Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2544280 A1 2005/05/12

(21) 2 544 280

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2004/10/28
(87) Date publication PCT/PCT Publication Date: 2005/05/12
(85) Entrée phase nationale/National Entry: 2006/04/27
(86) N° demande PCT/PCT Application No.: US 2004/036285
(87) N° publication PCT/PCT Publication No.: 2005/043948
(30) Priorités/Priorities: 2003/10/30 (US60/516,558);
2004/06/18 (US10/871,084)

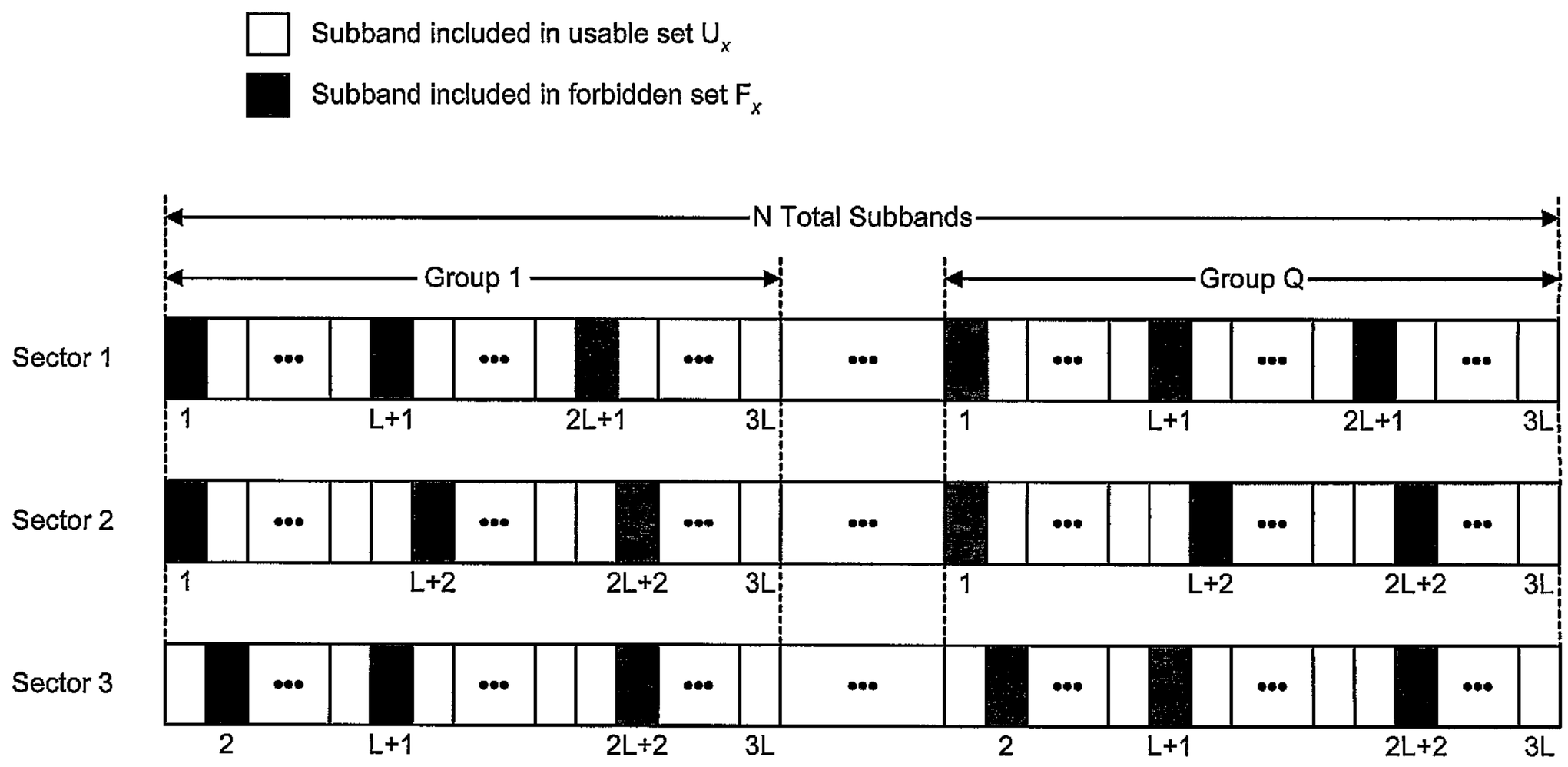
(51) Cl.Int./Int.Cl. *H04Q 7/36* (2006.01),
H04Q 7/38 (2006.01)

(71) Demandeur/Applicant:
QUALCOMM INCORPORATED, US

(72) Inventeurs/Inventors:
JI, TINGFANG, US;
AGRAWAL, AVNEESH, US;
TEAGUE, EDWARD H., US

(74) Agent: SMART & BIGGAR

(54) Titre : REUTILISATION RESTRICTIVE D'UN SYSTEME DE COMMUNICATION SANS FIL
(54) Title: RESTRICTIVE REUSE FOR A WIRELESS COMMUNICATION SYSTEM



(57) Abrégé/Abstract:
For restrictive reuse, each cell (or each sector) is assigned (1) a set of usable subbands that may be allocated to users in the cell and (2) a set of forbidden subbands that is not used. The usable and forbidden sets for each cell are orthogonal to one other. The usable set for each cell also overlaps the forbidden set for each neighboring cell. A user u in a cell x may be allocated subbands in the usable set for that cell. If user u observes/causes high level of interference from/to a neighboring cell y, then user u may be allocated subbands from a "restricted" set containing subbands included in both the usable set for cell x and the forbidden set for cell y. User u would then observe/cause no interference from/to cell y. The subband restriction may be extended to avoid interference from multiple neighboring cells.

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

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 May 2005 (12.05.2005)

PCT

(10) International Publication Number
WO 2005/043948 A3

(51) International Patent Classification[7]: H04Q 7/36, 7/38

(21) International Application Number:
PCT/US2004/036285

(22) International Filing Date: 28 October 2004 (28.10.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/516,558	30 October 2003 (30.10.2003)	US
10/871,084	18 June 2004 (18.06.2004)	US

(71) Applicant (*for all designated States except US*): **QUALCOMM INCORPORATED** [US/US]; 5775 Morehouse Drive, San Diego, CA 92121 (US).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **JI, Tingfang** [CN/US]; 3425 Lebon Drive #921, San Diego, CA 92122 (US). **AGRAWAL, Avneesh** [IN/US]; 7891 Doug Hill, #29, San Diego, CA 92127 (US). **TEAGUE, Edward, H.** [US/US]; 4614 Bryson Terrace, San Diego, CA 92130 (US).

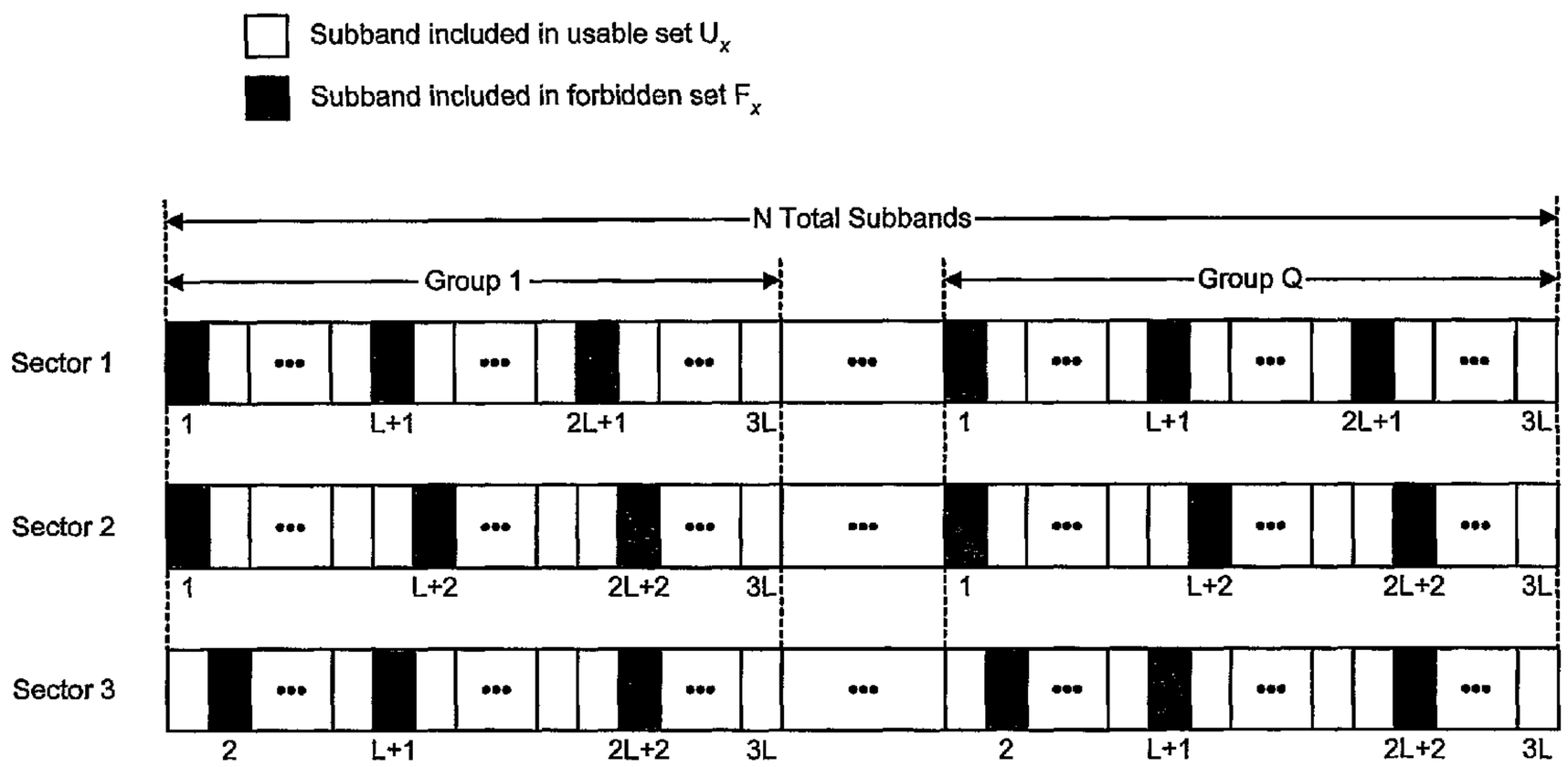
(74) Agents: **WADSWORTH, Philip, R.** et al.; 5775 Morehouse Drive, San Diego, CA 92121 (US).

(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, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, 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, IT, LU, 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).

[Continued on next page]

(54) Title: RESTRICTIVE REUSE FOR A WIRELESS COMMUNICATION SYSTEM



(57) Abstract: For restrictive reuse, each cell (or each sector) is assigned (1) a set of usable subbands that may be allocated to users in the cell and (2) a set of forbidden subbands that is not used. The usable and forbidden sets for each cell are orthogonal to one other. The usable set for each cell also overlaps the forbidden set for each neighboring cell. A user *u* in a cell *x* may be allocated subbands in the usable set for that cell. If user *u* observes/causes high level of interference from/to a neighboring cell *y*, then user *u* may be allocated subbands from a "restricted" set containing subbands included in both the usable set for cell *x* and the forbidden set for cell *y*. User *u* would then observe/cause no interference from/to cell *y*. The subband restriction may be extended to avoid interference from multiple neighboring cells.

WO 2005/043948 A3

WO 2005/043948 A3

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii)) for the following designations 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, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW, ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG)*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations*

Published:

— *with international search report*

(88) Date of publication of the international search report:
14 July 2005

(48) Date of publication of this corrected version:
15 September 2005

(15) Information about Correction:
see PCT Gazette No. 37/2005 of 15 September 2005, Section II

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

RESTRICTIVE REUSE FOR A WIRELESS COMMUNICATION SYSTEM

Claim of Priority under 35 U.S.C. §119

[0001] This application claims priority to U.S. Provisional Patent Application Serial No.60/516,558, filed October 30, 2003, and assigned to the assignee hereof and hereby expressly incorporated by reference herein.

BACKGROUND

I. Field

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

II. Background

[0003] A wireless multiple-access system can concurrently support communication for multiple wireless terminals on the forward and reverse links. The forward link (or downlink) refers to the communication link from base stations to terminals, and the reverse link (or uplink) refers to the communication link from terminals to base stations. Multiple terminals may simultaneously transmit data on the reverse link and/or receive data on the forward link. This may be achieved by multiplexing the data transmissions on each link to be orthogonal to one another in time, frequency, and/or code domain. The orthogonality ensures that the data transmission for each terminal does not interfere with the data transmissions for other terminals.

[0004] A multiple-access system typically has many cells, where the term "cell" can refer to a base station and/or its coverage area depending on the context in which the term is used. Data transmissions for terminals in the same cell may be sent using orthogonal multiplexing to avoid "intra-cell" interference. However, data transmissions for terminals in different cells may not be orthogonalized, in which case each terminal would observe "inter-cell" interference from other cells. The inter-cell interference may significantly degrade performance for certain disadvantaged terminals observing high levels of interference.

[0005] To combat inter-cell interference, a wireless system may employ a frequency reuse scheme whereby not all frequency bands available in the system are used in each cell. For example, a system may employ a 7-cell reuse pattern and a reuse factor of $K = 7$. For this system, the overall system bandwidth W is divided into seven equal frequency bands, and each cell in a 7-cell cluster is assigned one of the seven frequency bands. Each cell uses only one frequency band, and every seventh cell reuses the same frequency band. With this frequency reuse scheme, the same frequency band is only reused in cells that are not adjacent to each other, and the inter-cell interference observed in each cell is reduced relative to the case in which all cells use the same frequency band. However, a large reuse factor (e.g., two or more) represents inefficient use of the available system resources since each cell is able to use only a fraction of the overall system bandwidth.

[0006] There is therefore a need in the art for techniques to reduce inter-cell interference in a more efficient manner.

SUMMARY

[0007] Techniques to efficiently avoid or reduce interference from strong interferers in a wireless communication system are described herein. A strong interferer to a given user *u* may be a base station (on the forward link) or another user (on the reverse link). User *u* may also be a strong interferer to other users. A strong interference entity for user *u* may be a strong interferer causing high interference to user *u* and/or a strong interferee observing high interference from or due to user *u*. Strong interference entities (or interferers/interferees, or simply, interferers/ees) for each user may be identified as described below. Users are allocated system resources (e.g., frequency subbands) that are orthogonal to those used by their strong interferers/ees and thus avoid interfering with one another. These techniques are called "restrictive reuse" techniques and may be used for various wireless systems and for both the forward and reverse links.

[0008] In an embodiment of restrictive reuse, each cell/sector is assigned (1) a set of usable subbands that may be allocated to users in the cell/sector and (2) a set of forbidden subbands that are not allocated to the users in the cell/sector. The usable set and the forbidden set for each cell/sector are orthogonal to one other. The usable set for each cell/sector also overlaps the forbidden set for each neighboring cell/sector. A given user *u* in a cell/sector *x* may be allocated subbands in the usable set for that cell/

sector. If user *u* observes (or causes) high level of interference from (to) a neighboring cell/sector *y*, then user *u* may be allocated subbands from a "restricted" set that contains subbands included in both the usable set for cell/sector *x* and the forbidden set for cell/sector *y*. User *u* would then observe (cause) no interference from (to) cell/sector *y* since the subbands allocated to user *u* are members of the forbidden set not used by cell/sector *y*. The subband restriction may be extended to avoid interference from multiple neighboring cells/sectors.

[0009] Various aspects and embodiments of the invention are described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The features and nature of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

[0011] FIG. 1 shows a wireless multiple-access communication system;

[0012] FIGS. 2A and 2B show a sectorized cell and its model, respectively;

[0013] FIG. 3 shows an exemplary multi-cell layout with 3-sector cells;

[0014] FIG. 4 shows three overlapping forbidden sets for three sectors;

[0015] FIGS. 5A through 5D show four unrestricted and restricted sets for a sector;

[0016] FIG. 6 shows an example for forming three forbidden subband sets;

[0017] FIGS. 7A through 7D show a distribution of four users in a cluster of seven sectors and non-interference patterns for three of the users;

[0018] FIG. 8 shows a process for allocating subbands to users with restrictive reuse;

[0019] FIG. 9 shows a block diagram of a transmitting entity; and

[0020] FIG. 10 shows a block diagram of a receiving entity.

DETAILED DESCRIPTION

[0021] 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.

[0022] **FIG. 1** shows a wireless multiple-access communication system 100. System 100 includes a number of base stations 110 that support communication for a number of wireless terminals 120. A base station is a fixed station used for communicating with the terminals and may also be referred to as an access point, a Node B, or some other terminology. Terminals 120 are typically dispersed throughout the system, and each terminal may be fixed or mobile. A terminal may also be referred to as a mobile station, a user equipment (UE), a wireless communication device, or some other terminology. Each terminal may communicate with one or possibly multiple base stations on the forward and reverse links at any given moment.

[0023] For a centralized architecture, a system controller 130 couples to the base stations and provides coordination and control for these base stations. For a distributed architecture, the base stations may communicate with one another as needed, e.g., to serve a terminal, coordinate usage of system resources, and so on.

[0024] **FIG. 2A** shows a cell 210 with three sectors. Each base station provides communication coverage for a respective geographic area. The coverage area of each base station may be of any size and shape and is typically dependent on various factors such as terrain, obstructions, and so on. To increase capacity, the base station coverage area may be partitioned into three sectors 212a, 212b, and 212c, which are labeled as sectors 1, 2, and 3, respectively. Each sector may be defined by a respective antenna beam pattern, and the three beam patterns for the three sectors may point 120° from each other. The size and shape of each sector are generally dependent on the antenna beam pattern for that sector, and the sectors of the cell typically overlap at the edges. A cell/sector may not be a contiguous region, and the cell/sector edge may be quite complex.

[0025] **FIG. 2B** shows a simple model for sectorized cell 210. Each of the three sectors in cell 210 is modeled by an ideal hexagon that approximates the boundary of the sector. The coverage area of each base station may be represented by a clover of three ideal hexagons centered at the base station.

[0026] Each sector is typically served by a base transceiver subsystem (BTS). In general, 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 base station for that cell typically includes the BTSs for all sectors of that 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" base station or

"serving" sector is one with which a terminal communicates. The terms "terminal" and "user" are also used interchangeably herein.

[0027] The restrictive reuse techniques may be used for various communication systems. For clarity, these techniques are described for an Orthogonal Frequency Division Multiple Access (OFDMA) system that utilizes orthogonal frequency division multiplexing (OFDM). OFDM effectively partitions the overall system bandwidth into a number of (N) orthogonal frequency subbands, which are also referred to as tones, sub-carriers, bins, frequency channels, and so on. Each subband is associated with a respective sub-carrier that may be modulated with data.

[0028] In the OFDMA system, multiple orthogonal "traffic" channels may be defined whereby (1) each subband is used for only one traffic channel in any given time interval and (2) each traffic channel may be assigned zero, one, or multiple subbands in each time interval. A traffic channel may be viewed as a convenient way of expressing an assignment of subbands for different time intervals. Each terminal may be assigned a different traffic channel. For each sector, multiple data transmissions may be sent simultaneously on multiple traffic channels without interfering with one another.

[0029] The OFDMA system may or may not use frequency hopping (FH). With frequency hopping, a data transmission hops from subband to subband in a pseudo-random manner, which can provide frequency diversity and other benefits. For a frequency hopping OFDMA (FH-OFDMA) system, each traffic channel may be associated with a specific FH sequence that indicates the particular subband(s) to use for that traffic channel in each time interval (or hop period). The FH sequences for different traffic channels in each sector are orthogonal to one another so that no two traffic channels use the same subband in any given hop period. The FH sequences for each sector may also be pseudo-random with respect to the FH sequences for neighboring sectors. These properties for the FH sequences minimize intra-sector interference and randomize inter-sector interference.

[0030] In the OFDMA system, users with different channel conditions may be distributed throughout the system. These users may have different contribution and tolerance to inter-sector interference. The channel condition for each user may be quantified by a signal quality metric, which may be defined by a signal-to-interference-and-noise ratio (SINR), a channel gain, a received pilot power, and/or some other quantity measured for the user's serving base station, some other measurements, or any combination thereof. A weak user has a relatively poor signal quality metric (e.g., a low

SINR) for its serving base station, e.g., due to a low channel gain for its serving base station and/or high inter-sector interference. A weak user may in general be located anywhere within a sector but is typically located far away from the serving base station. In general, a weak user is less tolerant to inter-sector interference, causes more interference to users in other sectors, has poor performance, and may be a bottleneck in a system that imposes a fairness requirement.

[0031] Restrictive reuse can avoid or reduce interference observed/caused by weak users. This may be achieved by determining the likely sources of high inter-sector interference (or strong interferers) and/or the likely victims of high inter-sector interference (or strong interferees) for the weak users. The strong interferers may be base stations (on the forward link) and/or users (on the reverse link) in neighboring sectors. The strong interferees may be users in neighboring sectors. In any case, the weak users are allocated subbands that are orthogonal to those used by the strong interferers/ees.

[0032] In an embodiment of restrictive reuse, each sector x is assigned a usable subband set (denoted as U_x) and a forbidden or unused subband set (denoted as F_x). The usable set contains subbands that may be allocated to the users in the sector. The forbidden set contains subbands that are not allocated to users in the sector. The usable set and the forbidden set for each sector are orthogonal or disjoint in that no subband is included in both sets. The usable set for each sector also overlaps the forbidden set for each neighboring sector. The forbidden sets for multiple neighboring sectors may also overlap. The users in each sector may be allocated subbands from the usable set as described below.

[0033] Restrictive reuse may be used for systems composed of unsectorized cells as well as systems composed of sectorized cells. For clarity, restrictive reuse is described below for an exemplary system composed of 3-sector cells.

[0034] **FIG. 3** shows an exemplary multi-cell layout 300 with each 3-sector cell being modeled by a clover of three hexagons. For this cell layout, each sector is surrounded in the first tier (or the first ring) by sectors that are labeled differently from that sector. Thus, each sector 1 is surrounded by six sectors 2 and 3 in the first tier, each sector 2 is surrounded by six sectors 1 and 3, and each sector 3 is surrounded by six sectors 1 and 2.

[0035] **FIG. 4** shows a Venn diagram illustrating a formation of three overlapping sets of subbands, labeled as F_1, F_2 and F_3, which may be used as three forbidden

subband sets. In this example, each forbidden set overlaps with each of the other two forbidden sets (e.g., forbidden set F_1 overlaps with each of forbidden sets F_2 and F_3). Because of the overlapping, an intersection set operation on any two forbidden sets yields a non-empty set. This property may be expressed as follows:

$$F_{12} = F_1 \cap F_2 \neq \Theta , \quad F_{13} = F_1 \cap F_3 \neq \Theta , \quad \text{and} \quad F_{23} = F_2 \cap F_3 \neq \Theta , \qquad \text{Eq (1)}$$

where "$\cap$" denotes an intersection set operation;

F_{xy} is a set containing subbands that are members of both sets F_x and F_y; and

Θ denotes a null/empty set.

Each of the three forbidden sets F_1, F_2 and F_3 is a subset of a full set Ω that contains all N total subbands, or $F_1 \subset \Omega$, $F_2 \subset \Omega$, and $F_3 \subset \Omega$. For efficient utilization of the available subbands, the three forbidden sets may also be defined such that there is no overlap over all three sets, which may be expressed as:

$$F_{123} = F_1 \cap F_2 \cap F_3 = \Theta . \qquad \text{Eq (2)}$$

The condition in equation (2) ensures that each subband is used by at least one sector.

[0036] Three usable subband sets U_1, U_2 and U_3 may be formed based on the three forbidden subband sets F_1, F_2 and F_3, respectively. Each usable set U_x may be formed by a difference set operation between the full set Ω and forbidden set F_x, as follows:

$$U_1 = \Omega \setminus F_1 , \quad U_2 = \Omega \setminus F_2 , \quad \text{and} \quad U_3 = \Omega \setminus F_3 , \qquad \text{Eq (3)}$$

where "\" denotes a difference set operation; and

U_x is a set containing subbands in the full set Ω that are not in set F_x.

[0037] The three sectors in each 3-sector cell may be assigned a different pair of usable set and forbidden set. For example, sector 1 may be assigned usable set U_1 and forbidden set F_1, sector 2 may be assigned usable set U_2 and forbidden set F_2, and sector 3 may be assigned usable set U_3 and forbidden set F_3. Each sector is also aware of the forbidden sets assigned to neighboring sectors. Thus, sector 1 is aware of forbidden sets F_2 and F_3 assigned to neighboring sectors 2 and 3, sector 2 is aware of forbidden sets F_1 and F_3 assigned to neighboring sectors 1 and 3, and sector 3 is aware of forbidden sets F_1 and F_2 assigned to neighboring sectors 1 and 2.

[0038] **FIG. 5A** shows a Venn diagram for the usable set U_1 assigned to sector 1. Usable set U_1 (shown by diagonal hashing) includes all of the N total subbands except for those in the forbidden set F_1.

[0039] **FIG. 5B** shows a Venn diagram for a restricted usable set U_{1-2} (shown by cross-hashing) for sector 1. Restricted set U_{1-2} contains subbands included in both the usable set U_1 for sector 1 and the forbidden set F_2 for sector 2. Since the subbands in forbidden set F_2 are not used by sector 2, the subbands in restricted set U_{1-2} are free of interference from sector 2.

[0040] **FIG. 5C** shows a Venn diagram for a restricted usable set U_{1-3} (shown by vertical hashing) for sector 1. Restricted set U_{1-3} contains subbands included in both the usable set U_1 for sector 1 and the forbidden set F_3 for sector 3. Since the subbands in forbidden set F_3 are not used by sector 3, the subbands in restricted set U_{1-3} are free of interference from sector 3.

[0041] **FIG. 5D** shows a Venn diagram for a more restricted usable set U_{1-23} (shown by solid fill) for sector 1. Restricted set U_{1-23} contains subbands included in all three of the usable set U_1 for sector 1, the forbidden set F_2 for sector 2, and the forbidden set F_3 for sector 3. Since the subbands in forbidden sets F_2 and F_3 are not used by sectors 2 and 3, respectively, the subbands in restricted set U_{1-23} are free of interference from both sectors 2 and 3.

[0042] As shown in FIGS. 5A through 5D, the restricted usable sets U_{1-2}, U_{1-3} and U_{1-23} are different subsets of the unrestricted usable set U_1 assigned to sector 1. Restricted usable sets U_{2-1}, U_{2-3} and U_{2-13} may be formed for sector 2, and restricted usable sets U_{3-1}, U_{3-2} and U_{3-12} may be formed for sector 3 in similar manner. Table 1 lists the various usable subband sets for the three sectors and the manner in which these sets may be formed. The "reuse" sets in Table 1 are described below.

Table 1

Reuse Set	Usable Subband Sets	Description
(1)	$U_1 = \Omega \setminus F_1$	Main/unrestricted usable set for sector 1
(1, 2)	$U_{1\text{-}2} = U_1 \cap F_2 = F_2 \setminus (F_1 \cap F_2)$	Restricted usable set with no interference from sector 2
(1, 3)	$U_{1\text{-}3} = U_1 \cap F_3 = F_3 \setminus (F_1 \cap F_3)$	Restricted usable set with no interference from sector 3
(1, 2, 3)	$U_{1\text{-}23} = U_1 \cap F_2 \cap F_3 = F_2 \cap F_3$	More restricted usable set with no interference from sectors 2 & 3
(2)	$U_2 = \Omega \setminus F_2$	Main/unrestricted usable set for sector 2
(2, 1)	$U_{2\text{-}1} = U_2 \cap F_1 = F_1 \setminus (F_1 \cap F_2)$	Restricted usable set with no interference from sector 1
(2, 3)	$U_{2\text{-}3} = U_2 \cap F_3 = F_3 \setminus (F_2 \cap F_3)$	Restricted usable set with no interference from sector 3
(2, 1, 3)	$U_{2\text{-}13} = U_2 \cap F_1 \cap F_3 = F_1 \cap F_3$	More restricted usable set with no interference from sectors 1 & 3
(3)	$U_3 = \Omega \setminus F_3$	Main/unrestricted usable set for sector 3
(3, 1)	$U_{3\text{-}1} = U_3 \cap F_1 = F_1 \setminus (F_1 \cap F_3)$	Restricted usable set with no interference from sector 1
(3, 2)	$U_{3\text{-}2} = U_3 \cap F_2 = F_2 \setminus (F_2 \cap F_3)$	Restricted usable set with no interference from sector 2
(3, 1, 2)	$U_{3\text{-}12} = U_3 \cap F_1 \cap F_2 = F_1 \cap F_2$	More restricted usable set with no interference from sectors 1 & 2

[0043] Each sector x (where $x = 1,\ 2,$ or 3) may allocate subbands in its usable set U_x to users in the sector by taking into account the users' channel conditions so that reasonably good performance may be achieved for all users. Sector x may have weak users as well as strong users. A strong user has a relatively good signal quality metric for its serving base station and is typically more tolerant to higher level of inter-sector interference. A weak user is less tolerant to inter-sector interference. Sector x may allocate any of the subbands in its usable set U_x to the strong users in the sector. Sector x may allocate subbands in the restricted sets to the weak users in the sector. The weak users are, in effect, restricted to certain subbands known to be free of interference from strong interfering sectors.

[0044] For example, a given user u in sector x may be allocated subbands from usable set U_x for sector x. If user u is deemed to be observing/causing high inter-sector

interference from/to sector *y*, where $y \neq x$, then user *u* may be allocated subbands from the restricted set $U_{x-y} = U_x \cap F_y$. If user *u* is further deemed to be observing/causing high inter-sector interference from/to sector *z*, where $z \neq x$ and $z \neq y$, then user *u* may be allocated subbands from the more restricted set $U_{x-yz} = U_x \cap F_y \cap F_z$.

[0045] **FIG. 6** shows an example for forming the three forbidden subband sets F_1, F_2 and F_3. In this example, the N total subbands are partitioned into Q groups, with each group containing 3·L subbands that are given indices of 1 through 3L, where $Q \geq 1$ and $L > 1$. Forbidden set F_1 contains subbands 1, $L+1$, and $2L+1$ in each group. Forbidden set F_2 contains subbands 1, $L+2$, and $2L+2$ in each group. Forbidden set F_3 contains subbands 2, $L+1$, and $2L+2$ in each group. Set F_{12} then contains subband 1 in each group, set F_{13} contains subband $L+1$ in each group, and set F_{23} contains subband $2L+2$ in each group.

[0046] In general, each forbidden set may contain any number of subbands and any one of the N total subbands, subject to the constraints shown in equation (1) and possibly (2). To obtain frequency diversity, each forbidden set may contain subbands taken from across the N total subbands. The subbands in each forbidden set may be distributed across the N total subbands based on a predetermined pattern, as shown in FIG. 6. Alternatively, the subbands in each forbidden set may be pseudo-randomly distributed across the N total subbands. The three forbidden sets F_1, F_2 and F_3 may also be defined with any amount of overlap. The amount of overlap may be dependent on various factors such as, for example, the desired effective reuse factor for each sector (described below), the expected number of weak users in each sector, and so on. The three forbidden sets may overlap each other by the same amount, as shown in FIG. 4, or by different amounts.

[0047] Each user may be associated with a "reuse" set that contains the serving sector for the user as well as strong interferers/ees, if any, for the user. The serving sector is denoted by boldfaced and underlined text in the reuse set. The strong interferers/ ees are denoted by normal text, after the boldfaced and underlined text for the serving sector, in the reuse set. For example, a reuse set of (**2**, 1, 3) denotes sector 2 being the serving sector and sectors 1 and 3 being strong interferers/ees.

[0048] Strong interferers to a given user *u* on the forward link are typically fixed and may be specifically identified, e.g., based on pilots transmitted by the sectors. Strong interferers to user *u* on the reverse link may not be easily identified by forward

link measurement performed by user *u* and may be deduced, e.g., based on reverse link interference measurement by the serving base station of user *u*. Strong interferees for user *u* may also be specifically identified or deduced. Strong interferers/ees for each user may be determined in various manners.

[0049] In one embodiment, strong interferers/ees for a given user *u* are determined based on received pilot powers, as measured by user *u*, for different sectors. Each sector may transmit a pilot on the forward link for various purposes such as signal detection, timing and frequency synchronization, channel estimation, and so on. User *u* may search for pilots transmitted by the sectors and measure the received power of each detected pilot. User *u* may then compare the received pilot power for each detected sector against a power threshold and add the sector to its reuse set if the received pilot power for the sector exceeds the power threshold.

[0050] In another embodiment, strong interferers/ees for user *u* are determined based on an "active" set maintained by user *u*. The active set contains all sectors that are candidates for serving user *u*. A sector may be added to the active set, e.g., if the received pilot power for the sector, as measured by user *u*, exceeds an add threshold (which may or may not be equal to the power threshold described above). Each user in the system may be required to (e.g., periodically) update its active set and to report the active set to its serving sector. The active set information may be readily available at the sector and may be used for restrictive reuse.

[0051] In yet another embodiment, strong interferers/ees for user *u* are determined based on received pilot powers, as measured at different sectors, for user *u*. Each user may also transmit a pilot on the reverse link for various purposes. Each sector may search for pilots transmitted by users in the system and measure the received power of each detected pilot. Each sector may then compare the received pilot power for each detected user against the power threshold and inform the user's serving sector if the received pilot power exceeds the power threshold. The serving sector for each user may then add sectors that have reported high received pilot powers to that user's reuse set.

[0052] In yet another embodiment, strong interferers/ees for user *u* are determined based on a position estimate for user *u*. The position of user *u* may be estimated for various reasons (e.g., to provide location service to user *u*) and using various position determination techniques (e.g., Global Positioning System (GPS), Advanced Forward Link Trilateration (A-FLT), and so on, which are known in the art). The strong

interferers/ees for user *u* may then be determined based on the position estimate for user *u* and sector/cell layout information.

[0053] Several embodiments for determining strong interferers/ees for each user have been described above. Strong interferers/ees may also be determined in other manners and/or based on other quantities besides received pilot power. A good signal quality metric for determining strong interferers on the forward link is an average SINR measured at a user for a base station, which is also called "geometry". A good signal quality metric for determining strong interferees on the reverse link is a channel gain measured at a user for a base station, since SINR measurement is not available at the user for the base station. A single reuse set may be maintained for both the forward and reverse links, or separate sets may be used for the two links. The same or different signal quality metrics may be used to update the sectors in the reuse set for the forward and reverse links.

[0054] In general, strong interferers/ees may be specifically identified based on direct measurements (e.g., for the forward link) or deduced based on related measurements, sector/cell layout, and/or other information (e.g., for the reverse link). For simplicity, the following description assumes that each user is associated with a single reuse set that contains the serving sector and other sectors (if any) deemed to be strong interferers/ees for the user.

[0055] In a well-designed system, a weak user should have a relatively fair signal quality metric for at least one neighboring sector. This allows the weak user to be handed off from a current serving sector to a neighboring sector if necessary. Each such neighboring sector may be deemed as a strong interferer/ee to the weak user and may be included in the user's reuse set.

[0056] **FIG. 7A** shows an example distribution of four users in a cluster of seven sectors. In this example, user 1 is located near the middle of sector 1 and has a reuse set of (**1**). User 2 is located near the boundary between sectors 1 and 3 and has a reuse set of (**1**, 3). User 3 is also located near the boundary between sectors 1 and 3 but has a reuse set of (**3**, 1). User 4 is located near the boundary of sectors 1, 2 and 3 and has a reuse set of (**1**, 2, 3).

[0057] **FIG. 7B** shows a non-interference pattern for user 1 in FIG. 7A. User 1 is allocated subbands in usable set U_1 since its reuse set is (**1**). Because users in sector 1 are allocated orthogonal subbands, user 1 does not interfere with other users in sector 1. However, usable set U_1 is not orthogonal to usable sets U_2 and U_3 for sectors 2 and 3,

respectively. Thus, user 1 observes interference from the six neighboring sectors 2 and 3 in the first tier around sector 1. User 1 typically observes interference from distant or weak interferers in these six neighboring sectors because strong interferers (to sector 1/user 1) in these neighboring sectors are allocated subbands (e.g., in restricted sets U_{2-1} and U_{3-1}) that are orthogonal to those in usable set U_1. The area where other users do not interfere with user 1 is shown by cross-hashing and covers sector 1 and the edges of other sectors that neighbor sector 1 (since the users in these neighboring sectors 2 and 3 may be assigned subbands that are not used by sector 1).

[0058] **FIG. 7C** shows a non-interference pattern for user 2 in FIG. 7A. User 2 is allocated subbands in restricted set $U_{1-3} = U_1 \cap F_3$ since its reuse set is (**1**, 3). Because sector 3 does not use the subbands in its forbidden set F_3, the subbands allocated to user 2 are orthogonal to the subbands used by sector 3. Thus, user 2 does not observe any interference from other users in sector 1 as well as users in sector 3. User 2 observes interference from distant interferers in the three first-tier neighboring sectors 2. The area where other users do not interfere with user 2 covers sectors 1 and 3 and the edges of sectors 2 that neighbor sector1 (for the reason noted above for FIG. 7B).

[0059] **FIG. 7D** shows a non-interference pattern for user 4 in FIG. 7A. User 4 is allocated subbands in restricted set $U_{1-23} = U_1 \cap F_2 \cap F_3$ since its reuse set is (**1**, 2, 3). Because sectors 2 and 3 do not use the subbands in their forbidden sets F_2 and F_3, respectively, the subbands allocated to user 4 are orthogonal to the subbands used by sectors 2 and 3. Thus, user 4 does not observe any interference from other users in sector 1 as well as users in the six first-tier neighboring sectors 2 and 3. The area where other users do not interfere with user 4 covers sectors 1, 2 and 3.

[0060] In FIG. 7A, users 2 and 3 are located in close proximity and would have interfered strongly with each other without restrictive reuse. With restrictive reuse, user 2 is allocated subbands in restricted set $U_{1-3} = U_1 \cap F_3$ since its reuse set is (**1**, 3), and user 3 is allocated subbands in restricted set $U_{3-1} = U_3 \cap F_1$ since its reuse set is (**3**, 1). Restricted sets U_{1-3} and U_{3-1} are mutually orthogonal since each restricted set U_{x-y} contains only subbands that are excluded from the usable set U_y of which the other restricted set U_{y-x} is a subset. Because users 2 and 3 are allocated subbands from orthogonal restricted sets U_{1-3} and U_{3-1}, respectively, these two users do not interfere with one another.

[0061] As shown in FIGS. 7A through 7D, the interference experienced by a user decreases as the size of its reuse set increases. A user with a reuse set size of one (e.g., user 1 in FIG. 7B) is interfered by distant interferers in six first-tier neighboring sectors. A user with a reuse set size of two (e.g., user 2 in FIG. 7C) is interfered by distant interferers in three first-tier neighboring sectors. A user with a reuse set size of three is interfered by interferers in second-tier neighbor sectors. In contrast, without restrictive reuse, all users in the system would be interfered by randomly distributed interferers from all six first-tier neighboring sectors.

[0062] Restrictive reuse may be used to mitigate inter-sector interference for weak users on both the forward and reverse links. On the forward link, a weak user *u* in sector *x* may observe high inter-sector interference from base stations for neighboring sectors that are in its reuse set. Weak user *u* may be allocated subbands that are not used by these neighboring sectors and would then observe no interference from the base stations for these sectors. Restrictive reuse may thus directly improve the SINRs of individual weak user *u*.

[0063] On the reverse link, weak user *u* may observe high inter-sector interference from users in neighboring sectors that are in its reuse set. Weak user *u* may be allocated subbands that are not used by these neighboring sectors and would then observe no interference from the users in these sectors. Weak user *u* may also be a strong interferer to the users in the neighboring sectors. Weak user *u* typically transmits at a high power level in order to improve its received SINR at its serving sector *x*. The high transmit power causes more interference to all users in the neighboring sectors. By restricting weak user *u* to subbands not used by the neighboring sectors in the reuse set, weak user *u* would cause no interference to the users in these sectors.

[0064] When restrictive reuse is applied across the system, weak user *u* may benefit from lower inter-sector interference on the reverse link even if the strong interferers to weak user *u* cannot be identified. Weak users in neighboring sectors that have sector *x* in their reuse sets may be strong interferers to weak user *u* as well as other users in sector *x*. These strong interferers may be allocated subbands that are not used by sector *x* and would then cause no interference to the users in sector *x*. User *u* may thus observe no inter-sector interference from these strong interferers even though user *u* is not able to identify them. Restrictive reuse generally improves the SINRs of all weak users.

[0065] For both the forward and reverse links, restrictive reuse can avoid or reduce interference observed by weak users from strong interferers and thus improve the SINRs

for the weak users. Restrictive reuse may reduce the variation in SINRs among users in the system. As a result, improved communication coverage as well as higher overall system capacity may be achieved for the system.

[0066] **FIG. 8** shows a flow diagram of a process 800 for allocating subbands to users in a sector with restrictive reuse. Process 800 may be performed by/for each sector. Initially, strong "interference entities", if any, for each user in the sector are identified (block 812). A strong interference entity for a given user *u* may be (1) a strong interferer causing high interference to user *u* and/or (2) a strong interferee observing high interference from or due to user *u*. A strong interference entity for user *u* may thus be (1) a base station causing high interference to user *u* on the forward link, (2) another user causing high interference to user *u* on the reverse link, (3) a base station observing high interference from user *u* on the reverse link, (4) another user observing high interference from user *u*'s serving base station on the forward link, or (5) some other entity for which mitigation of interference with user *u* is sought. The strong interference entities may be identified based on, e.g., received pilot powers measured by the user for different sectors, received pilot powers measured by different sectors for the user, and so on. The strong interference entities for each user may be included in the user's reuse set, as described above. In any case, a restricted usable set is determined for each user with at least one strong interference entity (block 814). The restricted set for each user may be obtained by performing an intersection set operation on the usable set for the user's serving sector with the forbidden set for each strong interference entity, or $U_{x\text{-}y\ldots} = U_x \cap F_y \ldots$. Each user with at least one strong interference entity is allocated subbands in the restricted set determined for that user (block 816). Each user without a strong interference entity is allocated remaining subbands in the usable set for the sector (block 818). The process then terminates.

[0067] Process 800 shows allocation of subbands to weak users with at least one strong interference entity first, then allocation of remaining subbands to strong users. In general, the weak and strong users may be allocated subbands in any order. For example, users may be allocated subbands based on their priority, which may be determined from various factors such as the SINRs achieved by the users, the data rates supported by the users, the payload size, the type of data to be sent, the amount of delay already experienced by the users, outage probability, the maximum available transmit power, the type of data services being offered, and so on. These various factors may be

given appropriate weights and used to prioritize the users. The users may then be allocated subbands based on their priority.

[0068] Process 800 may be performed by each sector in each scheduling interval, which may be a predetermined time interval. Each sector may send signaling (e.g., to all users or to only users allocated different subbands) to indicate the subbands allocated to each user. Process 800 may also be performed (1) whenever there is a change in users in the sector (e.g., if a new user is added or a current user is removed), (2) whenever the channel conditions for the users change (e.g., whenever the reuse set for a user changes), or (3) at any time and/or due to any triggering criterion. At any given moment, all of the subbands may not be available for scheduling, e.g., some subbands may already be in use for retransmissions or some other purposes.

[0069] The forbidden sets represent overhead for supporting restrictive reuse. Since the subbands in forbidden set F_x are not used by sector x, the percentage of the total subbands usable by sector x, which is also the effective reuse factor for sector x, may be given as: $|U_x|/|\Omega| = (|\Omega| - |F_x|)/|\Omega|$, where $|U_x|$ denotes the size of set U_x. To reduce the amount of overhead for restrictive reuse, the forbidden sets may be defined to be as small as possible. However, the sizes of the restricted sets are dependent on the sizes of the forbidden sets. Thus, the forbidden sets may be defined based on expected requirements for weak users and possibly other factors.

[0070] The usable and forbidden sets may be defined in various manners. In one embodiment, the usable and forbidden sets are defined based on global frequency planning for the system and remain static. Each sector is assigned a usable set and a forbidden set, forms its restricted sets as described above, and thereafter uses the usable and restricted sets. This embodiment simplifies implementation for restrictive reuse since each sector can act autonomously, and no signaling between neighboring sectors is required. In a second embodiment, the usable and forbidden sets may be dynamically defined based on sector loading and possibly other factors. For example, the forbidden set for each sector may be dependent on the number of weak users in neighboring sectors, which may change over time. A designated sector or a system entity (e.g., system controller 130) may receive loading information for various sectors, define the usable and forbidden sets, and assign the sets to the sectors. This embodiment may allow for better utilization of system resources based on the distribution of users. In yet

another embodiment, the sectors may send inter-sector messages to negotiate the usable and forbidden sets.

[0071] Restrictive reuse can support handoff, which refers to the transfer of a user from a current serving base station to another base station that is deemed better. Handoff may be performed as needed to maintain good channel conditions for users on the edge of sector coverage (or "sector-edge" users). Some conventional systems (e.g., a Time Division Multiple Access (TDMA) system) support "hard" handoff whereby a user first breaks away from the current serving base station and then switches to a new serving base station. A Code Division Multiple Access (CDMA) system supports "soft" and "softer" handoffs, which allow a user to simultaneously communicate with multiple cells (for soft handoff) or multiple sectors (for softer handoff). Soft and softer handoffs can provide additional mitigation against fast fading.

[0072] Restrictive reuse can reduce interference for sector-edge users, which are good candidates for handoff. Restrictive reuse can also support hard, soft, and softer handoffs. A sector-edge user u in sector x may be allocated subbands in the restricted set U_{x-y}, which is free of interference from neighboring sector y. Sector-edge user u may also communicate with sector y via subbands in the restricted set U_{y-x}, which is free of interference from sector x. Since the restricted sets U_{x-y} and U_{y-x} are disjoint, user u may simultaneously communicate with both sectors x and y (and with no interference from strong interferers in both sectors) for soft or softer handoff. User u may also perform hard handoff from sector x to sector y. Since restricted sets U_{x-y} and U_{y-x} are absent of strong interferers from sectors y and x, respectively, the received SINR of user u may not change quite as abruptly when user u is handed off from sector x to sector y, which can ensure a smooth handoff.

[0073] Power control may or may not be used in combination with restrictive reuse. Power control adjusts the transmit power for a data transmission such that the received SINR for the transmission is maintained at a target SINR, which may in turn be adjusted to achieve a particular level of performance, e.g., 1% packet error rate (PER). Power control may be used to adjust the amount of transmit power used for a given data rate, so that interference is minimized. Power control be used for certain (e.g., fixed rate) transmissions and omitted for other (e.g., variable rate) transmissions. Full transmit power may be used for a variable rate transmission (such as a hybrid automatic

retransmission (H-ARQ), which is continual transmission of additional redundancy information for each packet until the packet is decoded correctly) in order to achieve the highest rate possible for a given channel condition.

[0074] In the above embodiment for restrictive reuse, each sector is associated with one usable set and one forbidden set. Some other embodiments of restrictive reuse are described below.

[0075] In another embodiment of restrictive reuse, each sector x is assigned an unrestricted usable subband set U_x and a "limited use" subband set L_x. The unrestricted usable set contains subbands that may be allocated to any users in the sector. The limited use set contains subbands having certain use restrictions such as, e.g., a lower transmit power limit. Sets U_x and L_x may be formed in the manner described above for sets U_x and F_x, respectively.

[0076] Each sector x may allocate the subbands in sets U_x and L_x by taking into account the channel conditions for the users so that good performance may be achieved for all users. The subbands in set U_x may be allocated to any user in sector x. Weak users in sector x may be allocated subbands in (1) a restricted set $U_{x-y} = U_x \cap L_y$, if high interference is observed from neighboring sector y, (2) a restricted set $U_{x-z} = U_x \cap L_z$, if high interference is observed from neighboring sector z, or (3) a restricted set $U_{x-yz} = U_x \cap L_y \cap L_z$, if high interference is observed from neighboring sectors y and z. Strong users in sector x may be allocated subbands in L_x.

[0077] A strong user v in sector x has a good signal quality metric for its serving sector x and may be allocated subbands in the limited use set L_x. On the forward link, sector x may transmit at or below the lower power limit for set L_x to strong user v. On the reverse link, strong user v may transmit at or below the lower power limit to serving sector x. Good performance may be achieved for strong user v for both the forward and reverse links, even with the lower transmit power, because of the good signal quality metric achieved by strong user v for sector x.

[0078] Strong user v typically has poor signal quality metrics for neighboring sectors. On the forward link, the lower transmit power used by sector x for strong user v causes low (and typically tolerable) levels of interference to users in neighboring sectors. On the reverse link, the lower transmit power used by strong user v plus the lower channel gains for neighboring sectors result in low (and typically tolerable) levels of interference to the users in the neighboring sectors.

[0079] In yet another embodiment of restrictive reuse, each reuse set is associated with a sorted list of subband sets that may be used for the reuse set. Due to frequency planning restrictions, the bandwidth of some restricted sets may be quite small, such as restricted set $U_{1\text{-}23}$ which corresponds to reuse set (**1**,2,3). Suppose user *u* observes high interference from sectors 2 and 3 and is assigned to reuse set (**1**,2,3). Although user *u* will experience higher SINR due to reduced interference, the bandwidth loss resulting from a restriction to a small restricted set $U_{1\text{-}23}$ may be detrimental in terms of the achievable throughput of user *u*. Hence, for users in reuse set (**1**,2,3), a sorted list of subband sets with descending preference may be defined, e.g., ($U_{1\text{-}23}$, [$U_{1\text{-}2}$, $U_{1\text{-}3}$], U_1), where the subband sets within the square brackets have equal preference. The users in reuse set (**1**,2,3) may then use larger bandwidth, if necessary, by using additional subband sets in the sorted list associated with reuse set (**1**,2,3). For users in reuse set (**1**,2), the sorted list may be ($U_{1\text{-}2}$, U_1, $U_{1\text{-}3}$, $U_{1\text{-}23}$). For users in reuse set (**1**), the sorted list may be (U_1, [$U_{1\text{-}2}$, $U_{1\text{-}3}$], $U_{1\text{-}23}$). The sorted list for each reuse set may be defined to (1) reduce the amount of interference observed by the users in the reuse set and/or (2) reduce the amount of interference caused by the users in the reuse set.

[0080] In still yet another embodiment of restrictive reuse, each sector *x* is assigned multiple (M) usable sets and multiple (e.g., M) forbidden sets. The number of usable sets may or may not be equal to the number of forbidden sets. As an example, multiple (M) pairs of usable and forbidden sets may be formed, with the usable set U_x and the forbidden set F_x in each pair being formed such that each of the N total subbands is included in only set U_x or set F_x, e.g., $\Omega = U_x \cup F_x$, where "$\cup$" denotes a union set operation. However, in general, the M usable sets and M forbidden sets may be formed in various manners.

[0081] For example, the M usable sets may be formed such that they are successively smaller subsets of the largest usable set. Each sector may then use the smallest possible usable set based on its loading. This may reduce the total interference to neighboring sectors when the sector is partially loaded. This may also increase the variation in the interference observed by neighboring sectors, which may be exploited to improve overall system performance.

[0082] The M forbidden sets may be formed such that they are non-overlapping. The number of weaker users in each sector and their data requirements are typically not known *a priori*. Each sector may utilize as many forbidden sets for neighboring sectors

as required to support its weak users. For example, sector *x* may utilize subbands in more forbidden sets for sector *y* to provide higher data rates to one or more weak users in sector *x* observing high interference from sector *y*, or to support more of these weak users. The sectors may coordinate usage of the forbidden sets.

[0083] In general, each sector may be assigned any number of unrestricted usable subband sets and any number of "constrained" subband sets. A constrained subband set may be a forbidden subband set or a limited use subband set. As an example, a sector may be assigned multiple constrained subband sets. One constrained subband set may be a forbidden subband set, and the remaining constrained subband set(s) may have different transmit power limits and may be allocated to different tiers of strong users. As another example, a sector may be assigned multiple constrained subband sets, where each constrained subband set may have a different transmit power limit (i.e., no forbidden set). The use of multiple usable and/or constrained sets for each sector may allow for better matching of subbands to weak users in different sectors.

[0084] For clarity, restrictive reuse has been specifically described for a system with 3-sector cells. In general, restrictive reuse may be used with any reuse pattern. For a K-sector/cell reuse pattern, the forbidden set for each sector/cell may be defined such that it overlaps with the forbidden set for each of the other $K-1$ sectors/cells, and may overlap with different combinations of other forbidden sets. Each sector/cell may form different restricted sets for different neighboring sectors based on its usable set and the forbidden sets for the neighboring sectors. Each sector/cell may then use the usable and restricted sets as described above.

[0085] Restrictive reuse has also been described for an OFDMA system. Restrictive reuse may also be used for a TDMA system, a Frequency Division Multiple Access (FDMA) system, a CDMA system, a multi-carrier CDMA system, an Orthogonal Frequency Division Multiple Access (OFDMA) system, and so on. A TDMA system uses time division multiplexing (TDM), and transmissions for different users are orthogonalized by transmitting in different time intervals. An FDMA system uses frequency division multiplexing (FDM), and transmissions for different users are orthogonalized by transmitting in different frequency channels or subbands. In general, the system resources to be reused (e.g., frequency subbands/channels, time slots, and so on) may be partitioned into usable and forbidden sets. The forbidden sets for neighboring sectors/cells overlap one another, as described above. Each sector may

form restricted sets based on its usable set and the forbidden sets for neighboring sectors/cells, as described above.

[0086] Restrictive reuse may be used for a Global System for Mobile Communications (GSM) system. A GSM system may operate in one or more frequency bands. Each frequency band covers a specific range of frequencies and is divided into a number of 200 kHz radio frequency (RF) channels. Each RF channel is identified by a specific ARFCN (absolute radio frequency channel number). For example, the GSM 900 frequency band covers ARFCNs 1 through 124, the GSM 1800 frequency band covers ARFCNs 512 through 885, and the GSM 1900 frequency band covers ARFCNs 512 through 810. Conventionally, each GSM cell is assigned a set of RF channels and only transmits on the assigned RF channels. To reduce inter-cell interference, GSM cells located near each other are normally assigned different sets of RF channels such that the transmissions for neighboring cells do not interfere with one another. GSM typically employs a reuse factor greater than one (e.g., $K = 7$).

[0087] Restrictive reuse may be used to improve efficiency and reduce inter-sector interference for a GSM system. The available RF channels for the GSM system may be used to form K pairs of usable and forbidden sets (e.g., $K = 7$), and each GSM cell may be assigned one of the K set pairs. Each GSM cell may then allocate RF channels in its usable set to users in the cell and RF channels in its restricted sets to weak users. Restrictive reuse allows each GSM cell to use a larger percentage of the available RF channels, and a reuse factor closer to one may be achieved.

[0088] Restrictive reuse may also be used for a multi-carrier communication system that utilizes multiple "carriers" for data transmission. Each carrier is a sinusoidal signal that may be independently modulated with data and is associated with a particular bandwidth. One such system is a multi-carrier IS-856 system (also called 3x-DO (data-only)) that has multiple 1.23 MHz carriers. Each sector/cell in the system may be allowed to use all carriers or only a subset of the carriers. A sector/cell may be forbidden to use a given carrier to avoid causing interference on the carrier, which may allow other sectors/cells using this carrier to observe less (or no) interference, achieve higher SINR, and attain better performance. Alternatively, a sector/cell may be constrained to use a lower transmit power limit on a given carrier to reduce interference on the carrier. For each sector, the constrained (forbidden or limited use) carrier(s) may be statically or dynamically assigned.

[0089] Each sector may assign its users to its usable carrier(s). Each sector may also assign each user to a carrier in a manner to avoid strong interferers/ees for the user. For example, if multiple usable carriers are available, then a user may be assigned one of the carriers having less interference for the user (e.g., a carrier not used by a strong interferer to the user).

[0090] The processing for data transmission and reception with restrictive reuse is dependent on system design. For clarity, exemplary transmitting and receiving entities in a frequency hopping OFDMA system for the restrictive reuse embodiment with a pair of usable and forbidden subband sets for each sector are described below.

[0091] **FIG. 9** shows a block diagram of an embodiment of a transmitting entity 110x, which may be the transmit portion of a base station or a terminal. Within transmitting entity 110x, an encoder/modulator 914 receives traffic/packet data from a data source 912 for a given user *u*, processes (e.g., encodes, interleaves, and modulates) the data based on a coding and modulation scheme selected for user *u*, and provides data symbols, which are modulation symbols for data. Each modulation symbol is a complex value for a point in a signal constellation for the selected modulation scheme. A symbol-to-subband mapping unit 916 provides the data symbols for user *u* onto the proper subbands determined by an FH control, which is generated by an FH generator 940 based on the traffic channel assigned to user *u*. FH generator 940 may be implemented with look-up tables, pseudo-random number (PN) generators, and so on. Mapping unit 916 also provides pilot symbols on subbands used for pilot transmission and a signal value of zero for each subband not used for pilot or data transmission. For each OFDM symbol period, mapping unit 916 provides N transmit symbols for the N total subbands, where each transmit symbol may be a data symbol, a pilot symbol, or a zero-signal value.

[0092] An OFDM modulator 920 receives N transmit symbols for each OFDM symbol period and generates a corresponding OFDM symbol. OFDM modulator 920 typically includes an inverse fast Fourier transform (IFFT) unit and a cyclic prefix generator. For each OFDM symbol period, the IFFT unit transforms the N transmit symbols to the time domain using an N-point inverse FFT to obtain a "transformed" symbol that contains N time-domain chips. Each chip is a complex value to be transmitted in one chip period. The cyclic prefix generator then repeats a portion of each transformed symbol to form an OFDM symbol that contains $N + C$ chips, where C is the number of chips being repeated. The repeated portion is often called a cyclic

prefix and is used to combat inter-symbol interference (ISI) caused by frequency selective fading. An OFDM symbol period corresponds to the duration of one OFDM symbol, which is $N + C$ chip periods. OFDM modulator 920 provides a stream of OFDM symbols. A transmitter unit (TMTR) 922 processes (e.g., converts to analog, filters, amplifies, and frequency upconverts) the OFDM symbol stream to generate a modulated signal, which is transmitted from an antenna 924.

[0093] Controller 930 directs the operation at transmitting entity 110x. Memory unit 932 provides storage for program codes and data used by controller 930.

[0094] **FIG. 10** shows a block diagram of an embodiment of a receiving entity 120x, which may be the receive portion of a base station or a terminal. One or more modulated signals transmitted by one or more transmitting entities are received by an antenna 1012, and the received signal is provided to and processed by a receiver unit (RCVR) 1014 to obtain samples. The set of samples for one OFDM symbol period represents one received OFDM symbol. An OFDM demodulator (Demod) 1016 processes the samples and provides received symbols, which are noisy estimates of the transmit symbols sent by the transmitting entities. OFDM demodulator 1016 typically includes a cyclic prefix removal unit and an FFT unit. The cyclic prefix removal unit removes the cyclic prefix in each received OFDM symbol to obtain a received transformed symbol. The FFT unit transforms each received transformed symbol to the frequency domain with an N-point FFT to obtain N received symbols for the N subbands. A subband-to-symbol demapping unit 1018 obtains the N received symbols for each OFDM symbol period and provides received symbols for the subbands assigned to user *u*. These subbands are determined by an FH control generated by an FH generator 1040 based on the traffic channel assigned to user *u*. A demodulator/ decoder 1020 processes (e.g., demodulates, deinterleaves, and decodes) the received symbols for user *u* and provides decoded data to a data sink 1022 for storage.

[0095] A controller 1030 directs the operation at receiving entity 120x. A memory unit 1032 provides storage for program codes and data used by controller 1030.

[0096] For restrictive reuse, each sector (or a scheduler in the system) selects users for data transmission, identifies the strong interferers/ees for the selected users, determines the usable or restricted set for each selected user based on its strong interferers/ees (if any), and allocates subbands (or assigns traffic channels) from the proper sets to the selected users. Each sector then provides each user with its assigned traffic channel, e.g., via over-the-air signaling. The transmitting and receiving entities

for each user then perform the appropriate processing to transmit and receive data on the subbands indicated by the assigned traffic channel.

[0097] The restrictive reuse 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 identify strong interferers/ees, determine restricted sets, allocate subbands, process data for transmission or reception, and perform other functions related to restrictive reuse 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.

[0098] For a software implementation, the restrictive reuse 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 932 in FIG. 9 or memory unit 1032 in FIG. 10) and executed by a processor (e.g., controller 930 in FIG. 9 or 1030 in FIG. 10). The memory unit may be implemented within the processor or external to the processor.

[0099] 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.

WHAT IS CLAIMED IS:

CLAIMS

1. A method of allocating system resources in a wireless communication system, comprising:

identifying strong interference entities, if any, for each of at least one terminal in communication with a current base station, each strong interference entity being an entity with which mitigation of interference is sought; and

allocating system resources to the at least one terminal based on the strong interference entities, if any, identified for the at least one terminal.

2. The method of claim 1, wherein each strong interference entity for each terminal is another base station deemed to cause high interference to the terminal on a forward link.

3. The method of claim 1, wherein each strong interference entity for each terminal is another base station deemed to observe high interference from the terminal on a reverse link.

4. The method of claim 1, wherein each strong interference entity for each terminal is another terminal deemed to cause high interference to the terminal on a reverse link.

5. The method of claim 1, wherein each terminal is allocated system resources not used by the strong interference entities, if any, identified for the terminal.

6. The method of claim 1, wherein the current base station is assigned a set of usable system resources and a set of unusable system resources, and wherein the system resources allocated to the at least one terminal are taken from the set of usable system resources.

7. The method of claim 6, wherein each strong interference entity is associated with a set of system resources that is unusable by the strong interference entity.

8. The method of claim 7, further comprising:

determining a set of system resources usable for each of the at least one terminal based on the set of usable system resources assigned to the current base station and sets of system resources unusable by the strong interference entities, if any, identified for the terminal, and wherein each terminal is allocated system resources from the set of system resources usable for the terminal.

9. The method of claim 8, wherein the set of system resources usable for each terminal is determined based on an intersection set operation between the set of usable system resources assigned to the current base station and each of the sets of system resources unusable by the strong interference entities, if any, identified for the terminal.

10. The method of claim 7, further comprising:

determining a list of resource sets for each of the at least one terminal, wherein the resource sets in the list for each terminal are formed based on different combinations of the set of usable system resources assigned to the current base station and sets of system resources unusable by the strong interference entities, if any, identified for the terminal, and wherein each terminal is allocated system resources from the resource sets in the list determined for the terminal.

11. The method of claim 10, wherein the resource sets in the list for each terminal are ordered to reduce interference caused or observed by the terminal, and wherein each terminal is allocated system resources from one or more of the ordered resource sets in the list determined for the terminal.

12. The method of claim 1, wherein the current base station is assigned a set of usable system resources and a set of constrained system resources, and wherein full transmit power is allowed for the usable system resources and reduced transmit power is allowed for the constrained system resources.

13. The method of claim 1, wherein each terminal is associated with a set containing strong interference entities, if any, identified for the terminal.

14. The method of claim 1, wherein each strong interference entity for each terminal is determined based on a signal quality metric achieved by the terminal for the strong interference entity.

15. The method of claim 1, wherein each strong interference entity for each terminal is determined based on received pilot power measured at the terminal for the strong interference entity.

16. The method of claim 1, wherein each strong interference entity for each terminal is determined based on a channel gain between the terminal and the strong interference entity.

17. The method of claim 1, wherein each strong interference entity for each terminal is determined based on a signal-to-interference-and-noise ratio (SINR) achieved by the terminal for the strong interference entity.

18. The method of claim 1, wherein the system resources allocated to the at least one terminal are used for data transmission on a reverse link.

19. The method of claim 1, wherein the system resources allocated to the at least one terminal are used for data transmission on a forward link.

20. The method of claim 1, wherein the wireless communication system utilizes orthogonal frequency division multiplexing (OFDM), and wherein the system resources allocated to the at least one terminal are frequency subbands obtained via OFDM.

21. The method of claim 1, wherein the system resources allocated to the at least one terminal are radio frequency (RF) channels.

22. The method of claim 1, wherein the wireless communication system is an orthogonal frequency division multiple access (OFDMA) system utilizing frequency hopping.

23. A method of allocating frequency subbands in a wireless communication system utilizing orthogonal frequency division multiplexing (OFDM), comprising:

identifying strong neighboring base stations, if any, for each of at least one terminal in communication with a current base station;

determining a set of frequency subbands usable for each of the at least one terminal based on a set of usable frequency subbands assigned to the current base station and sets of frequency subbands unusable by the strong neighboring base stations, if any, identified for the terminal; and

allocating to each of the at least one terminal frequency subbands selected from the set of frequency subbands usable for the terminal.

24. The method of claim 23, wherein each strong neighboring base station for each terminal is a base station deemed to cause high interference to the terminal, observe high interference from the terminal, or both cause high interference to and observe high interference from the terminal.

25. The method of claim 23, wherein each strong neighboring base station for each terminal is identified based on received pilot power measured at the terminal for the strong neighboring base station.

26. An apparatus operable to allocate system resources in a wireless communication system, comprising:

a controller operative to

identify strong interference entities, if any, for each of at least one terminal in communication with a current base station, each strong interference entity being an entity with which mitigation of interference is sought, and

allocate system resources to the at least one terminal based on the strong interference entities, if any, identified for the at least one terminal.

27. The apparatus of claim 26, wherein each terminal is allocated system resources not used by the strong interference entities, if any, identified for the terminal.

28. The apparatus of claim 26, wherein each strong interference entity for each terminal is a base station deemed to cause high interference to the terminal,

observe high interference from the terminal, or both cause high interference to and observe high interference from the terminal.

29. The apparatus of claim 26, wherein each strong interference entity for each terminal is determined based on received pilot power measured at the terminal for the strong interference entity.

30. The apparatus of claim 26, wherein the controller is further operative to

determine a set of system resources usable for each of the at least one terminal based on a set of usable system resources assigned to the current base station and sets of system resources unusable by the strong interference entities, if any, identified for the terminal, and

allocate to each terminal system resources from the set of system resources usable for the terminal.

31. An apparatus operable to allocate system resources in a wireless communication system, comprising:

means for identifying strong interference entities, if any, for each of at least one terminal in communication with a current base station, each strong interference entity being an entity with which mitigation of interference is sought; and

means for allocating system resources to the at least one terminal based on the strong interference entities, if any, identified for the at least one terminal.

32. The apparatus of claim 31, wherein each terminal is allocated system resources not used by the strong interference entities, if any, identified for the terminal.

33. The apparatus of claim 31, further comprising:

means for determining a set of system resources usable for each of the at least one terminal based on a set of usable system resources assigned to the current base station and sets of system resources unusable by the strong interference entities, if any, identified for the terminal, wherein the terminal is allocated system resources from the set of system resources usable for the terminal.

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

forming a plurality of sets of constrained system resources from among total available system resources, wherein each set of constrained system resources overlaps with each remaining one of the plurality of sets of constrained system resources;

forming a plurality of sets of usable system resources from among the total available system resources, wherein each set of usable system resources is associated with, and orthogonal to, at least one of the plurality of sets of constrained system resources; and

assigning the plurality of sets of usable system resources and the plurality of sets of constrained system resources to a plurality of base stations, wherein each base station is assigned one set of usable system resources and the at least one associated set of constrained system resources.

35. The method of claim 34, wherein each base station is permitted to use the set of usable system resources assigned to the base station for data transmission and is not permitted to use the at least one associated set of constrained system resources.

36. The method of claim 34, wherein full transmit power is allowed for the set of usable system resources assigned to each base station and reduced transmit power is allowed for the at least one associated set of constrained system resources.

37. The method of claim 34, wherein the total available system resources comprise a plurality of frequency subbands, and wherein each set of usable system resources and each set of constrained system resources is a different set of frequency subbands selected from among the plurality of frequency subbands.

38. The method of claim 34, wherein the total available system resources comprise a plurality of radio frequency (RF) carriers, and wherein each set of usable system resources and each set of constrained system resources is a different set of at least one carrier selected from among the plurality of RF carriers.

39. The method of claim 34, wherein the total available system resources comprise a plurality of radio frequency (RF) channels, and wherein each set of usable

system resources and each set of constrained system resources is a different set of at least one RF channel selected from among the plurality of RF channels.

40. The method of claim 34, wherein the plurality of sets of constrained system resources and the plurality of sets of usable system resources are dynamically formed and assigned to the plurality of base stations.

41. A method of processing data in a wireless communication system, comprising:

obtaining an allocation of system resources for a terminal, wherein the terminal is in communication with a current base station and is allocated system resources not used by strong interference entities, if any, identified for the terminal, and wherein each strong interference entity is an entity for which mitigation of interference with the terminal is sought; and

generating a control indicative of the system resources allocated to the terminal.

42. The method of claim 41, wherein the current base station is assigned a set of usable system resources, wherein each strong interference entity is associated with a set of system resources that is unusable by the strong interference entity, wherein a set of system resources usable for the terminal is determined based on the set of usable system resources assigned to the current base station and sets of system resources unusable by the strong interference entities, if any, identified for the terminal, and wherein the terminal is allocated system resources from the set of system resources usable for the terminal

43. The method of claim 41, further comprising:

receiving a data transmission sent using the system resources allocated to the terminal; and

processing the received data transmission in accordance with the control.

44. The method of claim 41, further comprising:

processing data for transmission in accordance with the control; and

sending a data transmission using the system resources allocated to the terminal.

45. The method of claim 41, wherein the system utilizes orthogonal frequency division multiplexing (OFDM), and wherein the system resources allocated to the terminal comprise one or more frequency subbands.

46. The method of claim 45, wherein the system utilizes frequency hopping, and wherein the control indicates different subbands to use for data transmission in different time intervals.

47. An apparatus in a wireless communication system, comprising:

a controller operative to obtain an allocation of system resources for a terminal, wherein the terminal is in communication with a current base station and is allocated system resources not used by strong interference entities, if any, identified for the terminal, and wherein each strong interference entity is an entity for which mitigation of interference with the terminal is sought; and

a generator operative to generate a control indicative of the system resources allocated to the terminal.

48. The apparatus of claim 47, further comprising:

a demodulator operative to receive a data transmission sent using the system resources allocated to the terminal; and

a processing unit operative to process the received data transmission in accordance with the control.

49. The apparatus of claim 47, further comprising:

a processing unit operative to process data for transmission in accordance with the control; and

a modulator operative to send a data transmission using the system resources allocated to the terminal.

50. An apparatus in a wireless communication system, comprising:

means for obtaining an allocation of system resources for a terminal, wherein the terminal is in communication with a current base station and is allocated system resources not used by strong interference entities, if any, identified for the terminal, and wherein each strong interference entity is an entity for which mitigation of interference with the terminal is sought; and

means for generating a control indicative of the system resources allocated to the terminal.

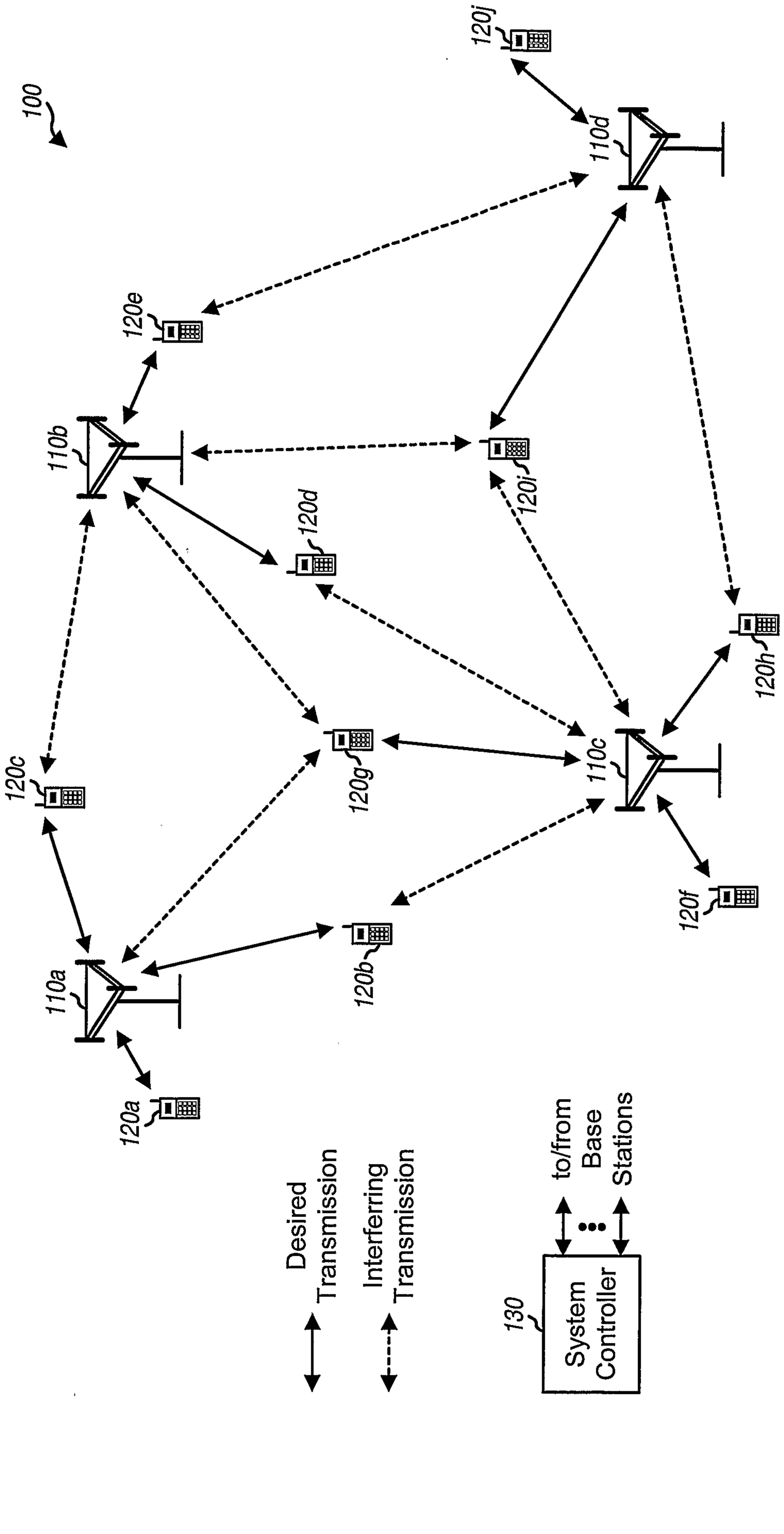

100
120j
110d
120e
110b
120d
120i
120h
120c
120g
110c
120f
110a
120b
120a
Desired Transmission
Interfering Transmission
130
System Controller
to/from Base Stations

FIG. 1

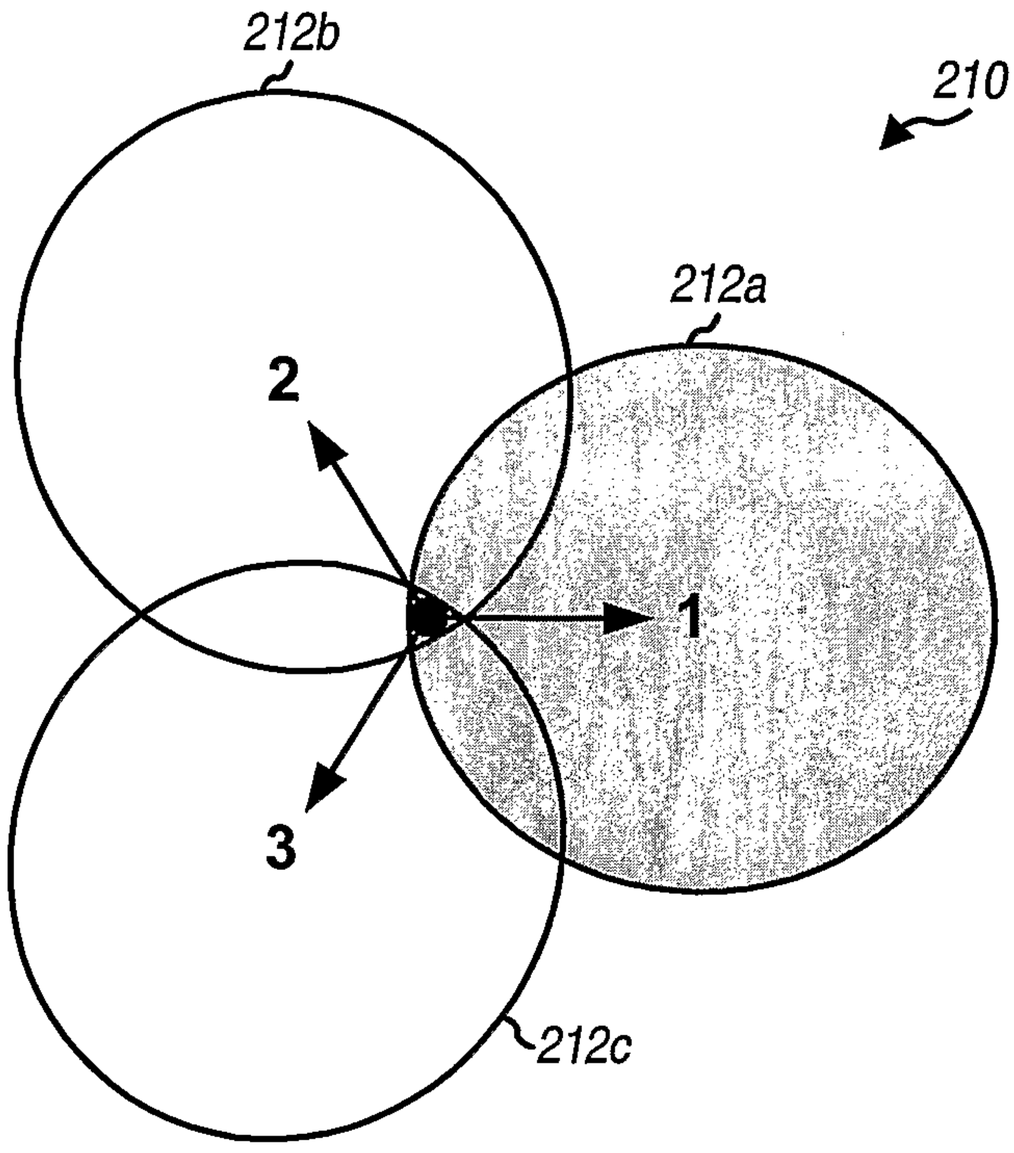


FIG. 2A

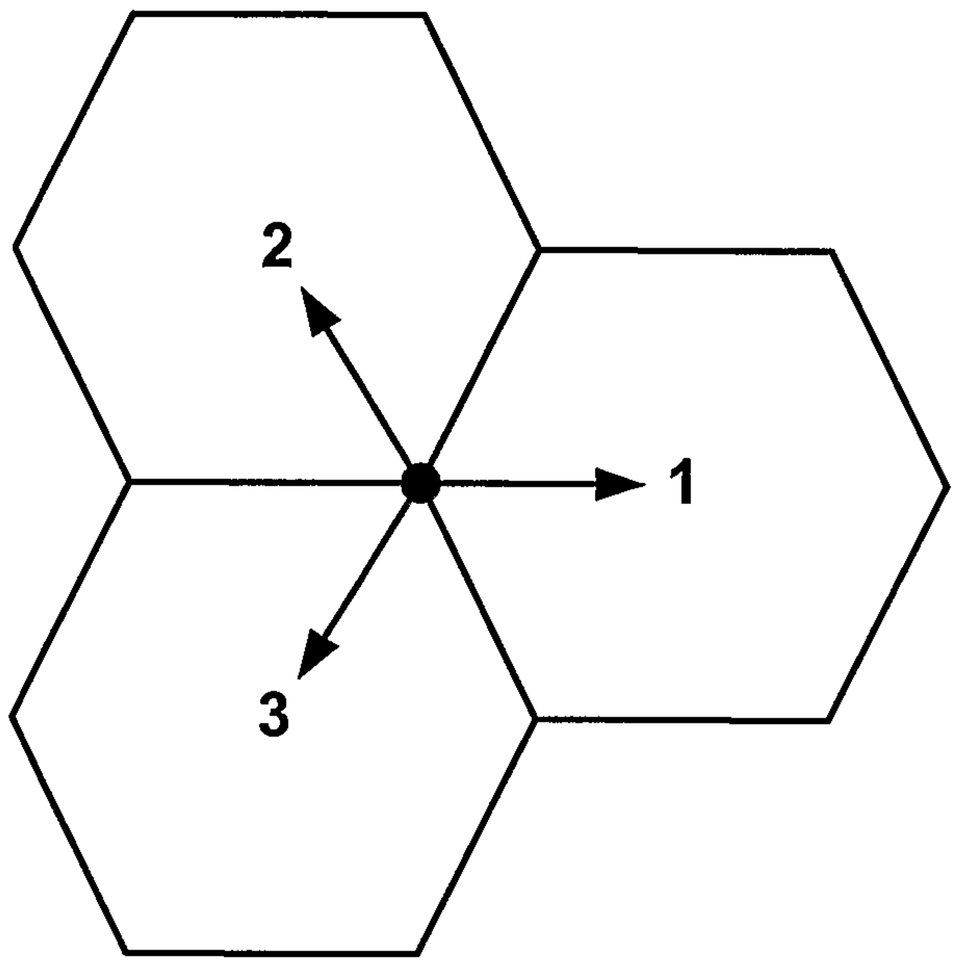


FIG. 2B

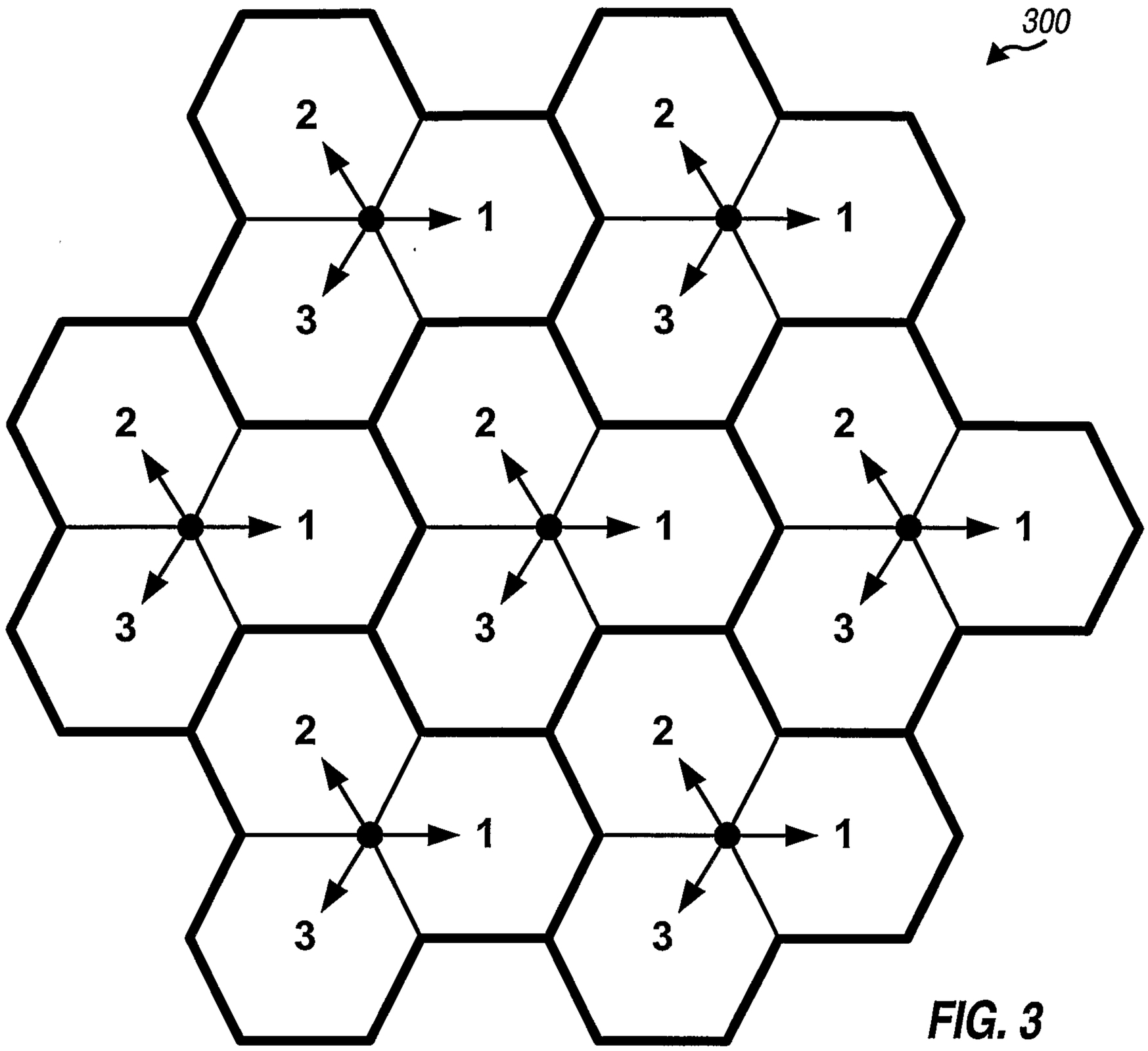


FIG. 3

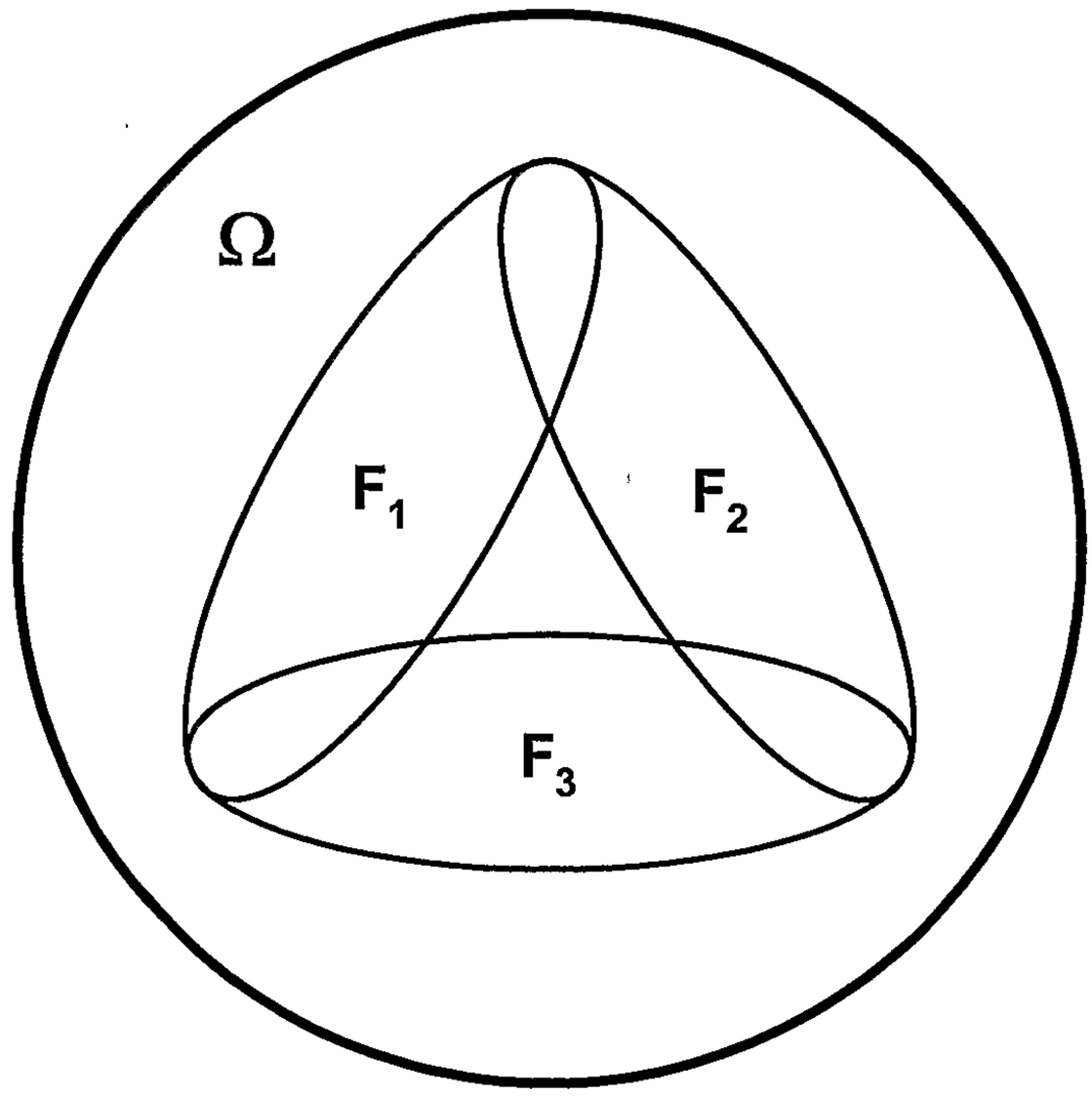


FIG. 4

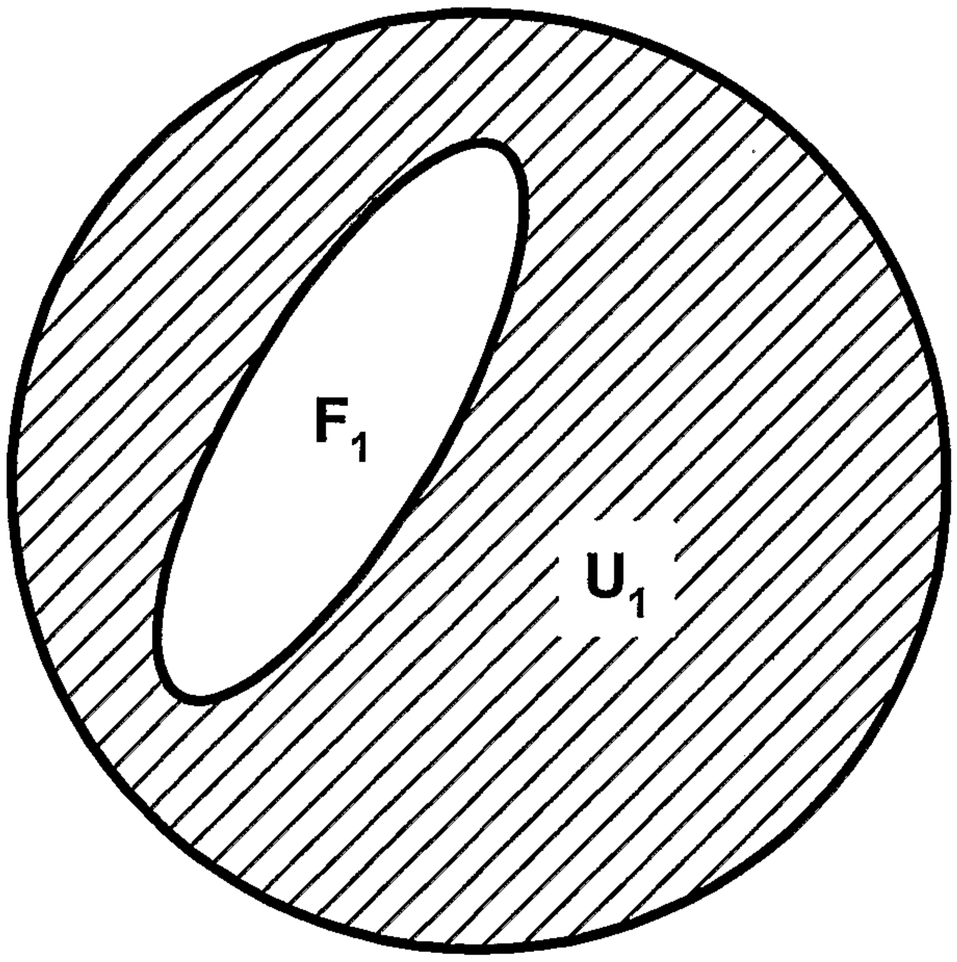


FIG. 5A

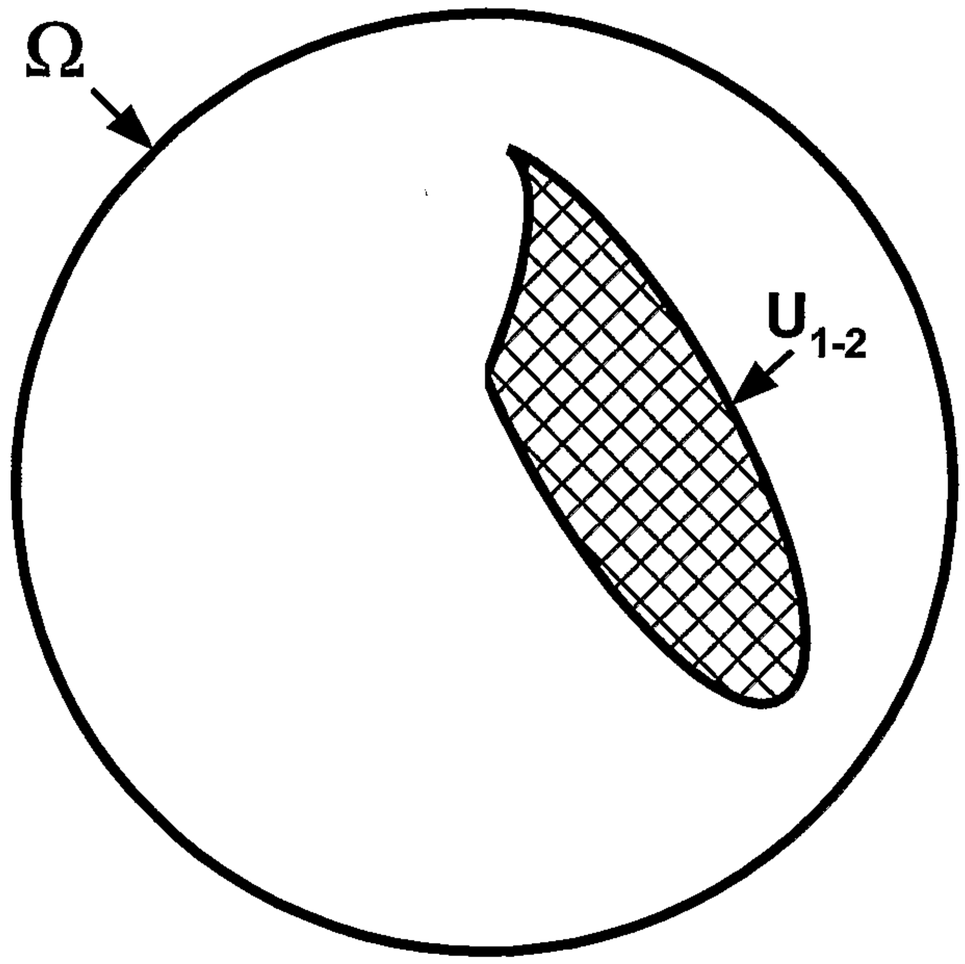


FIG. 5B

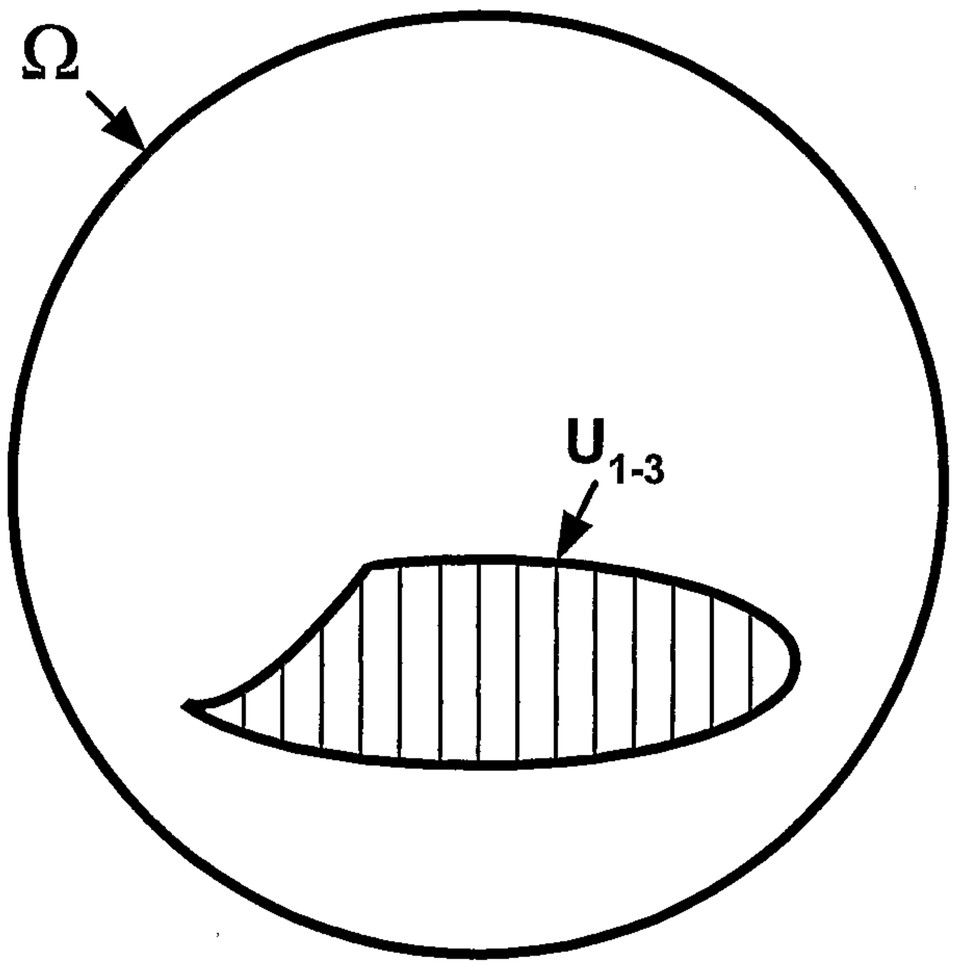


FIG. 5C

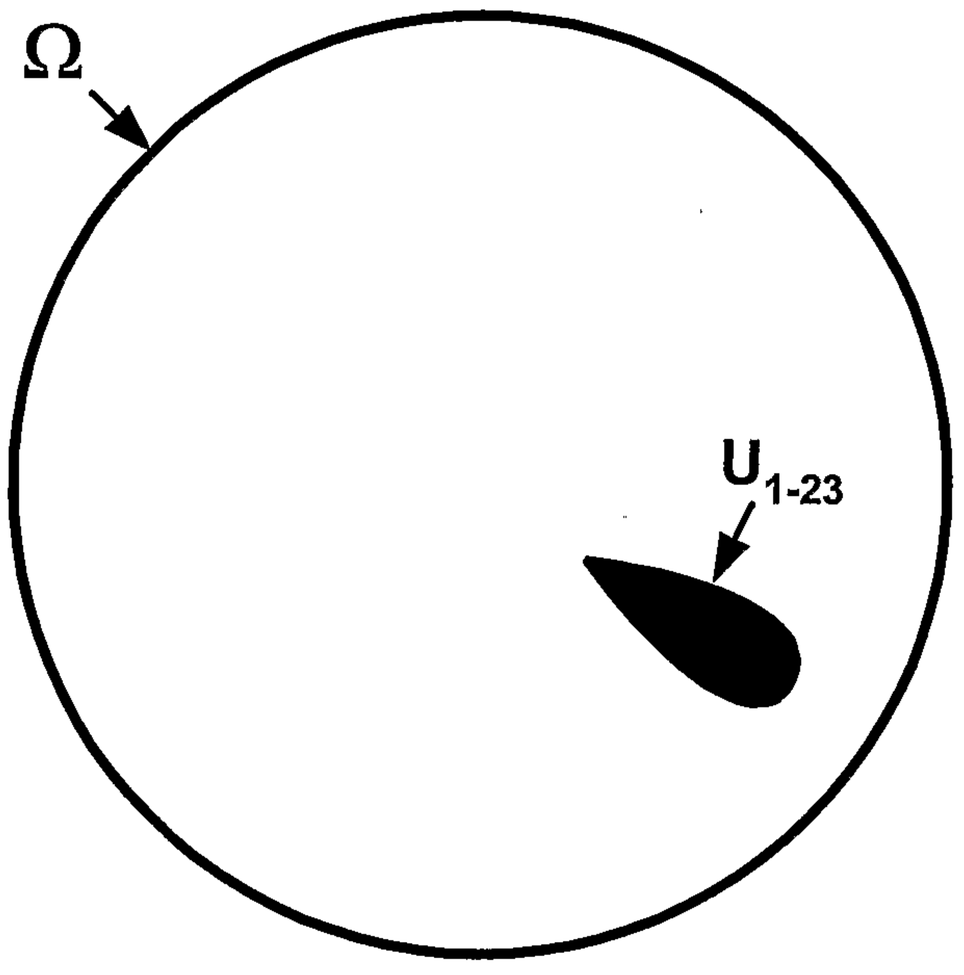


FIG. 5D

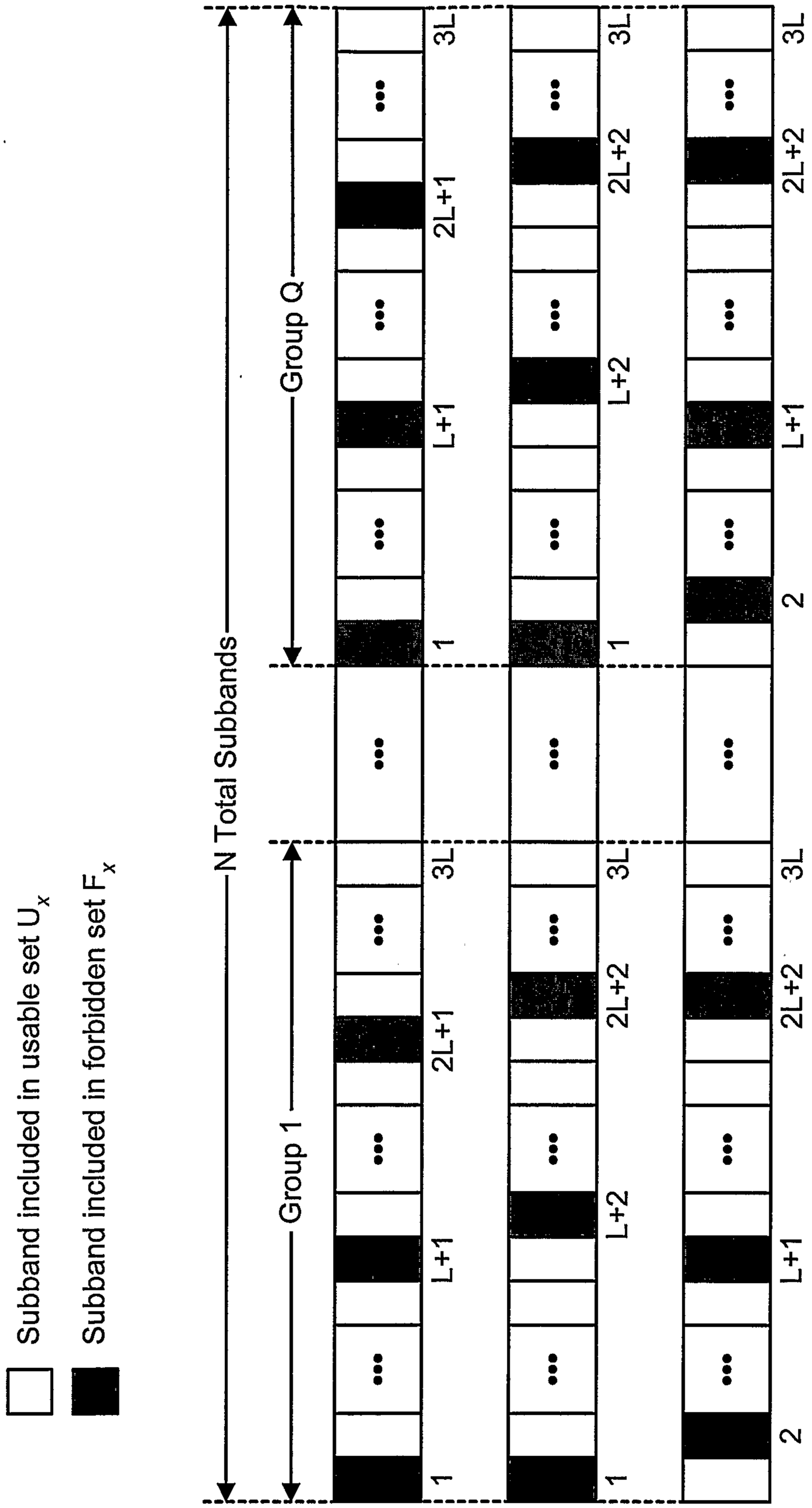

Subband included in usable set U_x
Subband included in forbidden set F_x
N Total Subbands
Group Q
Group 1
Sector 1
Sector 2
Sector 3
3L
2L+1
2L+2
L+1
L+2
1
2

FIG. 6

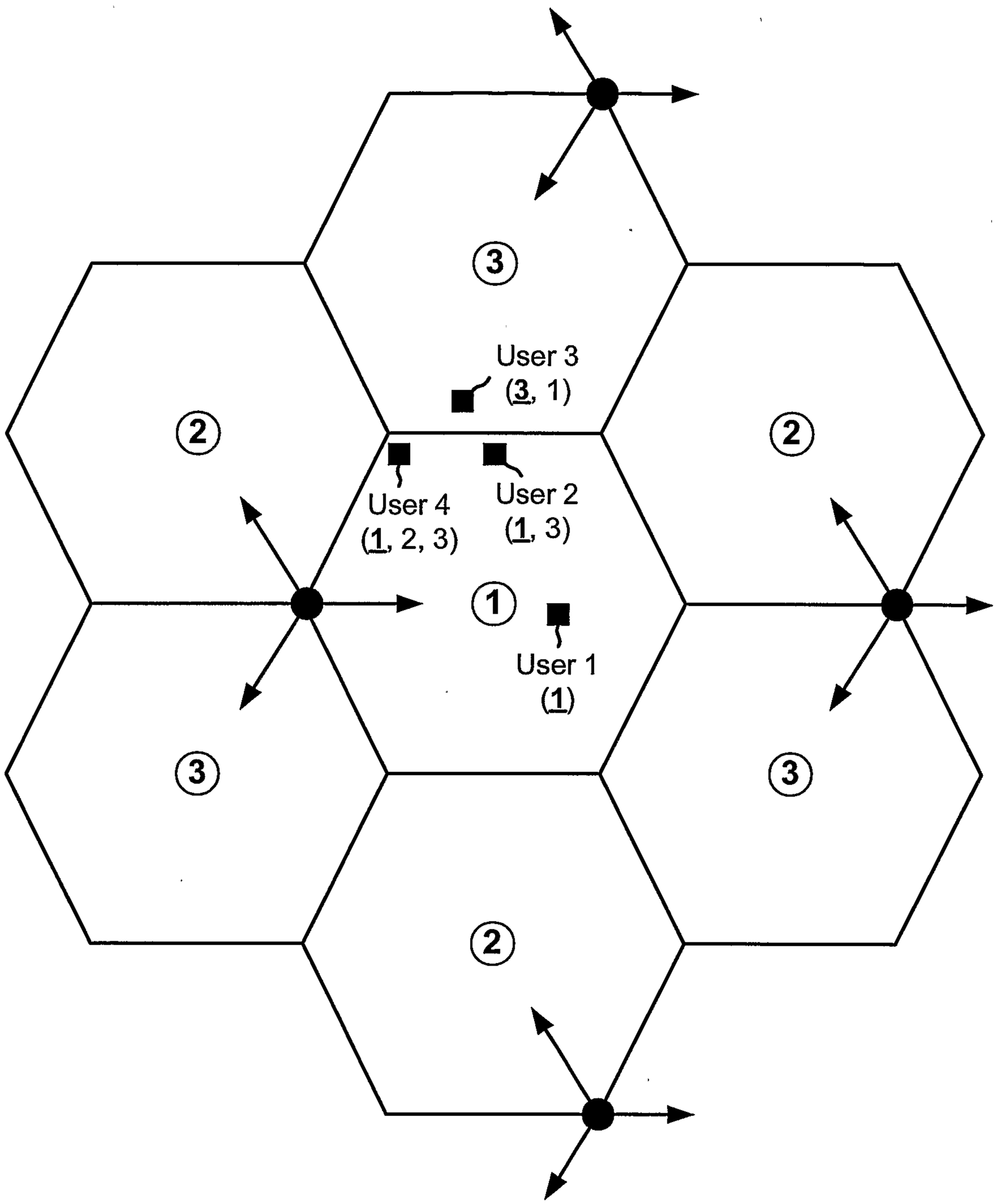
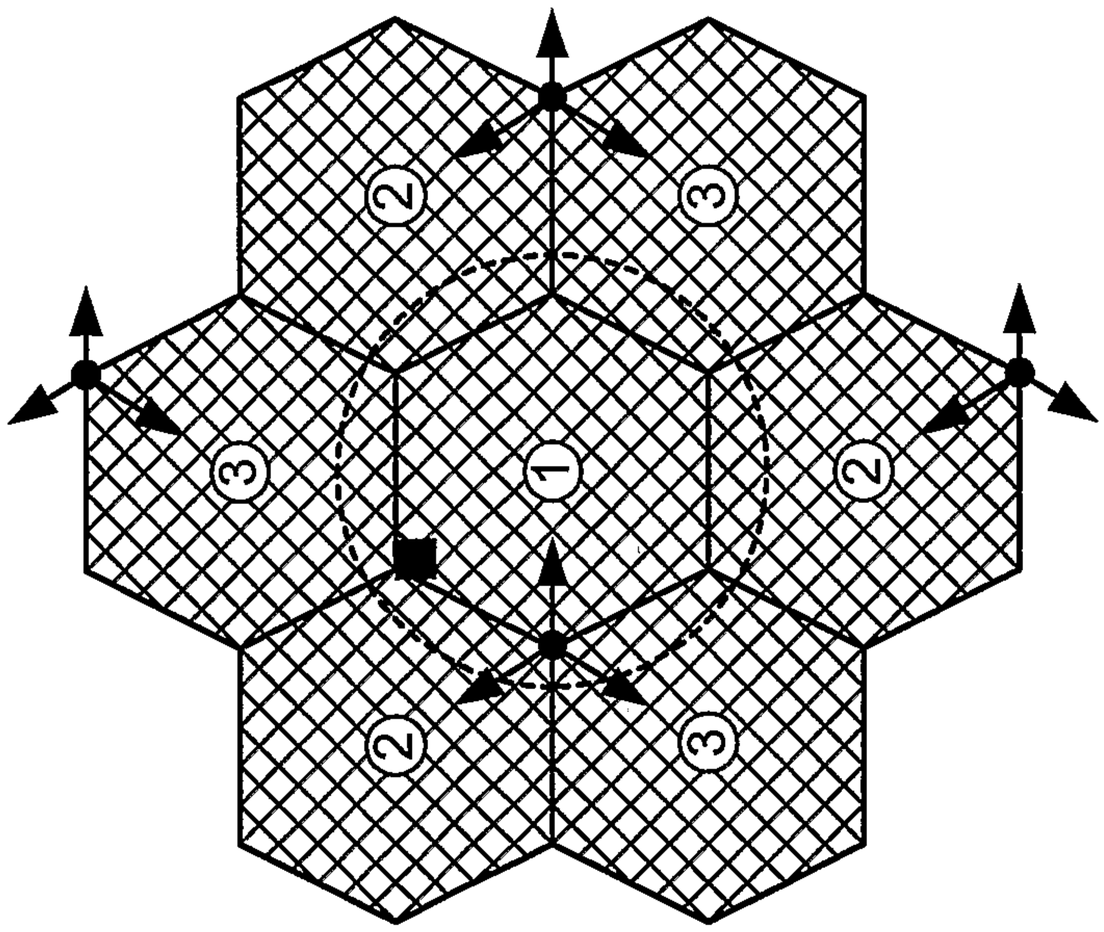
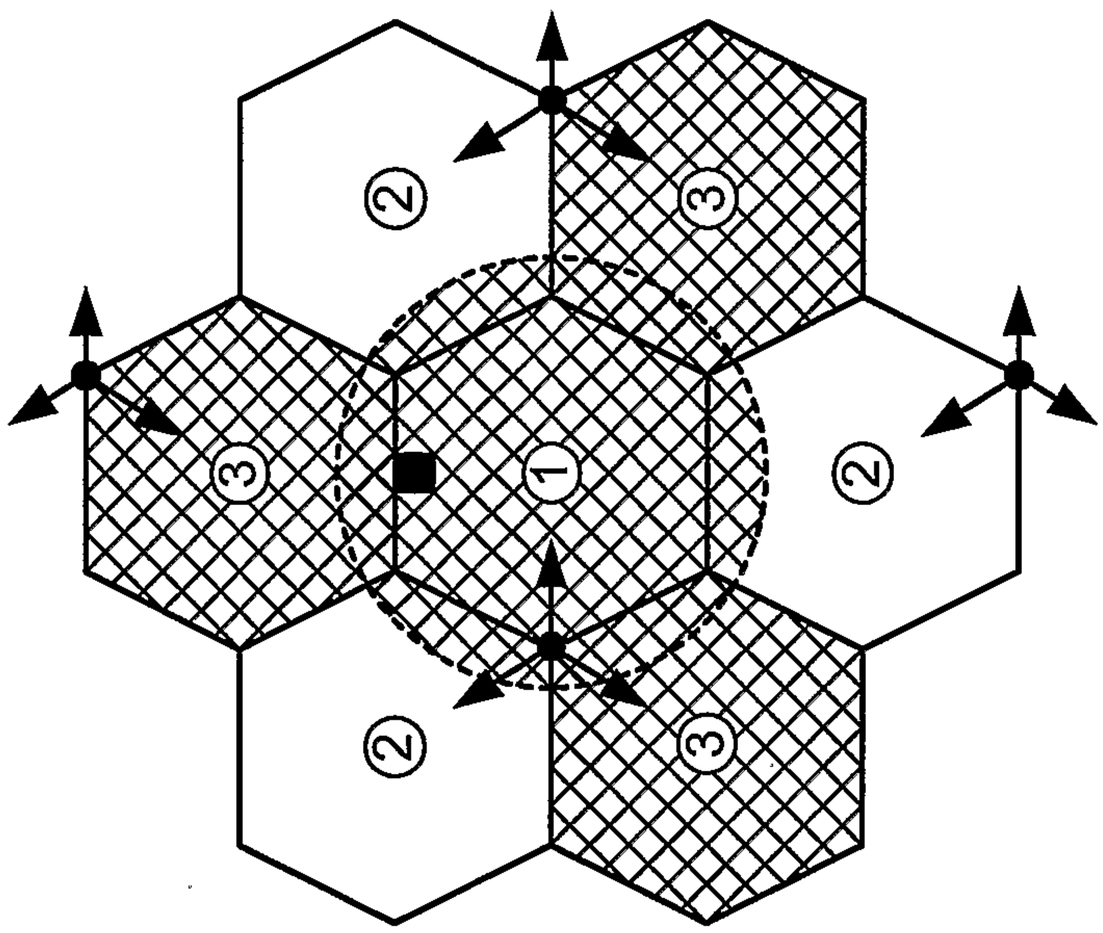


FIG. 7A



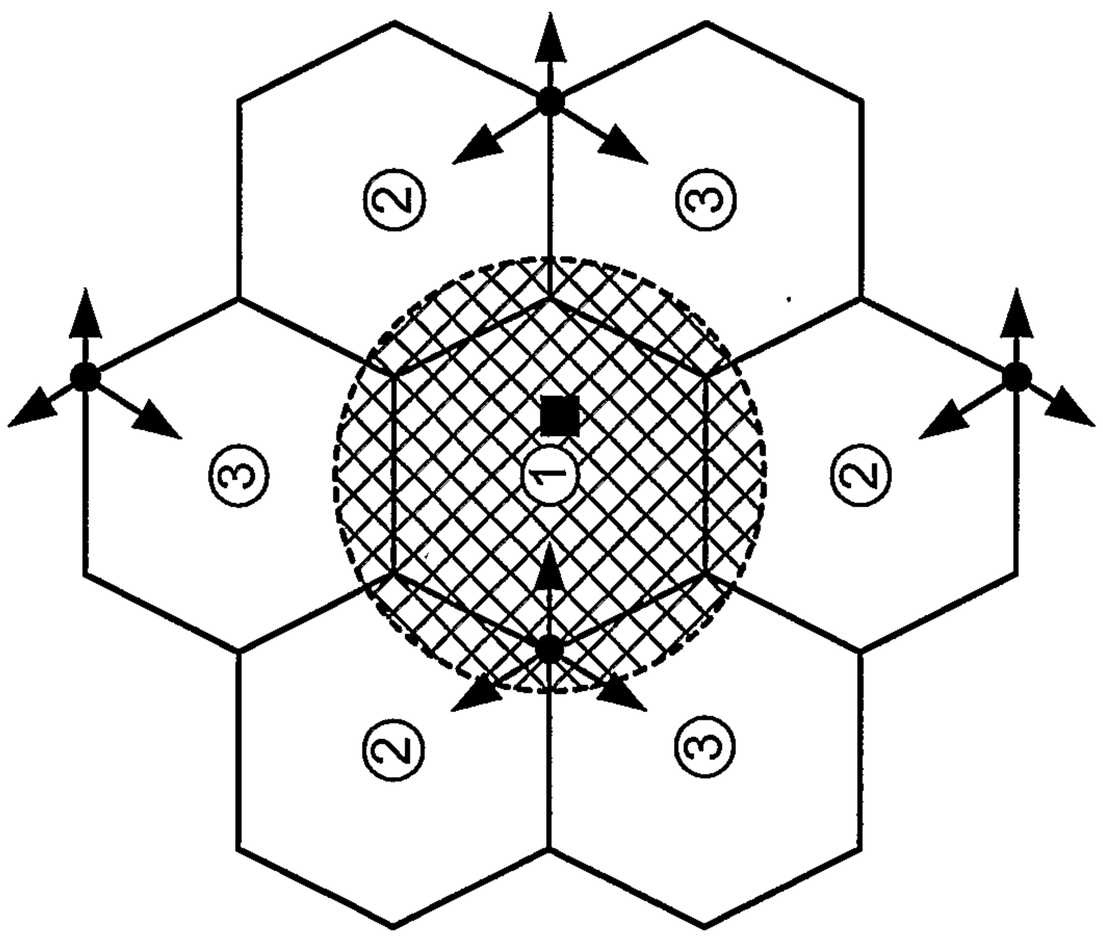
Non-Interference Pattern
User 4 with Reuse Set (1, 2, 3)

FIG. 7D



Non-Interference Pattern
User 2 with Reuse Set (1, 3)

FIG. 7C



Non-Interference Pattern
User 1 with Reuse Set (1)

FIG. 7B

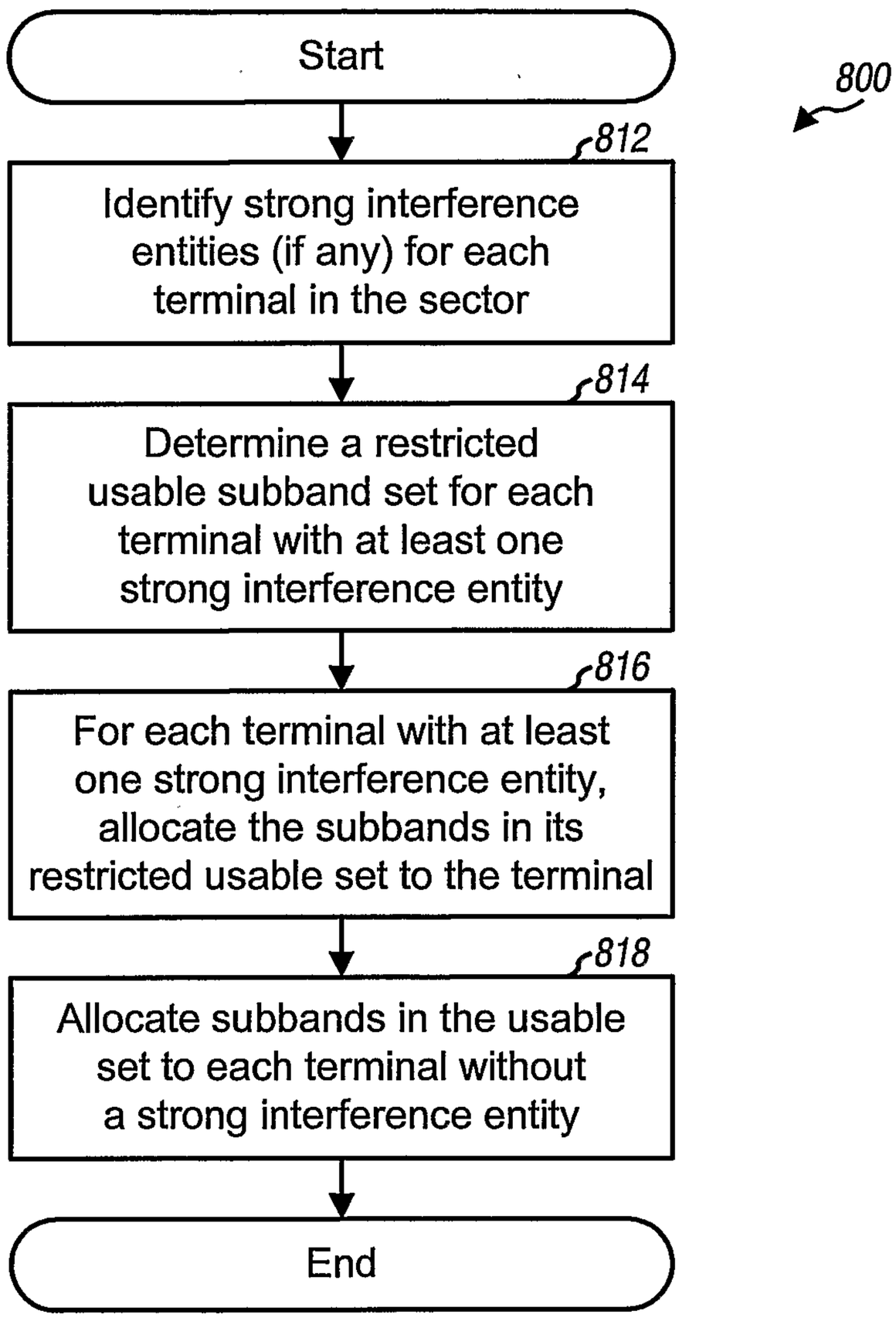

Start
800
812
Identify strong interference entities (if any) for each terminal in the sector
814
Determine a restricted usable subband set for each terminal with at least one strong interference entity
816
For each terminal with at least one strong interference entity, allocate the subbands in its restricted usable set to the terminal
818
Allocate subbands in the usable set to each terminal without a strong interference entity
End

FIG. 8

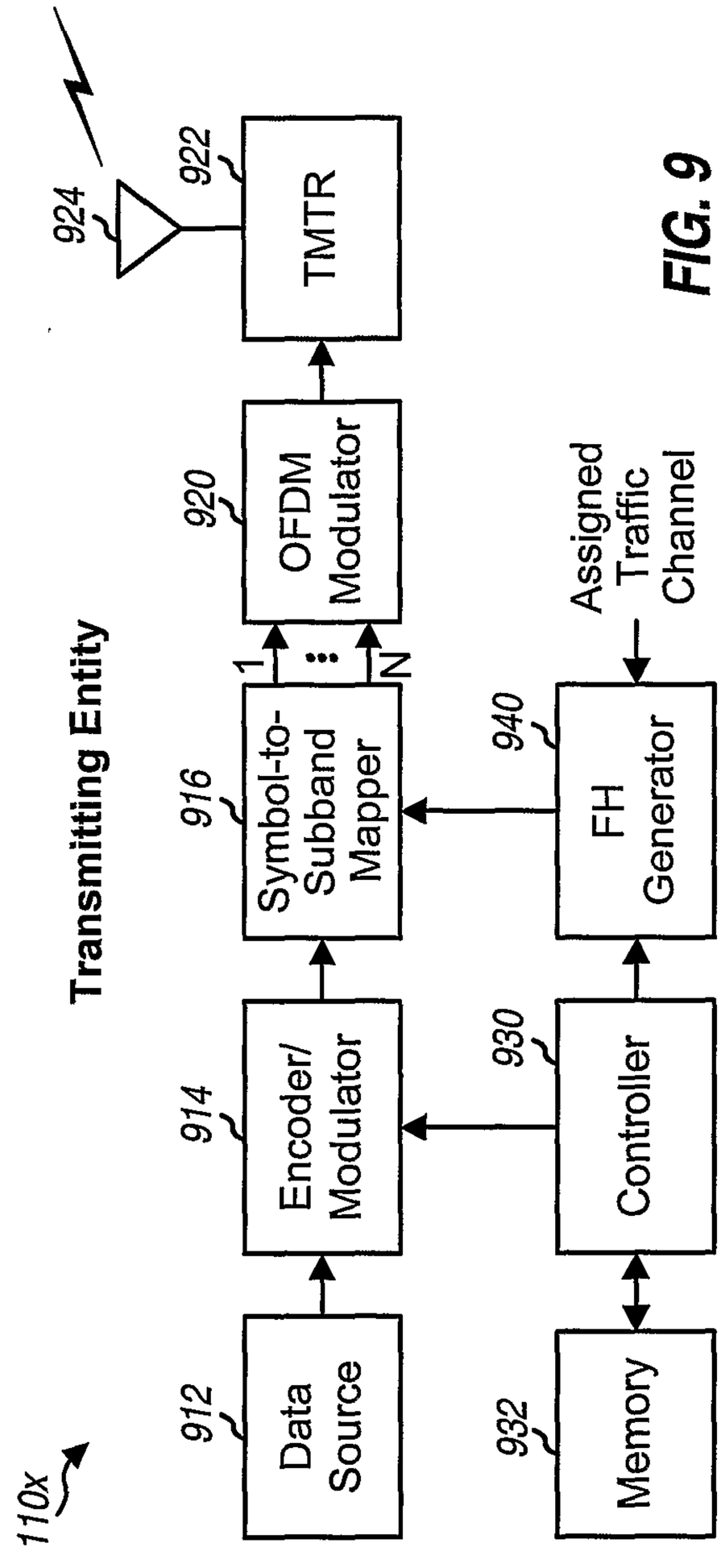

110x
Transmitting Entity
912
Data Source
914
Encoder/ Modulator
916
Symbol-to-Subband Mapper
920
OFDM Modulator
922
TMTR
924
930
Controller
932
Memory
940
FH Generator
Assigned Traffic Channel
1
N

FIG. 9

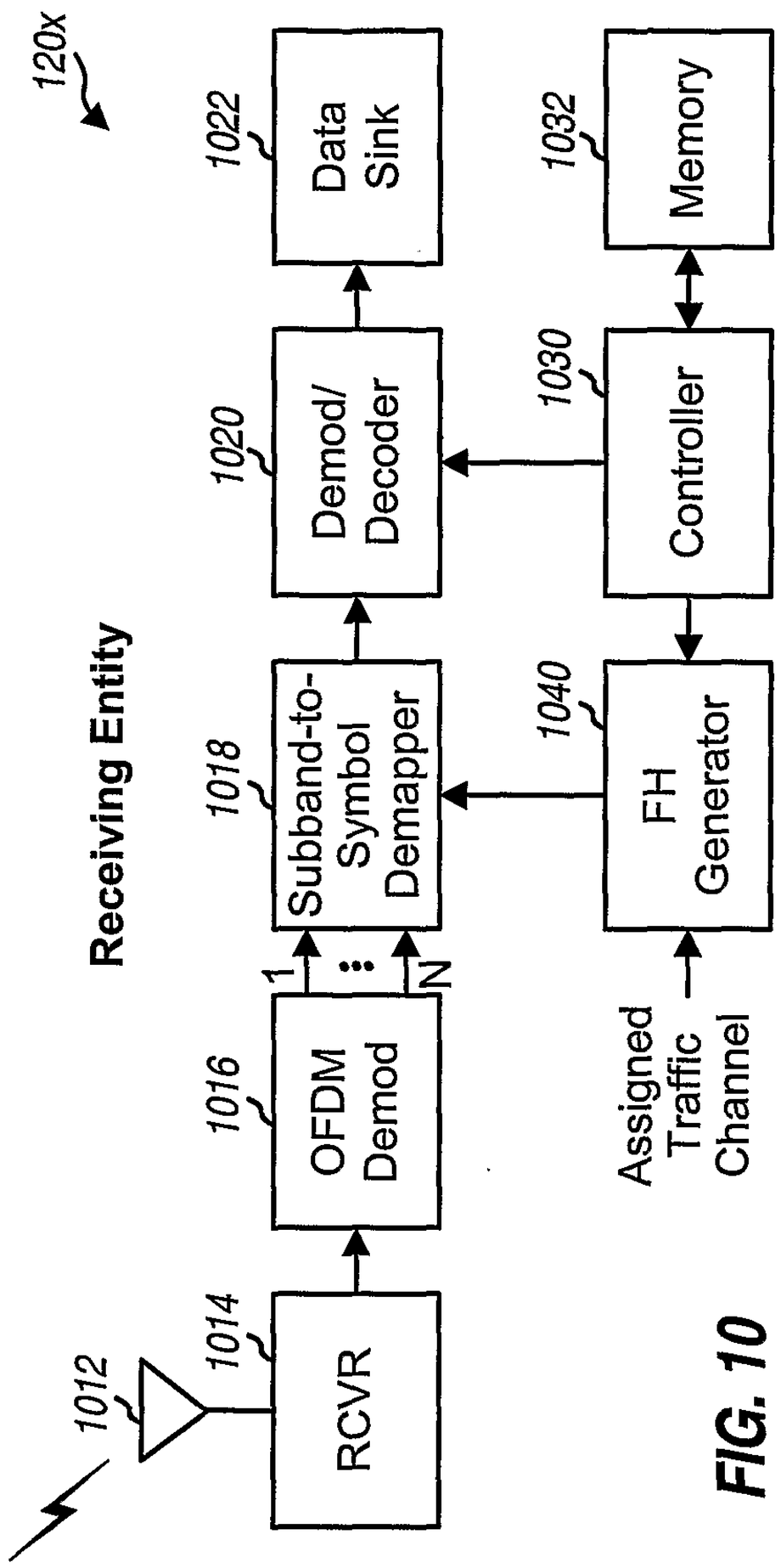
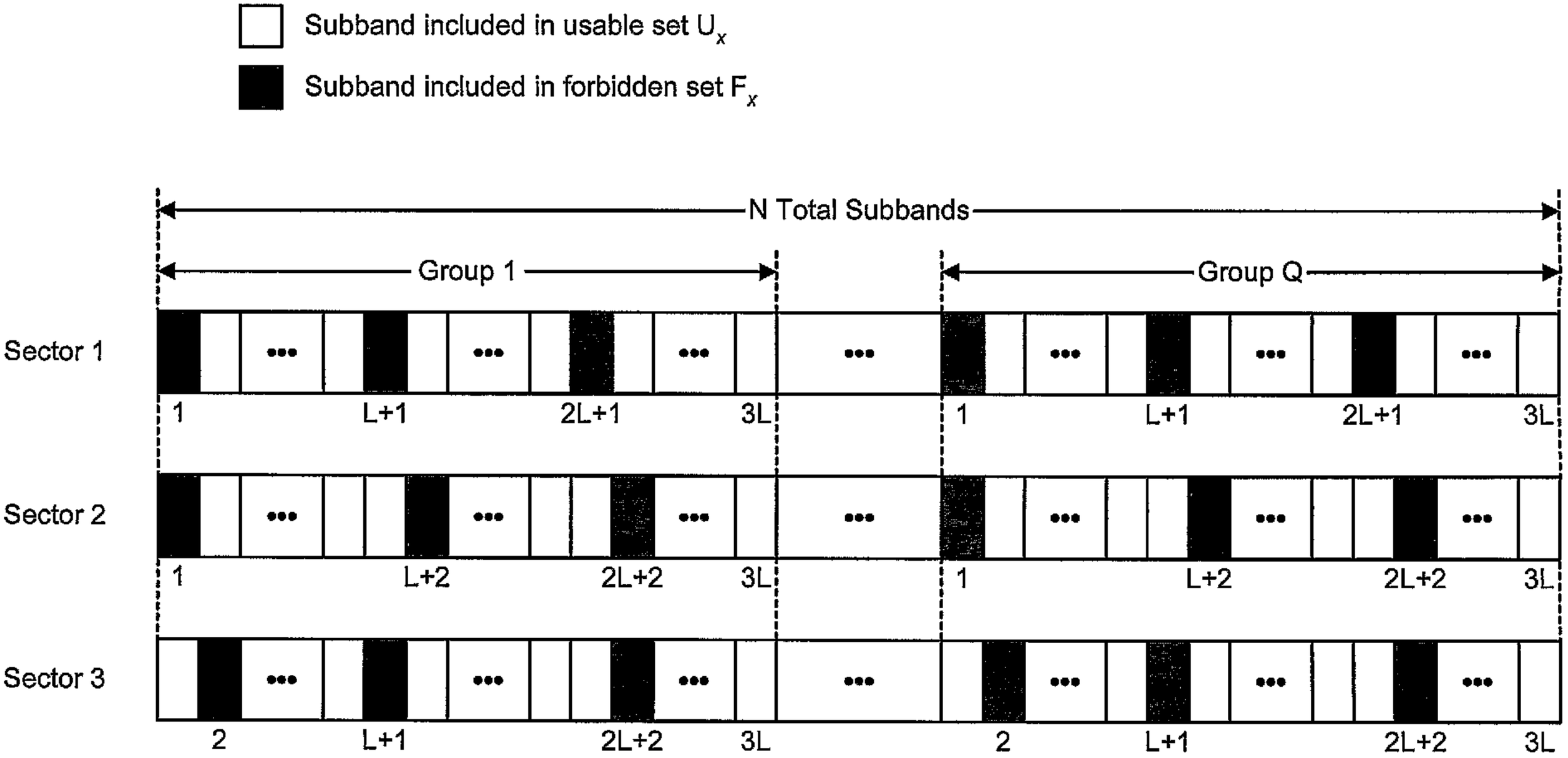

120x
Receiving Entity
1012
1014
RCVR
1016
OFDM Demod
1018
Subband-to-Symbol Demapper
1020
Demod/ Decoder
1022
Data Sink
1030
Controller
1032
Memory
1040
FH Generator
Assigned Traffic Channel
1
N

FIG. 10


Subband included in usable set U_x
Subband included in forbidden set F_x
N Total Subbands
Group 1
Group Q
Sector 1
Sector 2
Sector 3
1
L+1
2L+1
3L
1
L+2
2L+2
3L
2
L+1
2L+2
3L