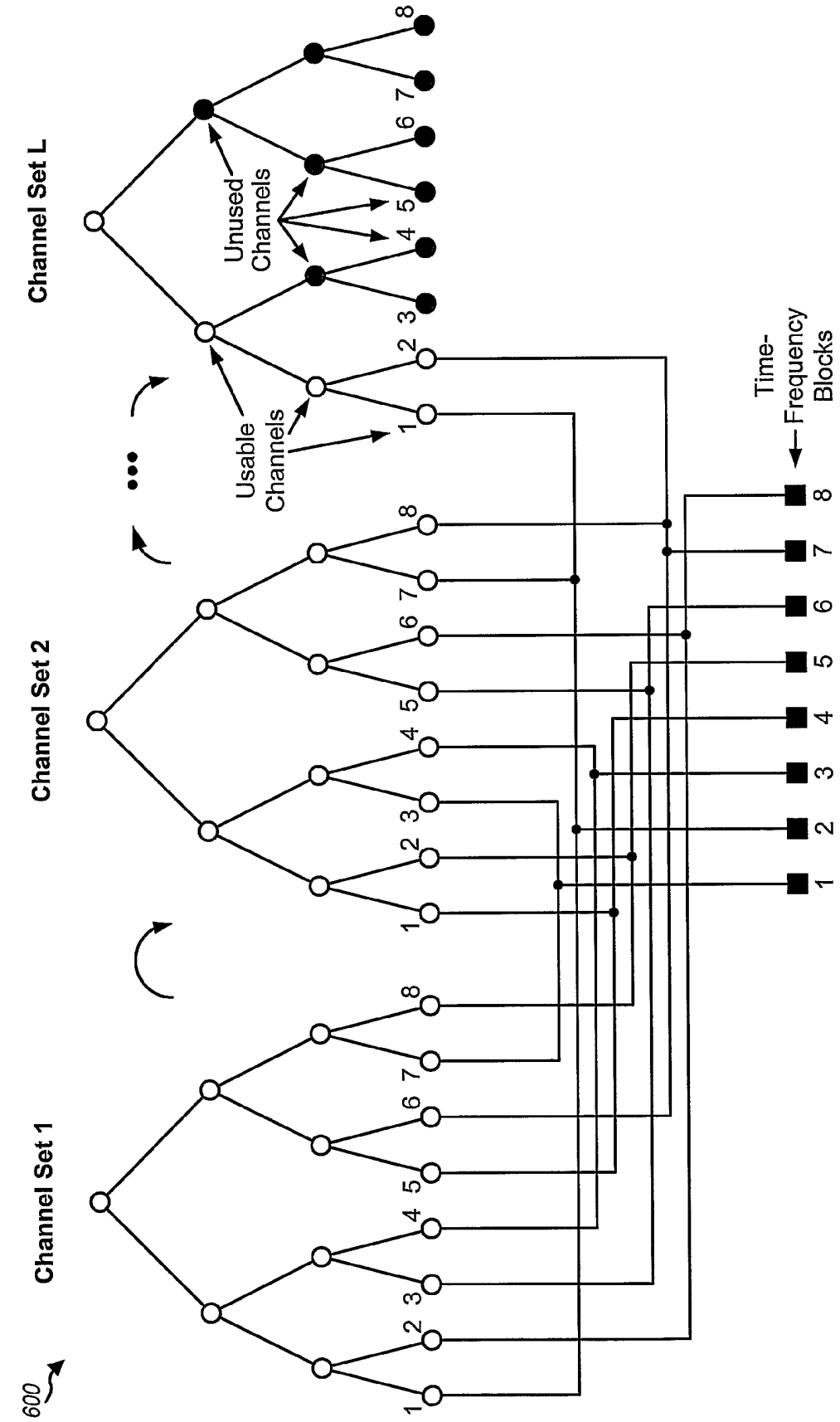
Random Overlapping - Sequentially Loaded Channel Sets
600
Channel Set 1
Channel Set 2
Channel Set L
Usable Channels
Unused Channels
Time-Frequency Blocks
1 2 3 4 5 6 7 8

FIG. 6

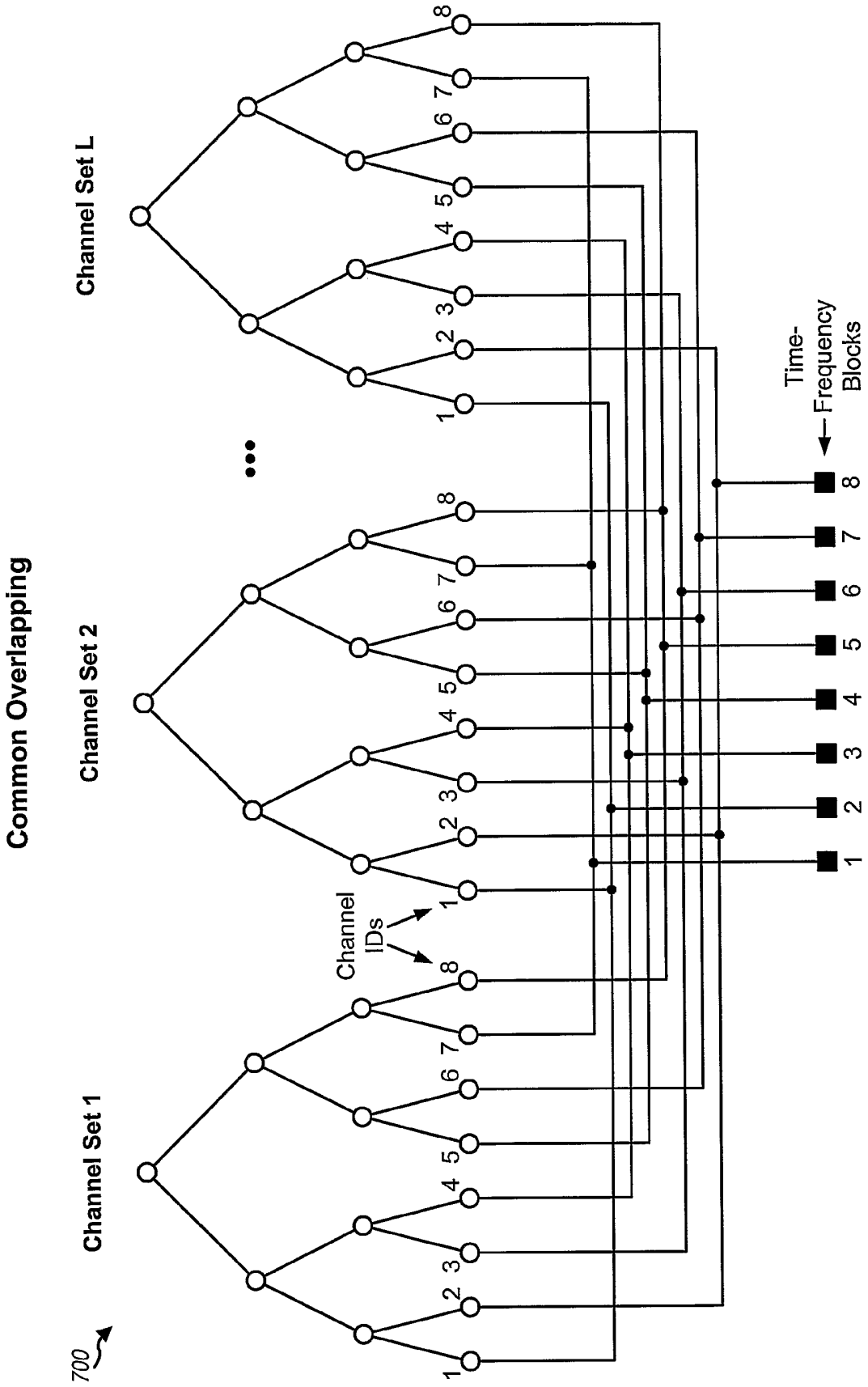
700
Common Overlapping
Channel Set 1
Channel Set 2
Channel Set L
Channel IDs
Time-Frequency Blocks
1 2 3 4 5 6 7 8

FIG. 7

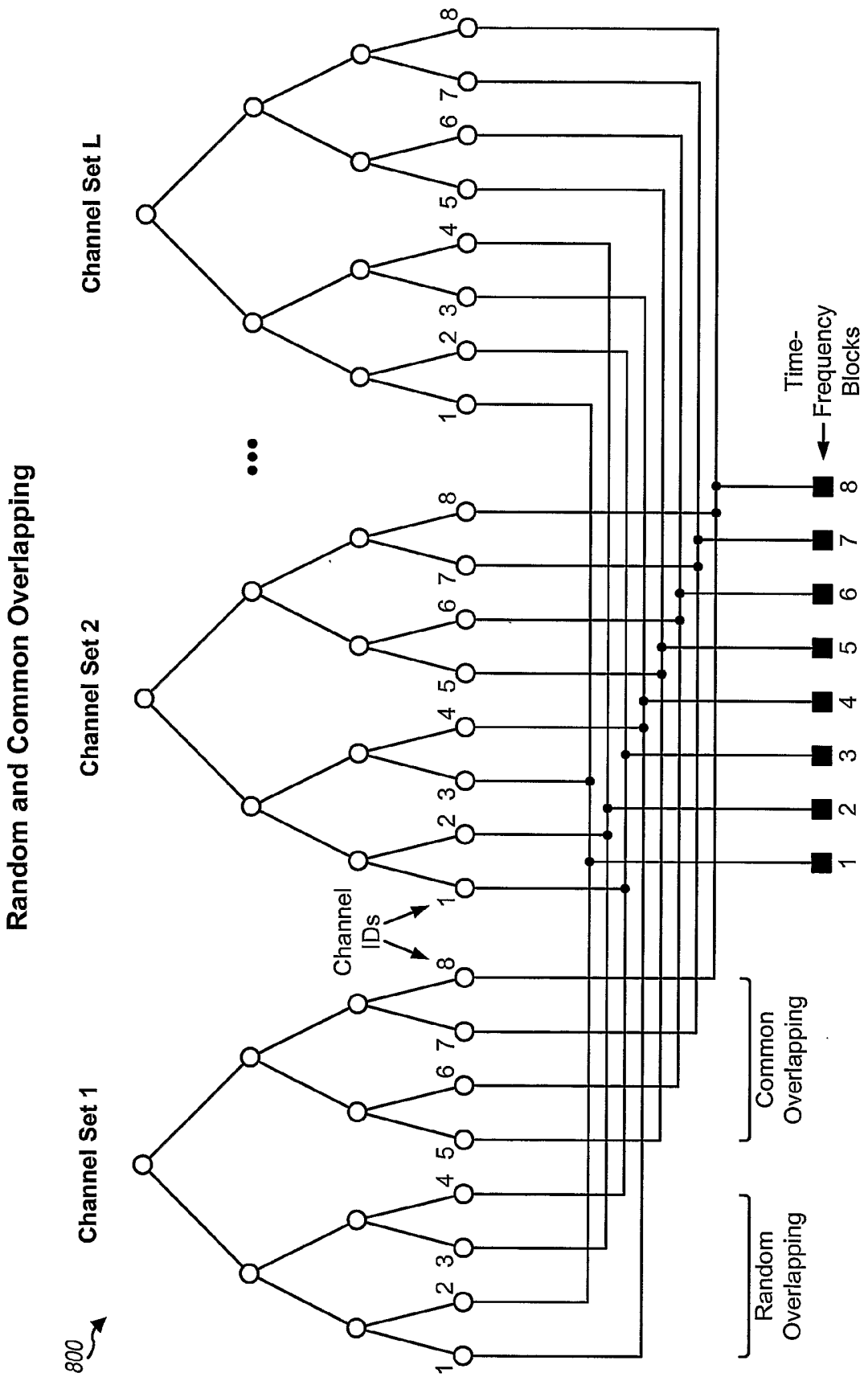
Random and Common Overlapping
800
Channel Set 1
Channel Set 2
Channel Set L
Channel IDs
Time-Frequency Blocks
Common Overlapping
Random Overlapping

FIG. 8

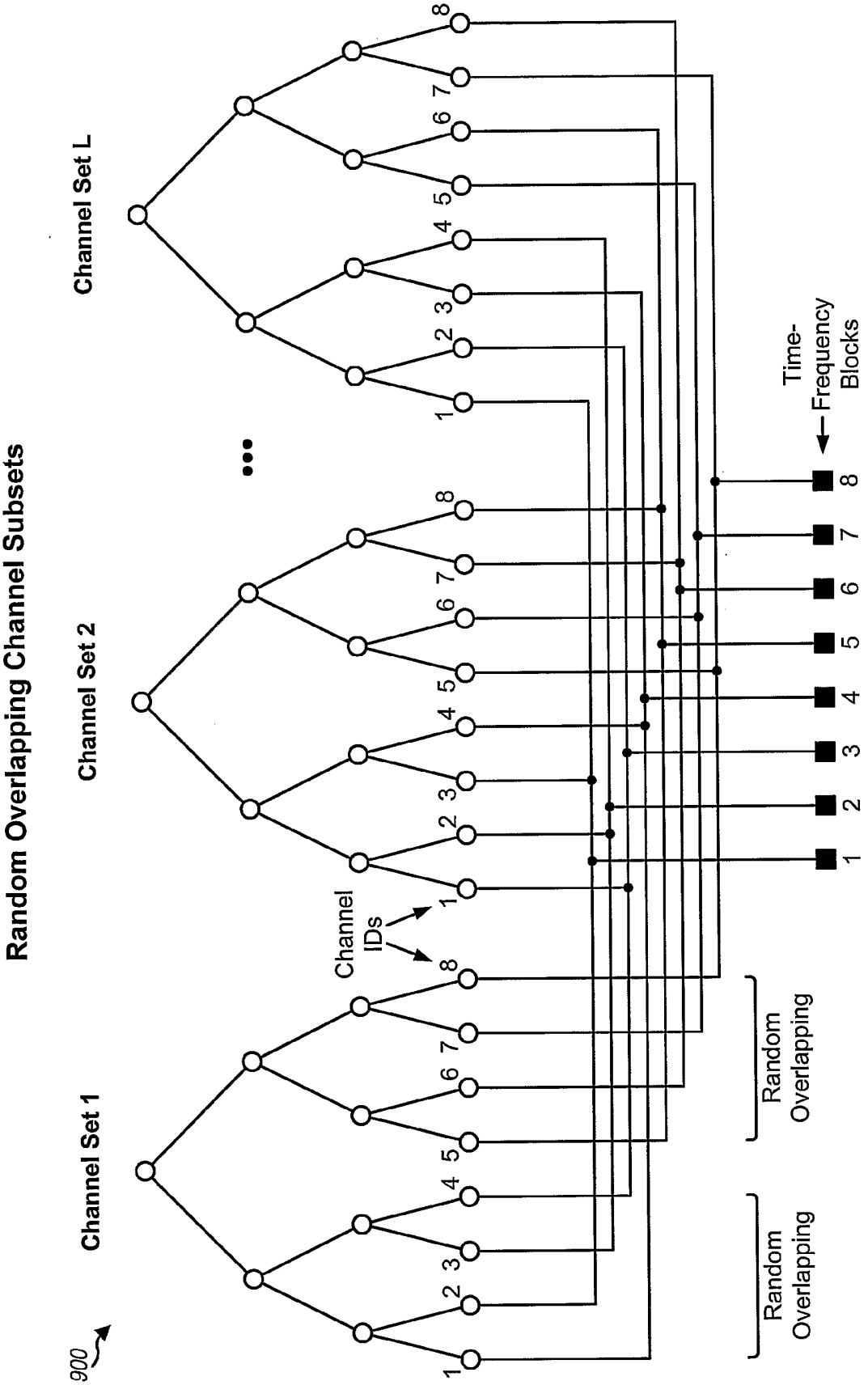
Random Overlapping Channel Subsets
900
Channel Set 1
Channel Set 2
Channel Set L
Channel IDs
Random Overlapping
Random Overlapping
Time-Frequency Blocks
1 2 3 4 5 6 7 8

FIG. 9

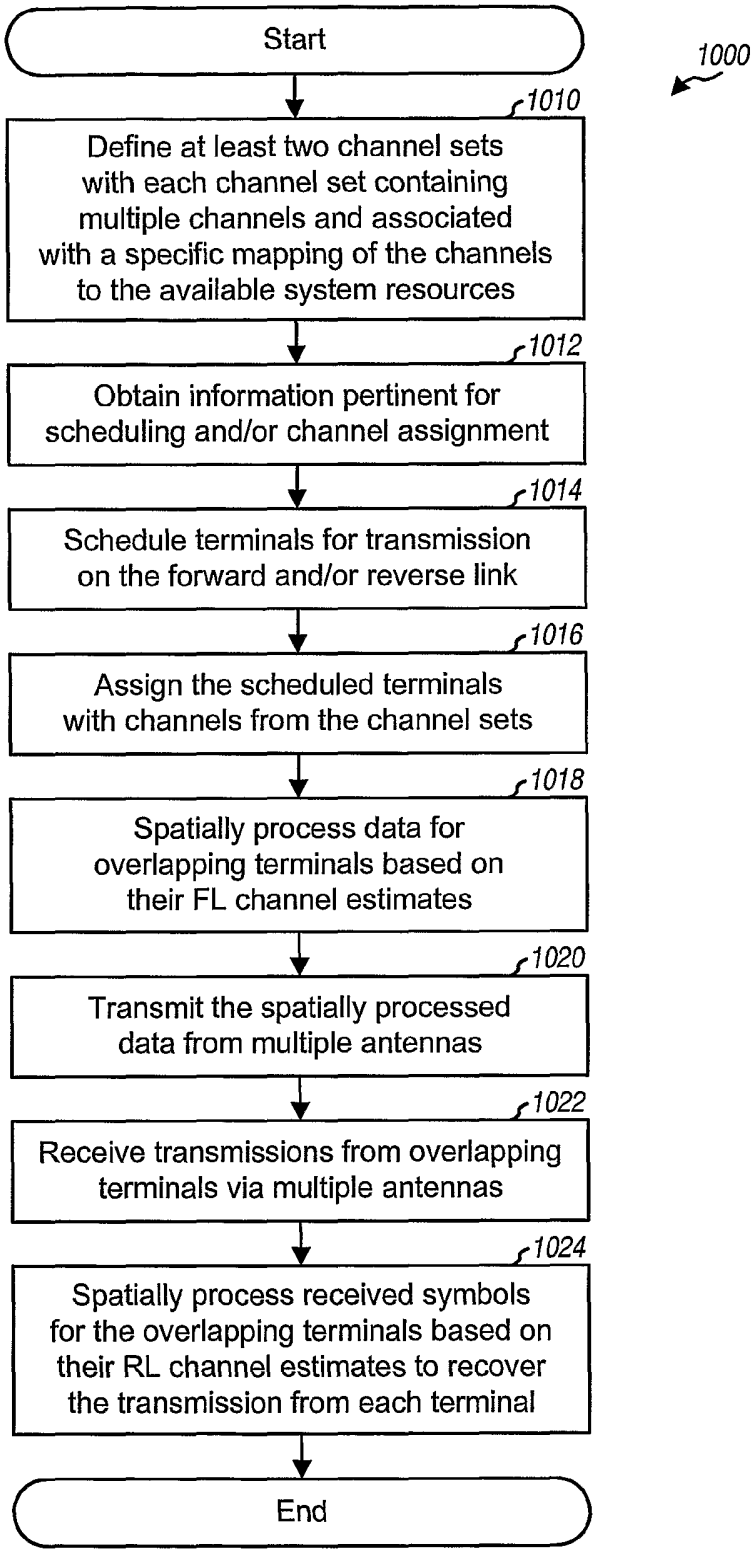
Start
1000
1010
Define at least two channel sets with each channel set containing multiple channels and associated with a specific mapping of the channels to the available system resources
1012
Obtain information pertinent for scheduling and/or channel assignment
1014
Schedule terminals for transmission on the forward and/or reverse link
1016
Assign the scheduled terminals with channels from the channel sets
1018
Spatially process data for overlapping terminals based on their FL channel estimates
1020
Transmit the spatially processed data from multiple antennas
1022
Receive transmissions from overlapping terminals via multiple antennas
1024
Spatially process received symbols for the overlapping terminals based on their RL channel estimates to recover the transmission from each terminal
End

FIG. 10

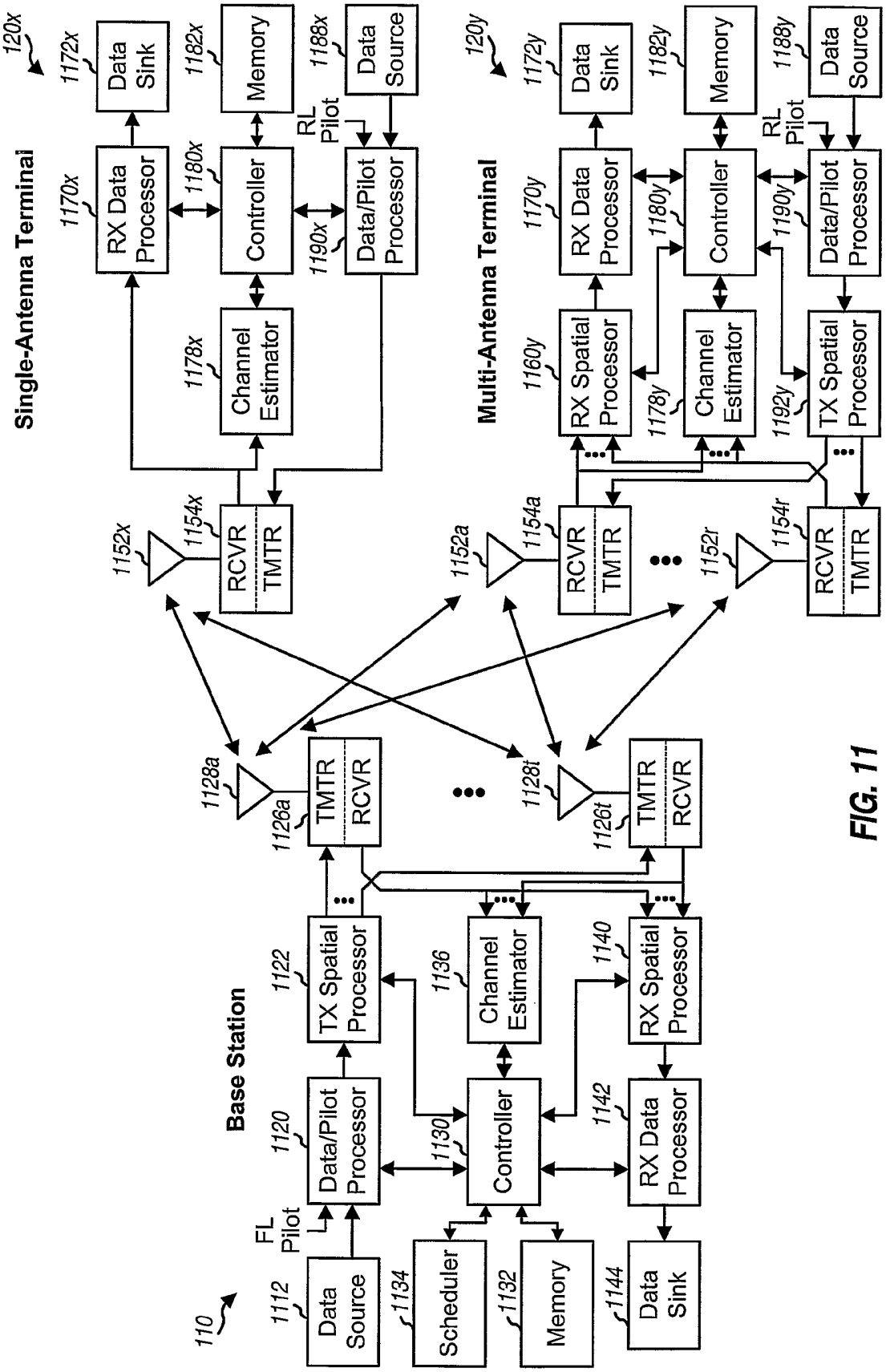
Single-Antenna Terminal
120x
1172x
Data Sink
1182x
Memory
1188x
Data Source
1170x
RX Data Processor
1180x
Controller
RL Pilot
1190x
Data/Pilot Processor
1178x
Channel Estimator
1152x
1154x
RCVR
TMTR
Multi-Antenna Terminal
120y
1172y
Data Sink
1182y
Memory
1188y
Data Source
1170y
RX Data Processor
1180y
Controller
RL Pilot
1190y
Data/Pilot Processor
1160y
RX Spatial Processor
1178y
Channel Estimator
1192y
TX Spatial Processor
1152a
1154a
RCVR
TMTR
1152r
1154r
RCVR
TMTR
1128a
1126a
TMTR
RCVR
1128t
1126t
TMTR
RCVR
Base Station
1122
TX Spatial Processor
1136
Channel Estimator
1140
RX Spatial Processor
1120
Data/Pilot Processor
1130
Controller
1142
RX Data Processor
FL Pilot
1112
Data Source
1134
Scheduler
1132
Memory
1144
Data Sink
110

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/009757

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04J11/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04J

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,A	US 6 870 826 B1 (ISHIZU FUMIO) 22 March 2005 (2005-03-22) abstract & PATENT ABSTRACTS OF JAPAN vol. 2000, no. 14, 5 March 2001 (2001-03-05) & JP 2000 332724 A (MITSUBISHI ELECTRIC CORP), 30 November 2000 (2000-11-30) abstract -----	
A	US 2004/131008 A1 (ZUNIGA JUAN CARLOS ET AL) 8 July 2004 (2004-07-08) paragraphs [0003], [0004] abstract -----	

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

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

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

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Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2006	26/07/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Bossen, M

2

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/009757

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/202560 A1 (TIEDEMANN EDWARD G ET AL) 30 October 2003 (2003-10-30) paragraphs [0008], [0012], [0013], [0031], [0040]; figure 3	
A	US 6 693 952 B1 (CHUAH MOOI CHOO ET AL) 17 February 2004 (2004-02-17) column 3, line 9 - line 20; figure 3 column 1, line 48 - line 57 abstract	

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2006/009757

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US 2003202560 A1	30-10-2003	AU 2003234291 A1	17-11-2003
		BR 0309614 A	15-03-2005
		CN 1659805 A	24-08-2005
		EP 1500215 A1	26-01-2005
		JP 2006507712 T	02-03-2006
		WO 03094391 A1	13-11-2003
US 6693952 B1	17-02-2004	NONE	