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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 December 2010 (09.12.2010)

PCT

(10) International Publication Number
WO 2010/141454 A1

(51) International Patent Classification:
H04W 88/06 (2009.01)

(21) International Application Number:
PCT/US2010/036882

(22) International Filing Date:
1 June 2010 (01.06.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/182,946 1 June 2009 (01.06.2009) US
12/549,678 28 August 2009 (28.08.2009) US

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

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **WIETFELDT, Richard, D.** [CA/US]; 5775 Morehouse Drive, San Diego, California 92121 (US). **CHRISIKOS, George** [US/US]; 5775 Morehouse Drive, San Diego, California 92121 (US).

(74) Agent: **PATEL, Rupit, M.**; 5775 Morehouse Drive, San Diego, California 92121 (US).

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

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, 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))*

[Continued on next page]

(54) **Title**: CONTROL OF MULTIPLE RADIOS USING A DATABASE OF INTERFERENCE-RELATED INFORMATION

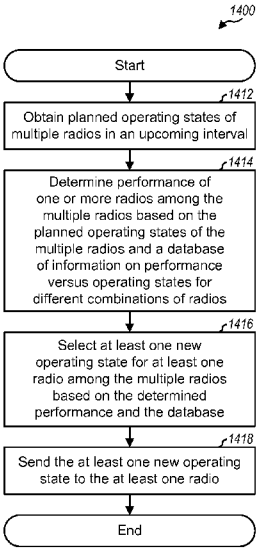

FIG. 14

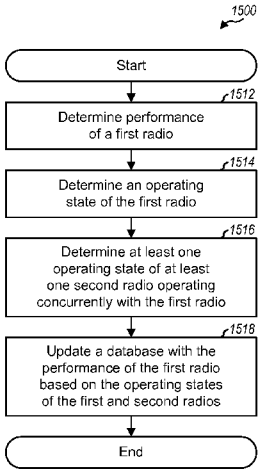

FIG. 15

(57) **Abstract**: Techniques for performing radio coexistence management are described. In an aspect, operation of multiple radios may be controlled using a database of interference-related information, which may be indicative of interference between different radios operating concurrently. In one design, an entity may obtain planned operating states of multiple radios in an upcoming interval. The entity may determine the performance of one or more radios based on the planned operating states of the radios and the database, which may store information on performance versus operating states for different combinations of radios. The entity may select at least one new operating state for at least one radio based on the determined performance and the database to achieve good performance. The entity may send the at least one new operating state to the at least one radio. Each radio may operate in accordance with its new operating state (if any) or its planned operating state.

WO 2010/141454 A1

Published:

— *with international search report (Art. 21(3))*

CONTROL OF MULTIPLE RADIOS USING A DATABASE OF INTERFERENCE-RELATED INFORMATION

[0001] The present application claims priority to provisional U.S. Application Serial No. 61/182,946 entitled "COEXISTENCE MANAGER FOR CONTROLLING OPERATION OF MULTIPLE RADIOS," filed June 1, 2009, having Attorney Docket No. 092262P1.

BACKGROUND

I. Field

[0002] The present disclosure relates generally to communication, and more specifically to techniques for controlling radios for wireless communication.

II. Background

[0003] Wireless communication systems are widely deployed to provide various communication content such as voice, video, packet data, messaging, broadcast, etc. These wireless systems may include multiple-access systems capable of supporting multiple users by sharing the available system resources. Examples of such multiple-access systems include Code Division Multiple Access (CDMA) systems, Time Division Multiple Access (TDMA) systems, Frequency Division Multiple Access (FDMA) systems, Orthogonal FDMA (OFDMA) systems, and Single-Carrier FDMA (SC-FDMA) systems. These wireless systems may also include broadcast systems and other systems.

[0004] A wireless communication device may include a number of radios to support communication with different wireless communication systems. Each radio may operate on certain frequency channels and bands and may have certain requirements. It may be desirable to control the radios in a manner to achieve good performance.

SUMMARY

[0005] Techniques for performing radio coexistence management to achieve good performance are described herein. In an aspect, operation of multiple radios operating concurrently may be controlled using a database of interference-related information. The interference-related information may be indicative of interference between different

radios operating concurrently and may be provided in various forms. In one design, an entity (e.g., a coexistence manager or a radio controller) may obtain planned operating states of multiple radios in an upcoming interval. The entity may determine the performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and the database. The database may comprise information on performance versus operating states for different combinations of radios. The operating state for each radio may be determined based on specific setting of at least one configurable parameter for the radio. The entity may select at least one new operating state for at least one radio based on the determined performance and the database such that good performance can be achieved for as many radios as possible. The entity may send the at least one new operating state to the at least one radio. Each radio may operate in accordance with its new operating state (if any) or its planned operating state.

[0006] In another aspect, the database of interference-related information may be determined *a priori* or dynamically. In one design, the performance of a first radio and its operating state may be determined. At least one operating state of at least one second radio operating concurrently with the first radio may also be determined. The database may be updated with the performance of the first radio based on the operating states of the first and second radios. The database may comprise a color chart storing performance of receiver radios versus operating states of transmitter and receiver radios. The database may also store the interference-related information in some other format or structure. The performance of the first radio may be determined based on computation, computer simulation, or empirical measurements. The performance of the first radio may also be determined based on measurements obtained with the first and second radios being operational. The database may be pre-configured with initial information prior to operation and may be updated with new information obtained from measurements made during operation. The information for the database may also be downloaded from a system during operation.

[0007] Various aspects and features of the disclosure are described in further detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 shows a wireless device communicating with various systems.

[0009] FIG. 2 shows a block diagram of the wireless device.

[0010] FIG. 3 shows a block diagram of two wireless devices.

[0011] FIGS. 4 and 5 show two exemplary color charts.

[0012] FIG. 6 shows a plot of performance for a cell in a color chart.

[0013] FIG. 7 shows another exemplary color chart.

[0014] FIGS. 8A and 8B show radio coexistence management with centralized and decentralized architectures, respectively.

[0015] FIG. 9 shows a message flow for centralized radio coexistence management.

[0016] FIG. 10 shows a message flow for decentralized radio coexistence management.

[0017] FIG. 11 shows a coexistence manager and multiple processing modules.

[0018] FIG. 12 shows two designs of radio controllers for radios.

[0019] FIGS. 13A and 13B show two designs of sharing antennas for radios.

[0020] FIG. 14 shows a process for controlling the operation of radios.

[0021] FIG. 15 shows a process for updating a database used to the control operation of radios.

DETAILED DESCRIPTION

[0022] **FIG. 1** shows a wireless device 110 capable of communicating with multiple communication systems. These systems may include one or more wireless wide area network (WWAN) systems 120 and 130, one or more wireless local area network (WLAN) systems 140 and 150, one or more wireless personal area network (WPAN) systems 160, one or more broadcast systems 170, one or more satellite positioning systems 180, other systems not shown in FIG. 1, or any combination thereof. The terms "network" and "system" are often used interchangeably. The WWAN systems may be cellular systems.

[0023] Cellular systems 120 and 130 may each be a CDMA, TDMA, FDMA, OFDMA, SC-FDMA, or some other system. A CDMA system may implement a radio technology such as Universal Terrestrial Radio Access (UTRA), cdma2000, etc. UTRA includes Wideband CDMA (WCDMA) and other variants of CDMA. cdma2000 covers IS-2000 (CDMA2000 1X), IS-95, and IS-856 (1xEVDO) standards. A TDMA system may implement a radio technology such as Global System for Mobile Communications (GSM), Digital Advanced Mobile Phone System (D-AMPS), etc. An OFDMA system may implement a radio technology such as Evolved UTRA (E-UTRA), Ultra Mobile

Broadband (UMB), IEEE 802.16 (WiMAX), IEEE 802.20, Flash-OFDM®, etc. UTRA and E-UTRA are part of Universal Mobile Telecommunication System (UMTS). 3GPP Long Term Evolution (LTE) and LTE-Advanced (LTE-A) are new releases of UMTS that use E-UTRA. UTRA, E-UTRA, UMTS, LTE, LTE-A and GSM are described in documents from an organization named "3rd Generation Partnership Project" (3GPP). cdma2000 and UMB are described in documents from an organization named "3rd Generation Partnership Project 2" (3GPP2). Cellular system 120 may include a number of base stations 122 that can support bi-directional communication for wireless devices within their coverage. Similarly, cellular system 130 may include a number of base stations 132 that can support bi-directional communication for wireless devices within their coverage.

[0024] WLAN systems 140 and 150 may each implement a radio technology such as IEEE 802.11 (Wi-Fi), Hiperlan, etc. WLAN system 140 may include one or more access points 142 that can support bi-directional communication. Similarly, WLAN system 150 may include one or more access points 152 that can support bi-directional communication. WPAN system 160 may implement a radio technology such as Bluetooth, IEEE 802.15, etc. WPAN system 160 may support bi-directional communication for various devices such as wireless device 110, a headset 162, a computer 164, a mouse 166, etc.

[0025] Broadcast system 170 may be a television (TV) broadcast system, a frequency modulation (FM) broadcast system, a digital broadcast system, etc. A digital broadcast system may implement a radio technology such as MediaFLO™, Digital Video Broadcasting for Handhelds (DVB-H), Integrated Services Digital Broadcasting for Terrestrial Television Broadcasting (ISDB-T), Advanced Television Systems Committee - Mobile/Handheld (ATSC-M/H), etc. Broadcast system 170 may include one or more broadcast stations 172 that can support one-way communication.

[0026] Satellite positioning system 180 may be the United States Global Positioning System (GPS), the European Galileo system, the Russian GLONASS system, the Quasi-Zenith Satellite System (QZSS) over Japan, the Indian Regional Navigational Satellite System (IRNSS) over India, the Beidou system over China, etc. Satellite positioning system 180 may include a number of satellites 182 that transmit signals used for positioning.

[0027] Wireless device 110 may be stationary or mobile and may also be referred to as a user equipment (UE), a mobile station, a mobile equipment, a terminal, an access terminal, a subscriber unit, a station, etc. Wireless device 110 may be a cellular phone, a personal digital assistant (PDA), a wireless modem, a handheld device, a laptop computer, a cordless phone, a wireless local loop (WLL) station, a broadcast receiver, etc. Wireless device 110 may communicate two-way with cellular systems 120 and/or 130, WLAN systems 140 and/or 150, devices within WPAN system 160, etc. Wireless device 110 may also receive signals from broadcast system 170, satellite positioning system 180, an indoor positioning system, etc. In general, wireless device 110 may communicate with any number of systems at any given moment.

[0028] **FIG. 2** shows a block diagram of a design of wireless device 110. In this design, wireless device 110 includes N radios 220a through 220n, where N may be any integer value. For example, wireless device 110 may include radios for 3GPP2 cellular systems (e.g., CDMA 1X, 1xEVDO, etc.), 3GPP cellular systems (e.g., GSM, GPRS, EDGE, WCDMA, HSPA, LTE, etc.), WLAN systems, WiMAX system, GPS, Bluetooth, FM radio (e.g., transmit and receive), broadcast systems (e.g., TV, MediaFLO^{TM}, DVB-H, ISDB-T, ATSC-M/H, etc.), Near Field Communication (NFC), Radio Frequency Identification (RFID), etc.

[0029] The N radios 220a through 220n may be coupled to N antennas 210a through 210n, respectively. For simplicity, FIG. 2 shows each radio 220 being paired with an associated antenna 210. In general, each radio 220 may be coupled to any number of antennas, and multiple radios may also share one or more antennas.

[0030] In general, a radio may be a unit that radiates or emits energy in an electro magnetic spectrum, receives energy in an electro magnetic spectrum, or generates energy that is passed via conductive means. As some examples, a radio may be (i) a unit that transmits a signal to a system or a device or (i) a unit that receives signals from a system or a device. A radio may thus support wireless communication. A radio may also be a unit (e.g., a screen on a computer, a circuit board, etc.) that emits noise, which may impact the performance of other radios. A radio may thus be a unit that emits noise and interference without supporting wireless communication. For simplicity, much of the description below is for radios used for wireless communication.

[0031] Radios 220 may comprise one or more types of radios. A radio may comprise a set of circuits designed to transmit or receive on a particular band for a

particular system. A radio may also be a software defined radio (SDR) that may be configured to support multiple systems and/or multiple bands. For example, an SDR may include programmable circuits (e.g., tunable/switchable radio frequency (RF) filters, switched filter bank, tunable matching networks, etc.) that can operate at different frequencies. An SDR may also include programmable processing units that can perform processing for different systems. An SDR may be configured to operate on a particular band for a particular system at any given moment. A radio may also be a cognitive radio that can search for a clear frequency channel and operate on the clear frequency channel. A frequency channel may also be referred to as simply a channel.

[0032] Each radio 220 may support communication with a particular system and may operate on one or more frequency channels in one or more frequency bands. Multiple radios 220 may also be used for a given system, e.g., one radio to transmit and another radio to receive for the system. Multiple radios 220 may also be defined for different frequency bands, e.g., cellular and PCS bands.

[0033] A digital processor 230 may be coupled to radios 220a through 220n and may perform various functions such as processing for data being transmitted or received via radios 220. The processing for each radio 220 may be dependent on the radio technology supported by that radio and may include encoding, decoding, modulation, demodulation, encryption, decryption, etc. Digital processor 230 may include a coexistence manager (CxM) 240 that may control the operation of radios 220 in order to achieve good performance, as described below. Coexistence manager 240 may have access to a radio coexistence database 242, which may store information used to control the operation of the radios. Digital processor 230 may also include an internal memory 244 to store data and program codes.

[0034] For simplicity, digital processor 230 is shown as a single processor in FIG. 2. In general, digital processor 230 may comprise any number and any type of processors, controllers, memories, etc. For example, digital processor 230 may comprise one or more processors, microprocessors, central processing units (CPUs), digital signal processors (DSPs), reduced instruction set computers (RISCs), advanced RISC machines (ARMs), controllers, etc. A controller/processor 250 may direct the operation of various units within wireless device 110. A memory 252 may store program codes and data for wireless device 110. Digital processor 230, controller/processor 250, and memory 252 may be implemented on one or more integrated circuits (ICs), application

specific integrated circuits (ASICs), etc. For example, digital processor 230 may be implemented on a Mobile Station Modem (MSM) ASIC.

[0035] **FIG. 3** shows a block diagram of a design of wireless device 110 (Device A) and a wireless device 112 (Device B). Device 112 includes M radios 222a through 222m coupled to M antennas 212a through 212m, respectively, where M may be any integer value. In general, a device may be any unit that may be packaged separately and may include any number of radios. For example, device 112 may correspond to headset 162 or computer 164 in FIG. 1 or some other device.

[0036] Devices 110 and 112 may communicate with one another via a wireline interface (as shown in FIG. 3) and/or a wireless interface. Coexistence manager 240 may receive inputs from radios 220 and/or 222 and may control the operation of these radios in order to achieve good performance, as described below.

[0037] As shown in FIGS. 2 and 3, multiple radios in one or more devices may be located in close proximity of one another and may cause or observe interference that may degrade performance. Each radio may operate on one or more frequency channels in one or more frequency bands. Each radio may cause interference to other radios or may observe interference from other radios. The impact of a given radio on another radio may be dependent on various factors such as the frequency channel and frequency band used by each radio, the radio technology supported by each radio, the radio conditions observed by each radio, the design and implementation of each radio, etc. In general, multiple radios in close proximity may often create significant operational issues, particularly under conditions of concurrency, with the multiple radios operating simultaneously. Insufficient isolation for co-located radios (for both radiated and conductive noise) and spectrum co-occupancy or adjacency may be major causes of radio coexistence problems.

[0038] Coexistence manager 240 may coordinate the operation of radios. Coexistence manager 240 may provide (i) a scalable and upgradeable solution for coexistence mitigation where point solutions may be incorporated and (ii) a unified framework that may be implemented in an evolutionary manner. Point solutions refer to solutions to problems between specific radios. The framework may also allow for incorporation of RF and baseband changes for future enhancements. The coexistence management function may arbitrate operations between various radios to provide resolutions when coexistence problems are detected.

[0039] Coexistence manager 240 may receive inputs from active radios, which may be radios that are currently operational. The inputs from each active radio may indicate a planned or expected operating state of the radio in an upcoming time interval, planned activity of the radio, etc. An activity may also be referred to as an event. Coexistence manager 240 may determine controls for the active radios based on the received inputs to mitigate interference between these radios. For example, the controls may relate to silencing, time arbitration, frequency arbitration, adaptive modulation, adaptive digital notch filtering, etc., to mitigate interference. Coexistence manager 240 may send the controls to all affected radios to achieve good performance.

[0040] Coexistence manager 240 may control the operation of the active radios to achieve good performance for as many radios as possible. A radio may have one or more configurable parameters that may be adjusted to mitigate interference from the radio and/or to improve performance of the radio. A configurable parameter may be for a physical component within the radio, such as an amplifier, a filter, an antenna, an antenna array, etc. A configurable parameter may also be for an operational parameter such as a transmit power level, a frequency channel, a traffic channel, etc. A received power level may also be a configurable parameter if it can be varied, e.g., by selecting different antennas and/or more antennas. Each configurable parameter may be set to one of multiple possible settings/values applicable for that parameter. The radio may have an operating state, which may be defined by a particular setting for each configurable parameter. A configurable parameter may also be referred to as a "knob", a configurable parameter setting may also be referred to as a "knob setting", and an operating state may also be referred to as a "knob state".

[0041] Coexistence manager 240 may utilize radio coexistence database 242 to control the operation of the active radios. In one design, database 242 may comprise information on performance versus operating states for different combinations of radios. Database 242 may store the information using various structures and formats.

[0042] **FIG. 4** shows a design of a color chart 400, which is one design of a radio coexistence database that may be used to control active radios. In color chart 400, the horizontal axis may be for a transmitter radio, which may cause interference and may be controllable. The vertical axis may be for a receiver radio, which may be adversely impacted by the interference from the transmitter radio and may also be controllable. The transmitter radio may be referred to as an aggressor, and the receiver radio may be

referred to as a victim. For simplicity, FIG. 4 shows only some frequency channels for the transmitter radio and only some frequency channels for the receiver radio. Color chart 400 may cover other radios and other frequency channels that are not shown in FIG. 4 for simplicity.

[0043] Color chart 400 includes a number of column sets for different frequency channels on which the transmitter radio can operate. Each column set includes a number of columns for different operating states (or knob states) of the transmitter radio. In the example shown in FIG. 4, each column set includes eight columns for eight different operating states of the transmitter radio. Fewer or more operating states may also be supported for the transmitter radio.

[0044] Color chart 400 also includes a number of row sets for different frequency channels on which the receiver radio can operate. Each row set includes a number of rows for different operating states of the receiver radio. In the example shown in FIG. 4, each row set includes eight rows for eight different operating states of the receiver radio. Fewer or more operating states may also be supported for the receiver radio. In general, each radio may have any number of operating states. One row or one column may be provided for each operating state that may be selected for the radio for interference management purposes.

[0045] In the design shown in FIG. 4, the performance of a radio may be quantified by (or quantized to) one of three possible levels – "acceptable", "marginal", and "unacceptable" or "severe". The acceptable, marginal, and unacceptable levels may be represented by green, yellow, and red colors, respectively, in color chart 400. The acceptable level may correspond to a case in which the performance of the radio meets all applicable requirements. The marginal level may correspond to a case in which (i) the performance of the radio meets all applicable requirements but possibly with small margins or (ii) the performance of the radio meets key requirements but possibly not all requirements. The unacceptable level may correspond to a case in which the performance of the radio does not meet applicable requirements and should be improved. In general, performance may be quantified with any number of levels, e.g., 2, 4, etc. Each level may be defined in any manner, which may be dependent on the requirements of the radio. More levels may allow for better control of the radios at the expense of more memory to store these levels.

[0046] In the design shown in FIG. 4, color chart 400 includes a cell (or a square box) for each unique combination of operating states for the transmitter and receiver radios. Cell (i, j) may correspond to operating state i for the transmitter radio and operating state j for the receiver radio. Cell (i, j) may be populated with a performance level for the receiver radio with the transmitter radio in operating state i and the receiver radio in operating state j.

[0047] The design in FIG. 4 may allow for selection of an operating state for the transmitter radio independently of selection of an operating state for the receiver radio. The performance of the receiver radio for the selected operating states for the transmitter and receiver radios may be determined by the cell covering this combination of operating states.

[0048] In general, for the design shown in FIG. 4, a color chart may cover U operating states for the transmitter radio and V operating states for the receiver radio for a specific frequency channel for each radio, where $U \geq 1$ and $V \geq 1$. A total of $U \times V$ cells may be used to quantify the performance of the receiver radio for different combinations of operating states for the transmitter and receiver radios. If $U = 1$ and $V = 1$, then the color chart may include a single cell for each frequency channel pair for a specific operating state for each radio.

[0049] **FIG. 5** shows a design of a color chart 500, which is another design of a radio coexistence database that may be used to control active radios. In color chart 500, the horizontal axis may be for transmitter radios, which may cause interference and may be controllable. The vertical axis may be for receiver radios, which may be impacted by the interference from the transmitter radios and may also be controllable. For simplicity, FIG. 5 shows only one transmitter radio and only one receiver radio.

[0050] In the design shown in FIG. 5, color chart 500 includes two cells for each channel combination covering a specific frequency channel for a transmitter radio (or aggressor) and a specific frequency channel for a receiver radio (or victim). Each cell may be associated with a specific operating scenario for the transmitter and receiver radios and may convey the performance of the receiver radio for the operating scenario. For example, the left cell for the frequency combination may convey the performance of the receiver radio for a "sensitivity" scenario, and the right cell may convey the performance of the receiver radio for a "nominal" scenario. The sensitivity scenario may be defined by (i) the transmitter radio transmitting at a maximum power level

(Pmax) and (ii) the receiver radio operating at or near sensitivity level (RXmin) and attempting to receive a very weak signal. Pmax and RXmin may be specified by the standards applicable for the transmitter and receiver radios, respectively. The sensitivity scenario may occur if wireless device 110 is located far away from a base station and needs to transmit an uplink signal at a high power level in order to reach the base station while also receiving a downlink signal from the base station at a low power level. The nominal scenario may be defined by (i) the transmitter radio transmitting at least X dBm lower than Pmax and (ii) the receiver radio operating at least Y decibel (dB) higher than RXmin, where X and Y may be any suitable values. The performance for the sensitivity and nominal scenarios may assume typical settings for various configurable parameters (or typical knob settings) for the transmitter and receiver radios.

[0051] In one design, the performance level for each cell in color chart 500 may be given by one of three levels – acceptable, marginal, and unacceptable, which may be defined as described above for FIG. 4. The performance level for each cell may also be given by fewer or more levels.

[0052] In general, for the design shown in FIG. 5, a color chart may include Q cells for each channel combination covering a specific frequency channel for a transmitter radio and a specific frequency channel for a receiver radio. Each cell may be associated with a specific operating scenario for the transmitter and receiver radios and may convey the performance of the receiver radio for the associated operating scenario. The Q cells for the color chart in FIG. 5 may be a subset of the cells for the color chart in FIG. 4, and these Q cells may be for the more likely operating scenarios. Performance may be quantified with any number of levels. Performance may also be quantified by a value, e.g., a margin between the achievable performance and the required performance. More cells and/or more performance levels may allow for better control of the radios.

[0053] **FIG. 6** shows a design of a 3-dimensional plot 600 of performance for one cell in a color chart. For example, plot 600 may be obtained for each cell in color chart 400 in FIG. 4, for each cell in color chart 500 in FIG. 5, etc. Performance may be quantified by a margin between achievable performance and required performance. Performance plot 600 may be obtained based on a function of specific parameter settings for a transmitter radio, specific parameter settings for a receiver radio, a

transmit power level for the transmitter radio, and a received power level for the receiver radio, as follows:

$$\text{Margin} = f(\text{TX power, RX power, other parameter settings}), \quad \text{Eq (1)}$$

where $f(\ )$ may be any suitable function.

[0054] In FIG. 6, the x-axis may represent the received power of the receiver radio, the y-axis may represent the transmit power of the transmitter radio, and the z-axis may represent margin. As shown in FIG. 6, performance (or margin) may be dependent on the transmit power and the received power. The desired performance may be obtained by adjusting the transmit power and/or the received power.

[0055] The performance levels for the cells in color chart 500 in FIG. 5 may be determined based on plots such as plot 600 in FIG. 6. For example, the margin at a given (x, y) point corresponding to the sensitivity scenario may be determined. This margin may be compared against two thresholds TH1 and TH2 to determine whether the performance is acceptable, marginal, or unacceptable, as shown in FIG. 6.

[0056] In one design, a set of plots may be obtained for different configurable parameter settings for the transmitter radio and the receiver radio. In one design, the operating states for the transmitter and receiver radios may be selected based on the set of plots. For example, the least restrictive operating states for the transmitter and receiver radios that can provide the desired performance may be selected. The plots may thus be used to select the operating states for the transmitter and receiver radios. In another design, configurable parameter settings for the transmitter and receiver radios may be selected based on other considerations. For both designs, the transmit power and/or the received power may be adjusted based on the plot for the selected parameter settings.

[0057] In another design, a set of performance plots may be obtained for different configurable parameter settings for the transmitter and receiver radios for a channel combination covering a specific frequency channel for the transmitter radio and a specific frequency channel for the receiver radio. The set of performance plots may be aggregated to obtain an overall plot. The aggregation may be performed in various manners. In one design, each (x, y) point in the overall plot may be assigned the best performance from the set of plots for that (x, y) point. The overall plot may thus be obtained by superimposing all of the plots in the set and saving the highest point for all

plots. The overall plot may then represent the best possible performance for each (x, y) point.

[0058] **FIG. 7** shows a design of a color chart 700, which is yet another design of a radio coexistence database that may be used to control active radios. In color chart 700, the horizontal axis may be for transmitter radios and may cover different frequency bands (instead of different frequency channels). A band may cover a number of frequency channels. The specific number of frequency channels in each band may be dependent on the radio technology, the band, etc. The vertical axis may be for receiver radios and may also cover different bands.

[0059] In the design shown in FIG. 7, color chart 700 includes six cells for each band combination covering a specific band for a transmitter radio and a specific band for a receiver radio. For a given band combination, three cells in the left column provide performance for the sensitivity scenario (Sen), and three cells in the right column provide performance for the nominal scenario (Nom). The two cells in the top row indicate the percentage of channels with acceptable performance, the two cells in the middle row indicate the percentage of channels with marginal performance, and the two cells in the bottom row indicate the percentage of channels with unacceptable performance. For example, in block 710 covering a Bluetooth transmitter in the 2.4 GHz band and an LTE receiver in the 2.6 GHz band, 47 percent of all frequency channels have acceptable performance for the sensitivity scenario, 10 percent of all frequency channels have marginal performance, and 43 percent of all frequency channels have unacceptable performance. The information in color chart 700 may be obtained by (i) determining the performance (e.g., acceptable, marginal, or unacceptable) for each frequency channel in the band combination for a given scenario (e.g., sensitivity or nominal) and (ii) determining the percentage of frequency channels for each performance level.

[0060] FIGS. 4 through 7 show exemplary designs of 2-dimensional color charts for two radios. In general, the performance of a given radio may be impacted by one or more other radios. A color chart may be defined with K dimensions for K radios operating concurrently, where K may be any integer value. For example, the performance of one or more radios may be given by the operating states of the K radios.

[0061] FIGS. 4 through 7 show some exemplary designs of color charts that may be used for a radio coexistence database. Information regarding interference due to

coexisting radios may also be captured and presented in a color chart or a database in other manners, e.g., quantized in other ways, presented using other formats or structures, etc.

[0062] Information for a radio coexistence database (e.g., a color chart) may be obtained in various manners. In one design, the information may be obtained via calculation, computer simulation, etc. Any suitable modeling and simulation tools may be used to analytically obtain information on interference between coexisting radios. The information may be analytical in nature and may be independent of the design and implementation of the radios.

[0063] In another design, information for the radio coexistence database may be obtained via empirical measurements, lab or field testing, etc. For example, testing may be performed for different configurable parameter settings and power levels for different combinations of transmitter and receiver radios. Performance data may be collected and used to derive information for the radio coexistence database. The information may be dependent on the design and implementation of the radios. The radio coexistence database may be loaded into wireless device 110 during the manufacturing phase. The database may also be downloaded over the air, e.g., from a system with which wireless device 110 is in communication.

[0064] In yet another design, information for the radio coexistence database may be obtained during actual operation of the radios. For example, wireless device 110 may determine the performance of a receiver radio for different combinations of operating states (e.g., different power levels) for a transmitter radio and the receiver radio during normal operation. The performance may be specific to wireless device 110. Wireless device 110 may update the radio coexistence database (e.g., the cells in a color chart) whenever performance data is obtained during normal operation.

[0065] The information for the radio coexistence database may also be obtained or updated in other manners. The radio coexistence database may be updated to account for various factors such as temperature, component aging/drift, voltage/current variations, antenna pulling (e.g., due to device proximity, obstacles, cables, etc.), frequency, transmit and received power levels, etc.

[0066] In one design, wireless device 110 may send information measured and collected by wireless device 110 to the system. The system may aggregate information obtained from different wireless devices to form a master radio coexistence database.

All or a portion of the master database may be downloaded to the wireless devices for use for coexistence management.

[0067] The radio coexistence database at wireless device 110 may also include other information beside interference information. For example, the database may include information regarding frequency bands of operation, maximum transmit power, and/or other information for each radio. The database may also include information pertinent to each activity of a radio such as event time, event duration, etc.

[0068] The radio coexistence database for all N radios 220 may be relatively large, especially for a large number of radios, a large number of frequency channels, a large number of operating states for each radio, etc. In one design, the entire radio coexistence database may be stored in a bulk non-volatile memory (e.g., memory 252 in FIG. 2). The bulk memory may be a NAND Flash, a NOR Flash, or some other type of memory with large storage capacity. A pertinent portion of the radio coexistence database may be loaded from the bulk memory into a faster memory for quick access by coexistence manager 240. The faster memory may be memory 244 within digital processor 230 and may be static random access memory (SRAM) or some other type of memory. The loaded portion of the radio coexistence database may include information for all active radios, for active radios that might collide with one another, etc. The loaded portion in the faster memory may be updated whenever a radio becomes active or an active radio becomes inactive.

[0069] The radio coexistence database may be used for various purposes such as radio selection, radio management, etc. Radio selection refers to selection of a particular radio for a particular application. Radio management refers to management of coexisting radios to achieve good performance for as many radios as possible. Radio selection may be performed based on the entire radio coexistence database. Radio management may be performed based on a portion of the radio coexistence database for the active radios.

[0070] For radio selection, multiple radios may be used for a particular application. The most suitable radio among these multiple radios may be selected for the application based on the radio environment and the radio coexistence database. For example, an LTE radio may be selected instead of a WLAN radio due to higher interference observed or caused by the WLAN radio in the radio environment. The selected radio may thus be a radio that can provide good (e.g., the best possible) performance for the

given radio environment. Radio selection may be static/semi-static or dynamic, depending on changes in the radio environment. For example, a particular radio in wireless device 110 may be selected and used for an extended period of time if the radio environment is relatively static, e.g., wireless device 110 is not mobile. Alternatively, different radios may be selected due to changing radio environment, e.g., resulting from mobility of wireless device 110. The radio environment may also change due to other radios within the vicinity of wireless device 110 being enabled or disabled.

[0071] For radio management, coexistence manager 240 may use the radio coexistence database (e.g., color chart 400) to control the operation of the active radios. For example, coexistence manager 240 may receive inputs indicative of planned operating states of transmitter and receiver radios and may determine the performance of the receiver radio with these planned operating states. If the performance of the receiver radio is unacceptable (or possibly marginal), then coexistence manager 240 may select a new operating state for the transmitter radio and/or a new operating state for the receiver radio such that the performance of the receiver radio is acceptable (or possibly marginal). The new operating state for the transmitter radio may comprise a change in transmit power level and/or other configurable parameters (e.g., a new frequency channel) for the transmitter radio. In any case, if a new operating state is selected for any radio, then coexistence manager 240 may send each new operating state to the corresponding radio.

[0072] Radio coexistence management may be implemented with various architectures such as a centralized architecture or a decentralized architecture. For the centralized architecture, coexistence manager 240 may receive inputs from active radios and may determine controls (e.g., operating states) for the radios such that good performance can be achieved for as many radios as possible. For the decentralized architecture, which may also be referred to as a distributed architecture, the active radios may communicate with each other to determine controls for the radios. Coexistence manager 240 may provide management function in the decentralized architecture.

[0073] **FIG. 8A** shows a design of radio coexistence management with the centralized architecture. In this architecture, coexistence manager 240 may communicate with all active radios 220 via a messaging bus. The messaging bus may support software-based messaging or hardware-based messaging. The messaging bus may have sufficiently short latency to support coordination of the active radios and their

respective messaging and system timing. The communication between coexistence manager 240 and active radios 220 may also be based on a suitable messaging protocol.

[0074] The active radios 220 may be located on a single device (e.g., device 110 in FIG. 2) or on multiple devices (e.g., devices 110 and 112 in FIG. 3). Each radio 220 may be considered as a separate entity to coexistence manager 240. Each radio 220 may be associated with a radio controller 224 that may support radio coexistence for the radio and may also communicate with coexistence manager 240. Each radio 220 may also have one or more configurable parameters that may be varied to mitigate interference caused or observed by that radio.

[0075] Coexistence manager 240 may perform various management functions to support radio coexistence. For example, coexistence manager 240 may support registration by radios 220, event notifications, resolution and arbitration of events, and notification responses. Coexistence manager 240 may receive inputs from all active radios 220. Coexistence manager 240 may utilize radio coexistence database 242 to make decisions on the operation of the active radios based on the received inputs. Coexistence manager 240 may determine controls (e.g., operating states) for the radios such that good performance can be achieved for the radios. Coexistence manager 240 may send the controls to the affected radios.

[0076] **FIG. 8B** shows an exemplary design of radio coexistence management with the decentralized architecture. In this architecture, the active radios 220 may communicate with one another and/or with coexistence manager 240 to support radio coexistence. The arbitration function for radio coexistence may be shared across the active radios 220 instead of concentrated at coexistence manager 240. The best operating states for the active radios may be determined by distributed processing by at least one and perhaps all of the active radios. The active radios may reside in multiple devices (e.g., devices 110 and 112), and the distributed processing may be extended to encompass all radios in all devices. Each active radio 220 may have an associated database 226 that may be used by radio controller 224 for that radio to made decisions affecting planned activities of the radio. Coexistence manager 240 may provide management function.

[0077] For both the centralized architecture in FIG. 8A and the decentralized architecture in FIG. 8B, various message flows may be defined to control the operation of the active radios to achieve good performance. The message flows may be

implemented in various manners depending on the selected architecture and other factors.

[0078] **FIG. 9** shows a design of a message flow 900 for controlling radios by coexistence manager 240 for the centralized architecture in FIG. 8A. In general, coexistence manager 240 may communicate with up to N active radios 220. For simplicity, only two radios X and Y are shown in FIG. 9. For clarity, the processing performed by radio X is described below. Similar processing may be performed by each active radio.

[0079] In one design, radio X may register itself with coexistence manager 240 via a registration event (RE). Radio X may perform registration when wireless device 110 is powered up, when radio X is selected for use, or when some other trigger condition occurs. Radio X may identify its configurable parameters, which may be dependent on its radio technology and design. The registration may allow coexistence manager 240 to become aware of radio X, to obtain pertinent information for radio X, to determine a pertinent portion of the radio coexistence database for radio X, to download this portion of the database from external memory to internal memory, to allocate communication resources to radio X, etc. Different radios may register with coexistence manager 240 at different times.

[0080] In one design, radio X may notify coexistence manager 240 of its planned activity via a notification, which may also be referred to as a notification event (NE). The planned activity or event may be for transmission or reception and may be associated with a planned operating state in which the planned activity will occur. For example, radio X may be a transmitter radio and may send a notification of its planned activity to request silence from other transmitter radios or to allow receiver radios to take appropriate actions, e.g., due to interference from radio X. Radio X may also be a receiver radio and may send a notification of its planned activity to allow transmitter radios to avoid collision with radio X on the same band and/or to allow other receiver radios to take appropriate actions.

[0081] Radio X may provide the planned activity, the planned operating state, and/or other information in the notification. In one design, the notification may convey one or more of the following:

- Radio identity (ID) of radio X,
- Planned operating state of radio X,

- Priority of the planned activity and/or priority of radio X,
- Start time and/or periodicity of the planned activity,
- Stop time and/or duration of the planned activity,
- Deadline of the planned activity,
- Transmit power level and frequency channel to use for the planned activity, and/or
- Other information for the planned activity or for radio X.

[0082] The priority of the planned activity and/or the priority of radio X may be assigned by coexistence manager 240 (e.g., during registration of radio X), or assigned by some other entity responsible for assigning priority, or ascertained in other manners. The entity assigning priority may reside within wireless device 110 or in a system. Priorities may have globally defined meanings, and activities from different radios with the same priority may have equal importance. Priorities may be static or may be dynamically changed. For example, the priority of an activity may increase as its deadline approaches.

[0083] In one design, radio X may send notifications periodically in each decision period when there is planned activity, e.g., as shown in FIG. 9. A decision period may cover a particular time duration, which may be selected based on the desired latency for decisions from coexistence manager 240. For example, a decision period may cover 100 microseconds (μs) or some other duration. In another design, radio X may send a notification whenever there is a change in the planned activity or the planned operating state of radio X. In this design, the activity and the operating state for radio X in a prior decision period may be used for the current decision period unless a new planned activity and/or a new planned operating state is sent by radio X.

[0084] Coexistence manager 240 may receive notifications from all active radios in a decision period and may perform evaluation and arbitration as necessary. Coexistence manager 240 may determine whether any of the active radios will collide with one another. A collision may occur between a transmitter radio and a receiver radio if their concurrent operation will adversely impact the performance of one radio (typically the receiver radio) beyond an acceptable level. For example, the transmit power of the transmitter radio may cause interference to the receiver radio and may result in unacceptable performance for the receiver radio. In one design coexistence manager 240 may arbitrate between colliding radios and may make decisions on activities for the next decision period. The arbitration may be based on a set of rules that may be defined

based on desired goals. The set of rules may operate on preferences, priorities, and/or other performance metrics. Coexistence manager 240 may essentially implement an event scheduling algorithm, which may be based on proportional fairness and/or other criteria. In another design, coexistence manager 240 may select one or more radios based on a set of rules, determine appropriate notification alerts for radios impacted by each selected radio, and send the notification alerts to the impacted radios.

[0085] Coexistence manager 240 may send a response to each affected radio. The response may also be referred to as a notification alert (NA). There may be multiple responses for multiple radios due to a notification from one radio. For example, a high-power transmit activity by a GSM transmitter radio may impact multiple coexisting radios such as a broadcast TV receiver radio and a GPS receiver radio. A response for a radio may indicate a selected operating state for the radio, at least one configurable parameter setting for the radio, etc. Each radio that receives a response may adjust its operation (e.g., change its operating state, adjust one or more configurable parameters, etc.) in accordance with the response to reduce interference to other radios or to combat interference from other radios.

[0086] In one design, radio coexistence management may be performed in a synchronous manner, e.g., as shown in FIG. 9. In this design, the active radios may send their notifications periodically in each decision period. For example, each radio may be assigned a particular time slot in each decision period and may send its notification in the assigned time slot. This design may allow a number of radios to share a common bus and to send their notifications without collision on the common bus. Coexistence manager 240 may make decisions and may send responses periodically in each decision period. For example, coexistence manager 240 may make decisions in a first interval and may send responses in a second interval of each decision period. Each response may include a radio ID of a radio to which the response is intended. All active radios may listen for responses sent by coexistence manager 240. Each radio may retain the response sent to that radio, as determined by the radio ID.

[0087] In another design, radio coexistence management may be performed in an asynchronous manner. In this design, each radio may send its notification whenever triggered, e.g., due to planned activity in an upcoming interval. Coexistence manager 240 may make decisions and send responses whenever notifications are received.

[0088] **FIG. 10** shows a design of a message flow 1000 for controlling radios for the decentralized architecture shown in FIG. 8B. In general, up to N radios 220 may communicate with each other and with coexistence manager 240. For simplicity, only three radios X, Y and Z are shown in FIG. 10. For clarity, the processing performed by radio X is described below. Similar processing may be performed by each active radio.

[0089] In one design, radio X may register itself with coexistence manager 240 via a registration event. The registration may allow coexistence manager 240 to become aware of radio X, to download a pertinent portion of the radio coexistence database to radio X, to allocate communication resources to radio X, etc.

[0090] In one design, coexistence manager 240 may determine a radio coexistence database for radio X and may provide this database to radio X. If radio X is a receiver radio, then the database may be referred to as a receive (RX) database. The RX database may include a set of transmitter radios that might collide with receiver radio X, one or more possible resolutions, etc. A resolution may be implemented solely by receiver radio X or may require a change to at least one configurable parameter of a transmitter radio. The RX database for radio X may be provided to radio X and may be used by radio X to control its operation and/or the operation of other radios. If radio X is a transmitter radio, then the database may be referred to as a transmit (TX) database. The TX database may include a set of receiver radios that might collide with transmitter radio X, one or more possible resolutions, etc.

[0091] In one design, radio X may send an event request (ER) to other active radios whenever there is planned activity for radio X in an upcoming time period. An event request may also be referred to as an event notification. The event request may convey pertinent information regarding the planned activity of radio X (denoted as "Event X1" in FIG. 10) and may include any of the information described above for message flow 900 such as planned parameter settings for radio X (denoted as "Settings S1" in FIG. 10). The other radios (e.g., radios Y and Z) may receive the event request from radio X and may determine whether the planned activity of radio X will collide with any planned activities for these radios. Each radio may use its RX or TX database to detect for possible collision with the planned activity of radio X. If there is a collision, then the radio may compare the priority of its planned activity with the priority of the planned activity of radio X, which may be provided by the event request. The radio may then send a response, which may include one of the responses shown in Table 1.

Table 1

Response		Description
Absolute NACK	aNACK	Planned activity of radio X should not occur.
Conditional NACK	cNACK	Planned activity of radio X should not occur unless one or more configurable parameters of radio X are changed.
Absolute ACK	aACK	Planned activity of radio X does not collide and can occur.
Conditional ACK	cACK	Planned activity of radio X can occur but one or more configurable parameters of radio X should be changed.

[0092] The aACK and aNACK may indicate whether or not the planned activity of radio X can occur. The cNACK may indicate that the planned activity of radio X can occur only if certain changes are made by radio X. The cNACK may result from (i) a collision between a transmit event of radio X and a receive event of another radio having a higher priority and (ii) a resolution to the collision being available. The cNACK may include information for the required changes. For example, radio X may be a transmitter radio and may be required to transmit on a different channel, or at a lower transmit power level, etc. Radio X may be required to implement the change, or the planned activity may not be granted.

[0093] The cACK may indicate that the planned activity of radio X can occur but certain changes should be made by radio X. The cACK may result from (i) a collision between a transmit event of radio X and a receive event of another radio having a lower priority and (ii) a resolution to the collision being available. The cACK may include information for the requested change. For example, radio X may be requested to transmit on a different channel, or at a lower transmit power level, etc. Radio X may or may not implement the requested change and may perform the planned activity regardless.

[0094] Radio X may receive responses from all other radios for its request. Radio X may perform its planned activity if aACK, cACK and/or cNACK are received from other radios and may implement the changes in any cNACK. Radio X may forgo its planned activity if aNACK is received from any radio. In this case, radio X may change one or more configurable parameters and may repeat the process described above for a second iteration with the new parameter settings (denoted as “Settings S2” in FIG. 10).

[0095] There may be cases in which radio X may apply a requested change from one radio, which may then adversely impact the operation of another radio. For example, radio X may be a transmitter radio and may send a request for a transmit activity, which may be received by receiver radios Y and Z. Radio Y may detect a collision with its planned activity and may respond with cACK or cNACK. Radio Z may detect no collision with its planned activity and may send aACK. Radio X may implement the requested change from receiver radio Y to improve the performance of radio Y. Unfortunately, radio X may collide with receiver radio Z and may cause more interference to radio Z as a result of the change.

[0096] In one design, the processing described above may be performed iteratively until all collisions can be addressed. For the example described above, transmitter radio X may send another request if it decides to implement a requested change and may stop when only aNACKs or aACKs are received for the planned activity. In another design, a receiver radio may return information that may be used by transmitter radio X to mitigate collision with the receiver radio.

[0097] In general, for both the centralized architecture in FIG. 8A and the decentralized architecture in FIG. 8B, the decisions on the operation of radios may be processed in a single iteration or in multiple iterations. Multiple iterations may be especially suitable for the decentralized architecture.

[0098] For both the centralized and decentralized architectures, interference between coexisting radios may be mitigated by controlling the operation of one or more radios. The interference mitigation may be based on one or more operational dimensions such as time, frequency, transmit power, code, space, polarization, etc. For time-based mitigation, the time of events of different radios may be adjusted (e.g., delayed and/or advanced) in a coordinated fashion so as to mitigate joint interference. The time adjustments may be limited so that each affected radio can conform to applicable specifications with sufficient margin. For frequency-based mitigation, one or more new frequency channels may be selected for one or more radios to mitigate interference for all radios. For transmit power-based mitigation, the transmit power of one or more transmitter radios may be adjusted so as to reduce joint interference (e.g., based on allowable requirements for receiver radios, not necessarily at sensitivity). The transmit power adjustment may override power control in order to achieve the desired interference mitigation. For code-based mitigation, different codes (e.g., orthogonal

codes, scrambling codes, etc.) may be used for different radios to mitigate (e.g., reduce or randomize) interference. For spatial-based mitigation, different radios may be associated with antennas at different physical locations. These antennas may be for different spatial directions and may be selected to reduce interference among the radios. The spatial directions may relate to beam steering or sectorization patterns. The control of these antennas may be achieved via coexistence manager 240 to mitigate joint interference. For polarization-based mitigation, different polarization directions (e.g., vertical and horizontal directions) may be used for different radios to reduce interference. A particular polarization may be obtained for a particular radio by rotating an antenna for the radio, by selecting an antenna or an antenna array that can provide the desired polarization, etc. Interference may also be mitigated based on any one or any combination of the dimensions described above. Interference may also be mitigated in other manners.

[0099] Coexistence manager 240 may communicate with radios 220 in various manners to support radio coexistence. The communication may be dependent on whether the centralized architecture in FIG. 8A or the decentralized architecture in FIG. 8B is employed. For clarity, communication between coexistence manager 240 and radios 220 for the centralized architecture is described below.

[00100] **FIG. 11** shows an exemplary design of coexistence manager 240 communicating with a number of processing modules 260 for a number of radios 220 supporting different radio technologies. Processing module 260a may support CDMA (e.g., CDMA 1X, WCDMA, and/or some other variant of CDMA) and may communicate with a transmitter radio 220a and a receiver radio 220b. Processing module 260b may support GSM and may communicate with a transmitter radio 220c and a receiver radio 220d. Processing module 260c may support LTE and may communicate with a transmitter radio 220e and a receiver radio 220f. Processing module 260d may support GPS and may communicate with a receiver radio 220g. Processing module 260e may support WLAN and may communicate with a transmitter radio 220h and a receiver radio 220i. Processing module 260f may support Bluetooth/FM and may communicate with a transmitter radio 220j and a receiver radio 220k. Processing module 260g may support broadcast reception and may communicate with a receiver radio 220l.

[00101] In the design shown in FIG. 11, coexistence manager 240 and all processing modules 260 may be implemented within digital processor 230. In another design, coexistence manager 240 and processing modules 260a, 260b, 260c and 260d may be implemented within digital processor 230, and remaining processing modules 260e, 260f and 260g may be implemented external to digital processor 230. In general, digital processor 230 may include any number of processing modules 260 for any set of radio technologies.

[00102] Processing modules 260a, 260b, 260c, 260e and 260f may each include (i) an interface unit 262 for communicating with coexistence manager 240 and/or other entities, (ii) a TX module 264 supporting the associated transmitter radio, and (iii) an RX module 266 supporting the associated receiver radio. Processing modules 260d and 260g may each include (i) an interface unit 262 for communicating with coexistence manager 240 and/or other entities and (ii) an RX module 266 supporting the associated receiver radio. Each processing module 260 may also perform processing for physical layer (L1), upper layer (L3), and/or other layers. Some processing modules may also communicate directly with one another to mitigate interference and for other functions. For example, WLAN processing module 260e and Bluetooth processing module 260f may communicate directly via a Packet Traffic Arbitration (PTA) interface.

[00103] In the design shown in FIG. 11, processing modules 260 may send notifications to coexistence manager 240 for planned activities and may receive responses from coexistence manager 240. Each processing module 260 may control its transmitter radio and/or its receiver radio based on the responses received from coexistence manager 240. For example, a given processing module 260 may control RF parameters, antenna parameters, baseband parameters, protocols and their parameters, etc. The RF parameters may include receiver sensitivity, spurious response, linearity and noise, filtering, traps, insertion loss, adjacent channel rejection, filter selectivity, large signal parameters (e.g., RX blocking, wanted signals and unwanted harmonics, cross-compression, reciprocal mixing, oscillator pulling, etc.), small signal parameters (e.g., out-of-band phase noise of transmitter in receive band, reciprocal mixing, spurious receiver response, etc.), dynamic control mechanisms, transmit power control, digital predistortion (DPD), tunable filters, etc. The antenna parameters may include the number of antennas, diversity scheme, antenna sharing and switching control, physical geometry, antenna to antenna coupling loss, isolation, transmit/receive (T/R) switch,

antenna spacing, polarization, etc. The baseband parameters may include interference cancellation algorithms, adaptive notch filter, spectrum sensing, adaptive algorithms, jamming scenarios, adaptive hopping, traffic sensing and detection, cognitive methods to orthogonalize radios, coding and modulation control (back-off), cognitive methods to orthogonalize radios, etc. The protocols and their parameters may include time division multiplex (TDM) coordination, Medium Access Control (MAC) scheduling, temporal solutions, interference avoidance, band selection, deferred transmission, packet timing information, priority information, inhibit transmissions, packet retries, queuing, etc. Other configurable parameters may also be controlled to mitigate interference and achieve good performance.

[00104] As an example, a receiver radio may support multiple modes. A first mode may have a higher gain and a lower noise figure and may be selected when jammers are not present and higher sensitivity is desired. A second mode may have a lower gain and a higher IIP3 and may be selected when jammers are present and higher linearity is desired. One mode may be selected for the receiver radio based on the presence or absence of interference from other radios as well as the presence or absence of jammers. Other configurable parameters for the receiver radio may include changes to bias conditions, linearity, frequency plan, filtering, PLL modes, power levels, sampling rates, etc.

[00105] A transmitter radio may also include various configurable parameters. For example, the linearity of a power amplifier may be improved (e.g., by increasing the bias current) to reduce adjacent channel power ratio (ACPR) and hence reduce the amount of interference to other receiver radios. Predistortion and other linearization techniques may also be used to lower ACPR and avoid desense of receiver radios. Other configurable parameters for the transmitter radio may include changes to a fractional-N PLL (e.g., changes to divide ratios or reference clock) to reduce or move spurs causing desense, changes to the clock rate (e.g., chipx32, 64, or 96) of digital-to-analog converters (DACs) to reduce DAC image or to avoid receiver bands (e.g., GPS band), etc.

[00106] FIG. 11 shows exemplary communication between coexistence manager 240 and processing modules 260 for different radios 220. In general, coexistence manager 240 and processing modules 260 may exchange messages for registration, notifications, responses, and/or other functions via (i) software-based messages passed between

different logical entities and/or (ii) hardware-based messages passed via a common bus to which all entities are connected. Direct interface between processing modules 260 (e.g., the PTA interface between WLAN and Bluetooth processing modules 260e and 260f) may also be implemented with, and absorbed by, messaging via the common bus.

[00107] Coexistence manager 240 may support an arbitrary collection of radios. Each radio may be responsible for controlling its configurable parameters to mitigate interference caused or observed by that radio. Each radio may be associated with a radio controller that may receive responses for that radio and set the configurable parameters accordingly. The radio controller may also be referred to as a Notification Handler (NH), a host RF driver (DRV), etc.

[00108] **FIG. 12** shows two designs of radio controllers for radios. A processing module 260x for a given radio technology may include an interface unit 262x to exchange messages with coexistence manager 240, a TX module 264x supporting an associated transmitter radio 220x, and an RX module 266x supporting an associated receiver radio 220y.

[00109] For a first design, a radio controller may reside outside of an associated radio (e.g., within a processing module) and may set the configurable parameters of the radio. For a second design, a radio controller may reside within an associated radio and may set the configurable parameters of the radio. In the example shown in FIG. 12, a radio controller 224x is implemented with the first design and resides within TX module 264x. Radio controller 224x may receive responses from coexistence manager 240 for radio 220x and may set the configurable parameters for radio 220x in accordance with the received responses. A radio controller 224y is implemented with the second design and resides within radio 220y. Processing module 260x may receive responses from coexistence manager 240 for radio 220y and may forward the responses to radio controller 224y. Radio controller 224y may set the configurable parameters for radio 220y in accordance with the received responses.

[00110] Wireless device 110 may include a number of antennas to support the N radios 220. For example, wireless device 110 may include multiple antennas for WWAN systems for different bands, one or more antennas for GPS, one or more antennas for broadcast systems, one or more antennas for WLAN systems and Bluetooth, one or more antennas for FM systems, etc. Having one or more dedicated antennas for each radio may result in a large number of antennas for all N radios.

[00111] **FIG. 13A** shows a design of supporting N radios 220 with shared antennas. Wireless device 110 may include a set of K antennas 210a through 210k that can support N radios 220a through 220n, where K may be any suitable integer value. For example, wireless device 110 may include two antennas for WWAN, WLAN, Bluetooth and GPS and one antenna for broadcast. A switchplexer 214 may couple to the K antennas 210 and also to the N radios 220. Switchplexer 214 may couple each radio 220 to one or more antennas 210 based on an antenna control. Switchplexer 214 may allocate the K antennas 210 to one or more active radios depending on which radios are active. For example, multiple antennas may be allocated to WWAN for receive diversity during a voice or data connection. These antennas may be switched to WLAN for receive diversity when WWAN is not in use or when dictated by requirements. The K available antennas may be configured for receive diversity, selection diversity, multiple-input multiple-output (MIMO), or beamforming for any of the radios. The operation of switchplexer 214 may be controlled by coexistence manager 240 and/or some other entity.

[00112] **FIG. 13B** shows a design of supporting N radios 220 with one or more antenna arrays. Wireless device 110 may include Q antenna arrays 208a through 208q, where $Q \geq 1$. The first antenna array 208a may include L antennas 210aa through 210al, where $L > 1$. Each remaining antenna array may include the same or different number of antennas. Switchplexer 214 may couple to the Q antenna arrays 208 and also to the N radios 220. Switchplexer 214 may couple each radio 220 to one or more antenna arrays 208 based on an antenna control. The phases of the antennas in a selected antenna array may be controlled to achieve steering, beamforming, etc. The operation of switchplexer 214 may be controlled by coexistence manager 240 and/or some other entity.

[00113] **FIG. 14** shows a design of a process 1400 for controlling the operation of radios. Planned operating states of multiple radios in an upcoming interval may be obtained (block 1412). The performance of one or more radios among the multiple radios may be determined based on the planned operating states of the multiple radios and a database of information on performance versus operating states for different combinations of radios (block 1414). At least one new operating state for at least one radio among the multiple radios may be selected based on the determined performance and the database such that good performance can be achieved for as many radios as

possible (block 1416). In one design, the multiple radios may be arranged into one or more sets, with each set including radios that collide. The operating states of all radios in each set may be determined jointly to obtain good performance for the radios in that set. The operating states of the multiple radios may also be determined in other manners. In any case, the at least one new operating state may be sent to the at least one radio (block 1418). Each radio may operate in accordance with its new operating state (if any) or its planned operating state.

[00114] In one design, the database may comprise information on performance of a receiver radio versus operating state of the receiver radio and operating state of at least one transmitter radio, e.g., as shown in FIG. 4. The operating state for each radio may be determined based on specific setting of at least one configurable parameter for the radio. The operating state may also be determined based on radio conditions observed by the radio and/or other factors.

[00115] In another design, the database may comprise information on performance of a receiver radio for at least one operating scenario for the receiver radio and at least one transmitter radio, e.g., as shown in FIG. 5. Each operating scenario may be associated with a particular operating state for the receiver radio and a particular operating state for the transmitter radio. The at least one operating scenario may comprise a sensitivity scenario associated with a low received power level for the receiver radio and a high transmit power level for the transmitter radio. The at least one operating scenario may also comprise a nominal scenario associated with received power of the receiver radio being above a first level and transmit power of the transmitter radio being below a second level.

[00116] In yet another design, the database may comprise information on performance of a receiver radio versus at least one configurable parameter for at least one transmitter radio. The at least one configurable parameter may comprise transmit power level, e.g., as shown in FIG. 6. The performance of the receiver radio may also be based on at least one default parameter setting for the receiver radio and at least one default parameter setting for the transmitter radio.

[00117] In one design, the performance of a radio in the database may be quantized using a set of L levels, where L may be any integer greater than one. For example, L may be equal to three, and the performance of the radio may be quantized as acceptable,

marginal, or unacceptable. The performance may also be quantified in other manners, e.g., with percentage of channels for different performance levels, as shown in FIG. 7.

[00118] In one design, for a centralized architecture, process 1400 may be performed by a coexistence manager designated to control the operation of all of the multiple radios. The coexistence manager may maintain the database for all radios, e.g., as shown in FIG. 8A. The coexistence manager may communicate with a radio for registration of the radio. The coexistence manager may determine a portion of the database for controlling operation of the radio and may load this portion of the database from external memory (e.g., memory 252 in FIG. 2) to internal memory (e.g., memory 244 in FIG. 2).

[00119] In another design, for a decentralized architecture, process 1400 may be performed by a controller for one of the multiple radios. The controller may communicate with the coexistence manager for registration of the radio and may receive the database from the coexistence manager. The database may include information for controlling the operation of the radio. Each remaining radio may also have a controller that may similarly perform process 1400 for that radio. Different radios may have different databases, e.g., as shown in FIG. 8B.

[00120] **FIG. 15** shows a design of a process 1500 for updating a database used to control the operation of radios. The performance of a first radio may be determined (block 1512). An operating state of the first radio may also be determined (block 1514). At least one operating state of at least one second radio operating concurrently with the first radio may also be determined (block 1516). The database may be updated with the performance of the first radio based on the operating states of the first and second radios (block 1518). The frequency channels and frequency bands of the first and second radios may also be determined. The database may be updated based further on the frequency channels and frequency bands of the first and second radios. The database may comprise a color chart storing the performance of receiver radios versus operating states of transmitter and receiver radios, e.g., as shown in FIG. 4. The database may also store the information in some other format or structure.

[00121] In one design, the performance of the first radio may be determined based on computation, computer simulation, or empirical measurements. In another design, the performance of the first radio may be determined based on measurements obtained with the first and second radios being operational. In one design, the database may be pre-

configured with initial information prior to operation and may be updated with new information obtained from measurements during operation. Information for the database may also be downloaded from a system during operation.

[00122] In one design, the database may be updated for a subset of all possible combinations of operating states for the first and second radios. The subset may comprise supported or likely combinations of operating states for the first and second radios, which may correspond to different operating scenarios for the first and second radios. In one design, the database may be updated with the performance of the first radio based on the operating state of a single second radio, e.g., as shown in FIG. 4. In another design, the database may be updated with the performance of the first radio based on the operating states of multiple second radios. In general, the database may be updated with the performance of the first radio based on the operating states of any number of radios, e.g., a set of radios that collide.

[00123] In one design, the performance of the first radio may be quantized to one of a set of levels, e.g., three levels comprising an acceptable level, a marginal level, and an unacceptable level. The performance of the first radio may also be quantified in other manners.

[00124] The database may be used to control the operation of multiple radios operating concurrently. In one design, planned operating states of the multiple radios in an upcoming interval may be obtained. The performance of one or more radios among the multiple radios may be determined based on the planned operating states of the multiple radios and the database. At least one new operating state for at least one radio among the multiple radios may be selected, if necessary, based on the determined performance and the database to achieve good performance for as many radios as possible.

[00125] Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[00126] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the

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

[00127] The various illustrative logical blocks, modules, and circuits described in connection with the disclosure herein may be implemented or performed with a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[00128] The steps of a method or algorithm described in connection with the disclosure herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[00129] In one or more exemplary designs, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If

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

[00130] The previous description of the disclosure is provided to enable any person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the spirit or scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

CLAIMS

1. A method of supporting wireless communication, comprising:

obtaining planned operating states of multiple radios in an upcoming interval;

determining performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and a database of information on performance versus operating states for different combinations of radios;

selecting at least one new operating state for at least one radio among the multiple radios based on the determined performance and the database; and

sending the at least one new operating state to the at least one radio.

2. The method of claim 1, wherein an operating state of a radio is determined based on specific setting of at least one configurable parameter for the radio.

3. The method of claim 2, wherein an operating state of a radio is determined based further on radio conditions observed by the radio.

4. The method of claim 1, wherein the database comprises information on performance of a receiver radio versus operating state of the receiver radio and operating state of at least one transmitter radio.

5. The method of claim 1, wherein the database comprises information on performance of a receiver radio for at least one operating scenario for the receiver radio and at least one transmitter radio.

6. The method of claim 5, wherein each operating scenario is associated with a particular operating state for the receiver radio and a particular operating state for each transmitter radio.

7. The method of claim 5, wherein the at least one operating scenario comprises a sensitivity scenario associated with a low received power level for the receiver radio and a high transmit power level for each transmitter radio,

8. The method of claim 5, wherein the at least one operating scenario comprises a nominal scenario associated with received power of the receiver radio being above a first level and transmit power of each transmitter radio being below a second level.

9. The method of claim 1, wherein the database comprises information on performance of a receiver radio versus at least one configurable parameter for at least one transmitter radio.

10. The method of claim 9, wherein the at least one configurable parameter comprises transmit power level of each transmitter radio.

11. The method of claim 9, wherein the performance of the receiver radio is based on at least one first default parameter setting for the receiver radio and at least one second default parameter setting for each transmitter radio.

12. The method of claim 1, wherein the performance of a radio in the database is quantized using a set of L levels, where L is an integer greater than one.

13. The method of claim 12, wherein L is equal to three, and wherein the performance of the radio is quantized as acceptable, marginal, or unacceptable.

14. The method of claim 1, wherein the obtaining, determining, selecting and sending are performed by a coexistence manager designated to control operation of all of the multiple radios.

15. The method of claim 1, further comprising:
communicating with a radio for registration of the radio;
determining a portion of the database for controlling operation of the radio; and
loading the portion of the database from external memory to internal memory.

16. The method of claim 1, wherein the obtaining, determining, selecting and sending are performed by a controller for one of the multiple radios.

17. The method of claim 1, further comprising:

communicating with a coexistence manager for registration of a radio; and

receiving the database from the coexistence manager.

18. An apparatus supporting wireless communication, comprising:

means for obtaining planned operating states of multiple radios in an upcoming interval;

means for determining performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and a database of information on performance versus operating states for different combinations of radios;

means for selecting at least one new operating state for at least one radio among the multiple radios based on the determined performance and the database; and

means for sending the at least one new operating state to the at least one radio.

19. The apparatus of claim 18, wherein the database comprises information on performance of a receiver radio versus operating state of the receiver radio and operating state of at least one transmitter radio.

20. The apparatus of claim 18, further comprising:

means for communicating with a radio for registration of the radio;

means for determining a portion of the database for controlling operation of the radio; and

means for loading the portion of the database from external memory to internal memory.

21. The apparatus of claim 18, further comprising:

means for communicating with a coexistence manager for registration of a radio; and

means for receiving the database from the coexistence manager.

22. An apparatus supporting wireless communication, comprising:

at least one processor configured to obtain planned operating states of multiple radios in an upcoming interval, to determine performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and a database of information on performance versus operating states for different combinations of radios, to select at least one new operating state for at least one radio among the multiple radios based on the determined performance and the database, and to send the at least one new operating state to the at least one radio.

23. The apparatus of claim 22, wherein the database comprises information on performance of a receiver radio versus operating state of the receiver radio and operating state of at least one transmitter radio.

24. The apparatus of claim 22, wherein the at least one processor is configured to communicate with a radio for registration of the radio, to determine a portion of the database for controlling operation of the radio, and to load the portion of the database from external memory to internal memory.

25. The apparatus of claim 22, wherein the at least one processor is configured to communicate with a coexistence manager for registration of a radio, and to receive the database from the coexistence manager.

26. A computer program product, comprising:

a computer-readable medium comprising:

code for causing at least one computer to obtain planned operating states of multiple radios in an upcoming interval,

code for causing the at least one computer to determine performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and a database of information on performance versus operating states for different combinations of radios,

code for causing the at least one computer to select at least one new operating state for at least one radio among the multiple radios based on the determined performance and the database, and

code for causing the at least one computer to send the at least one new operating state to the at least one radio.

27. A method of supporting wireless communication, comprising:

determining performance of a first radio;

determining at least one operating state of at least one second radio operating concurrently with the first radio; and

updating a database with the performance of the first radio based on the at least one operating state of the at least one second radio.

28. The method of claim 27, further comprising:

determining an operating state of the first radio, and wherein the database is updated with the performance of the first radio based further on the operating state of the first radio.

29. The method of claim 27, wherein the performance of the first radio is determined based on measurements obtained with the first radio and the at least one second radio being operational.

30. The method of claim 27, wherein the performance of the first radio is determined based on computation, computer simulation, or empirical measurements.

31. The method of claim 27, wherein the database is updated for a subset of all possible combinations of operating states for the first and second radios, the subset comprising supported or likely combinations of operating states for the first and second radios.

32. The method of claim 27, wherein the at least one second radio comprises multiple second radios, and wherein the database is updated with the performance of the first radio based on operating states of the multiple second radios

33. The method of claim 27, wherein the database comprises a color chart storing performance of radios versus operating states of the radios.

34. The method of claim 27, further comprising:

determining frequency bands of the first radio and the at least one second radio, and wherein the database is updated based further on the frequency bands.

35. The method of claim 34, further comprising:

determining frequency channels of the first radio and the at least one second radio, and wherein the database is updated based further on the frequency channels.

36. The method of claim 27, further comprising:

quantizing the performance of the first radio to one of a set of levels.

37. The method of claim 27, further comprising:

quantizing the performance of the first radio to one of at least three levels comprising an acceptable level, a marginal level, and an unacceptable level.

38. The method of claim 27, further comprising:

using the database to control operation of multiple radios operating concurrently.

39. The method of claim 38, wherein the using the database to control operation of the multiple radios comprises

obtaining planned operating states of the multiple radios in an upcoming interval,

determining performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and the database, and

selecting at least one new operating state for at least one radio among the multiple radios, if necessary, based on the determined performance and the database.

40. The method of claim 27, wherein the database is pre-configured with initial information prior to operation and is updated with new information during operation.

41. The method of claim 27, further comprising:

downloading information for the database from a system.

42. An apparatus supporting wireless communication, comprising:

means for determining performance of a first radio;

means for determining at least one operating state of at least one second radio operating concurrently with the first radio; and

means for updating a database with the performance of the first radio based on the at least one operating state of the at least one second radio.

43. The apparatus of claim 42, further comprising:

means for determining an operating state of the first radio, and wherein the database is updated with the performance of the first radio based further on the operating state of the first radio.

44. The apparatus of claim 42, wherein the performance of the first radio is determined based on measurements obtained with the first radio and the at least one second radio being operational.

45. The apparatus of claim 42, further comprising:

means for obtaining planned operating states of the multiple radios in an upcoming interval;

means for determining performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and the database; and

means for selecting at least one new operating state for at least one radio among the multiple radios, if necessary, based on the determined performance and the database.

46. The apparatus of claim 42, wherein the database is pre-configured with initial information prior to operation and is updated with new information during operation.

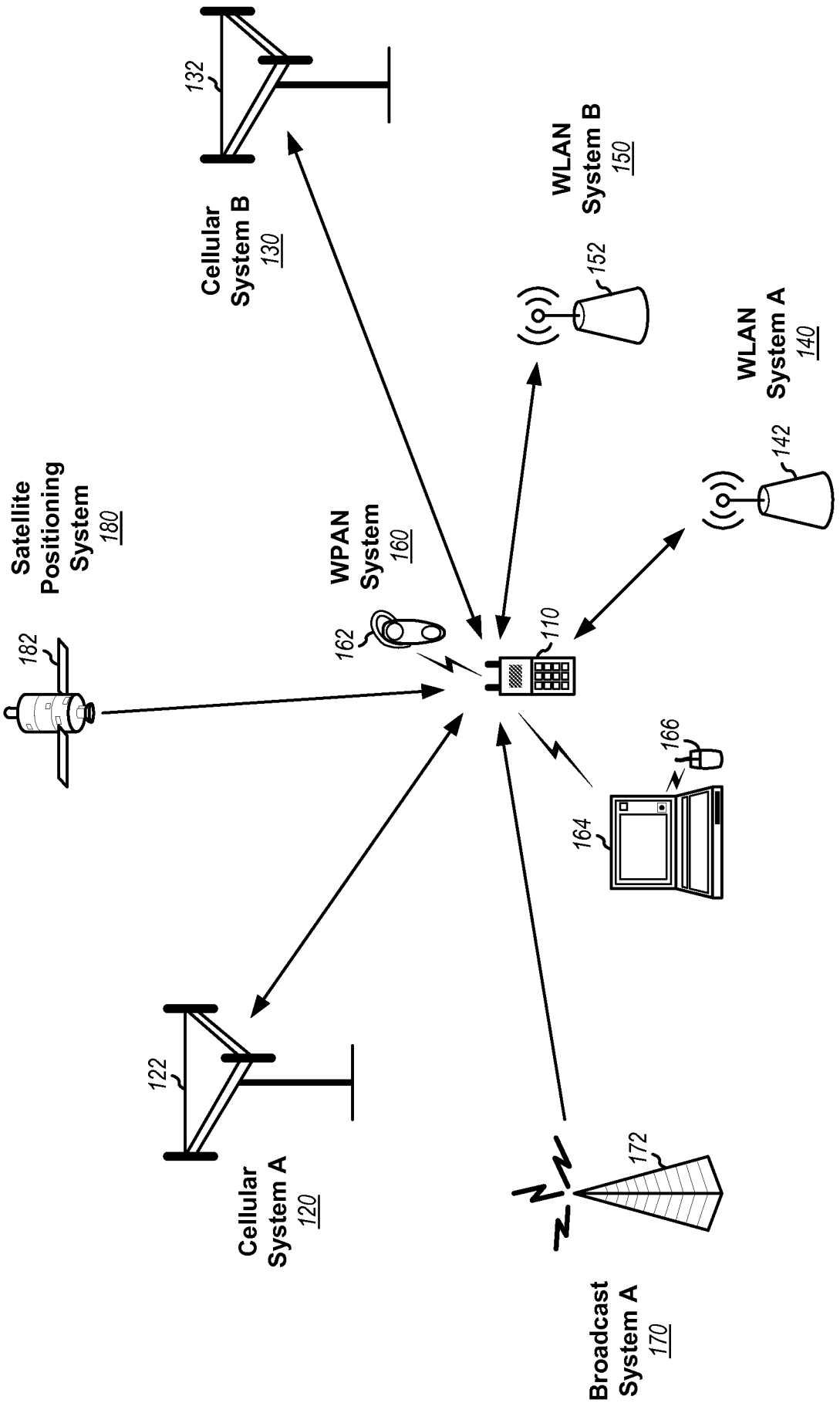
Cellular System B 130
132
WLAN System B 150
152
WLAN System A 140
142
Satellite Positioning System 180
182
WPAN System 160
162
110
166
164
Cellular System A 120
122
172
Broadcast System A 170

FIG. 1

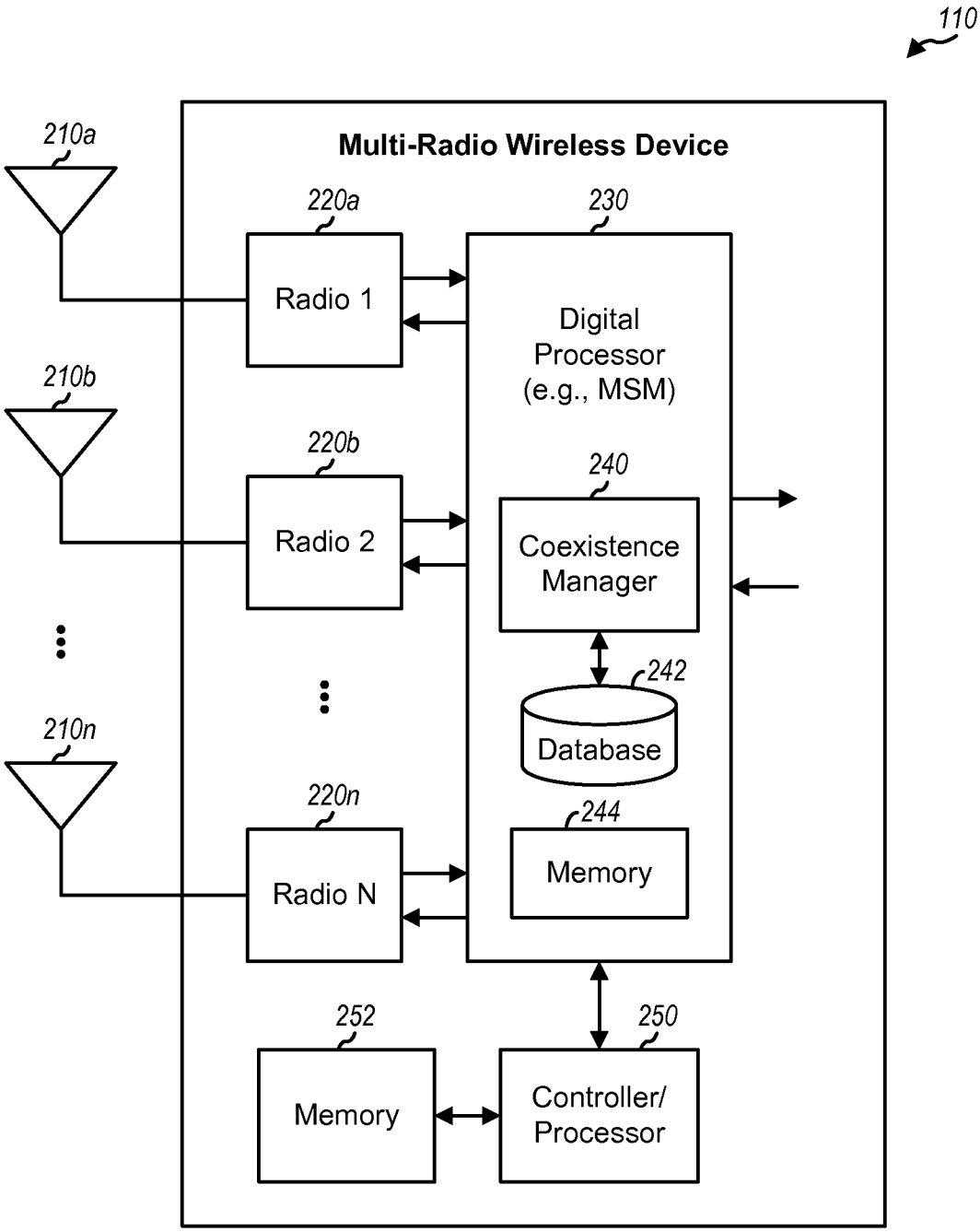
110
Multi-Radio Wireless Device
210a
210b
210n
220a
220b
220n
Radio 1
Radio 2
Radio N
230
Digital Processor (e.g., MSM)
240
Coexistence Manager
242
Database
244
Memory
252
Memory
250
Controller/ Processor

FIG. 2

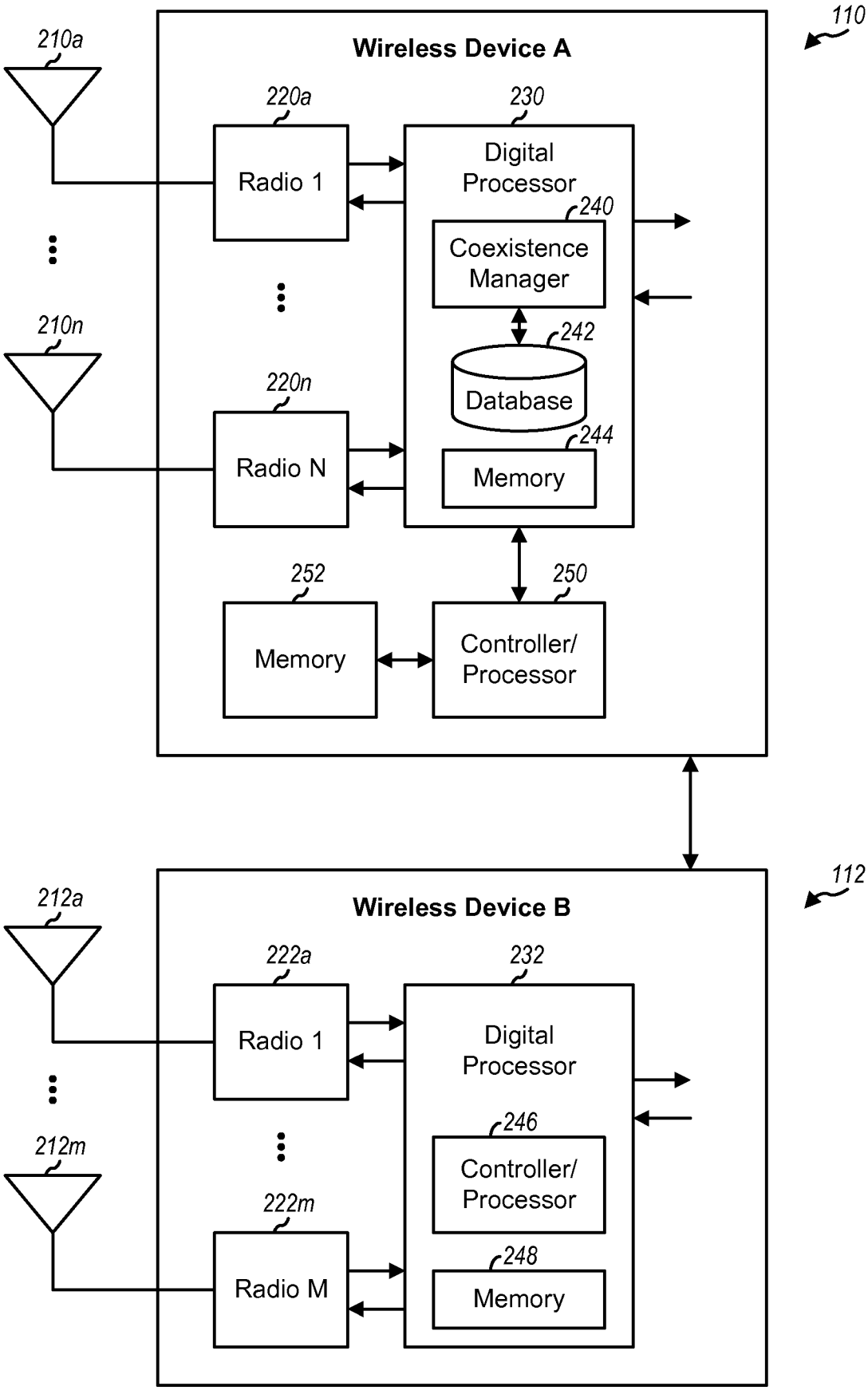
110
Wireless Device A
210a
220a
230
Radio 1
Digital Processor
240
Coexistence Manager
242
Database
210n
220n
Radio N
244
Memory
252
250
Memory
Controller/ Processor
112
Wireless Device B
212a
222a
232
Radio 1
Digital Processor
246
Controller/ Processor
212m
222m
Radio M
248
Memory

FIG. 3

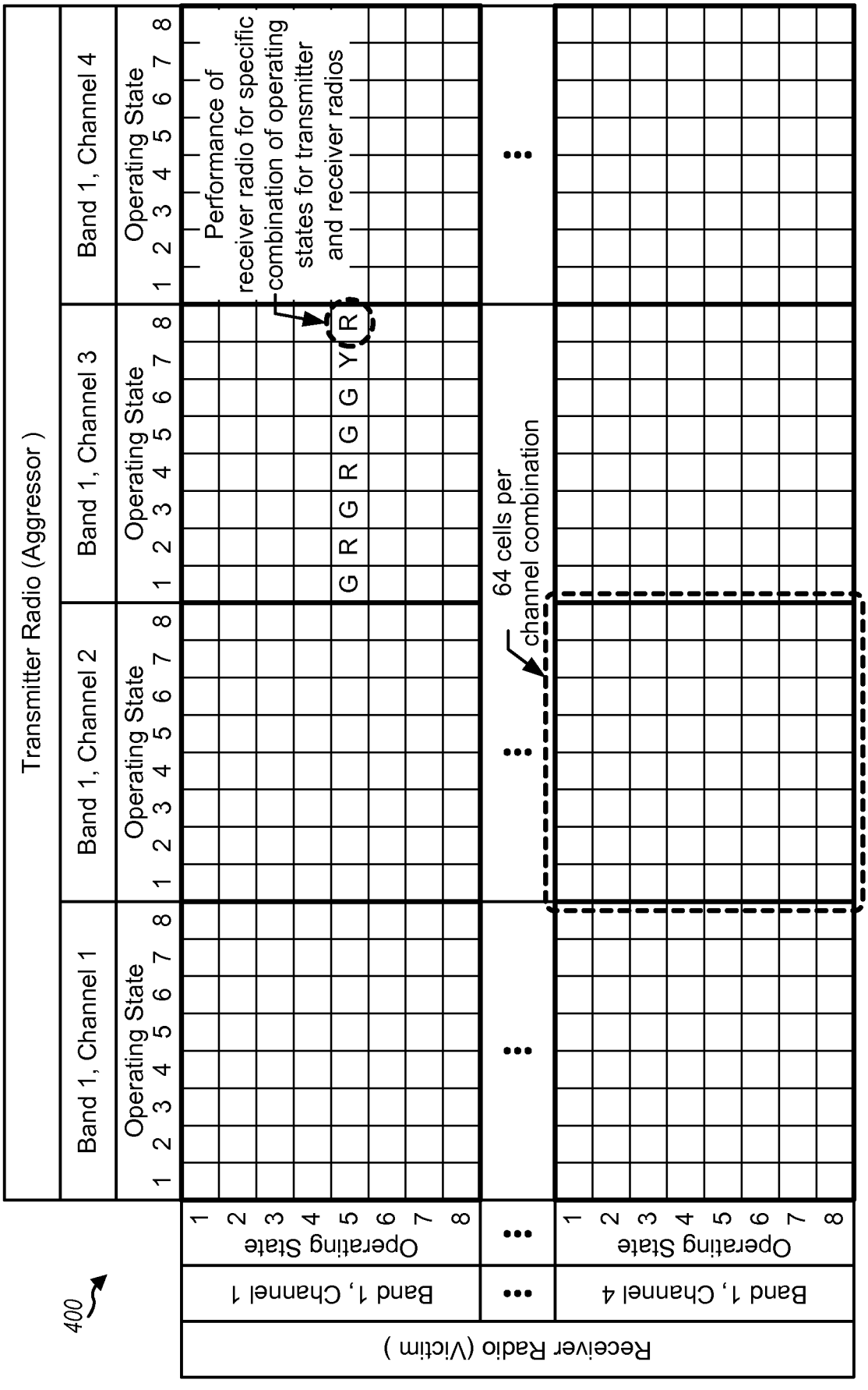
400
Transmitter Radio (Aggressor)
Band 1, Channel 1
Band 1, Channel 2
Band 1, Channel 3
Band 1, Channel 4
Operating State
1 2 3 4 5 6 7 8
Performance of receiver radio for specific combination of operating states for transmitter and receiver radios
G R G R G G Y R
64 cells per channel combination
Receiver Radio (Victim)
Band 1, Channel 1
Band 1, Channel 4
Operating State
Green (G) = Acceptable performance
Yellow (Y) = Marginal performance
Red (R) = Unacceptable performance

FIG. 4

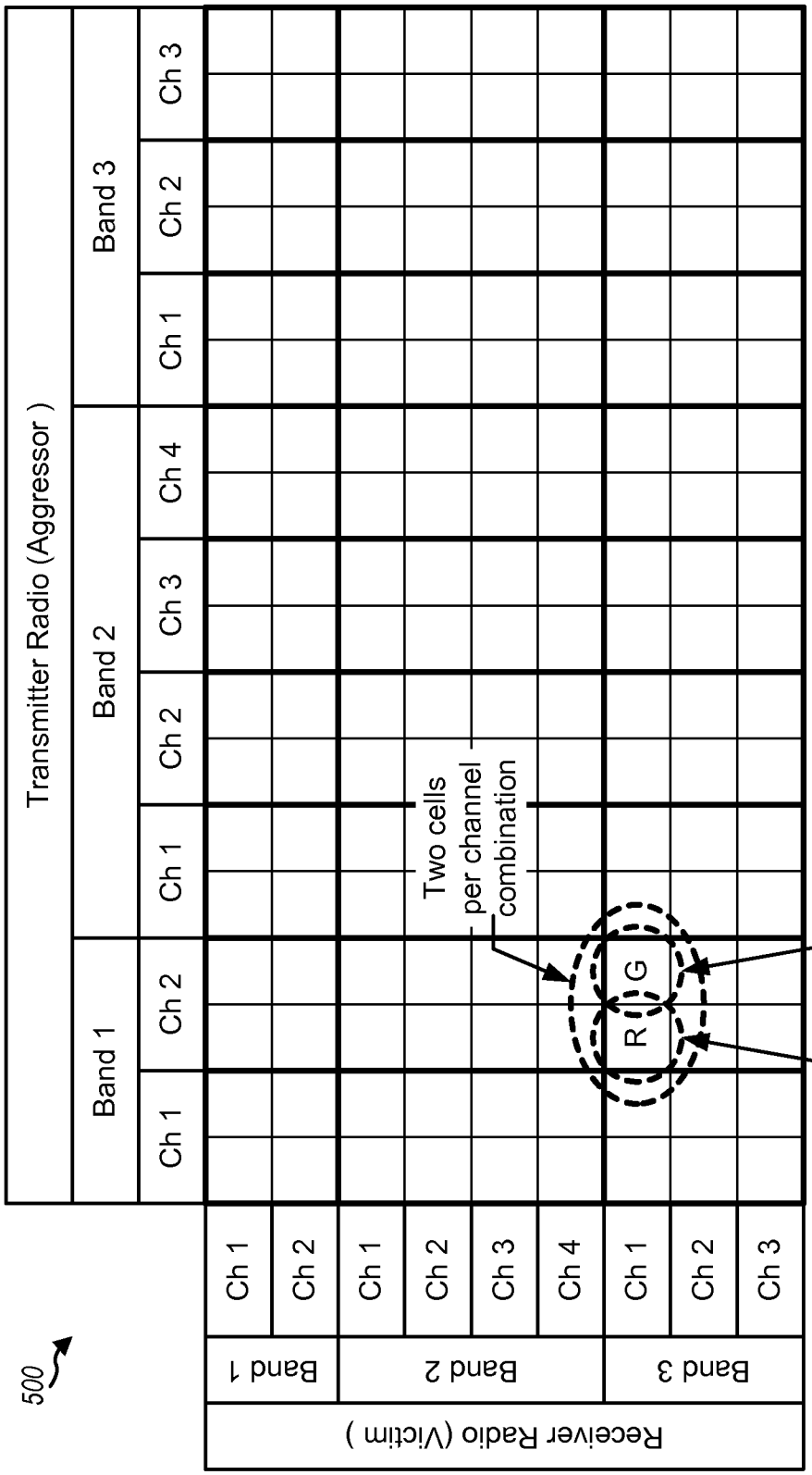
500
Receiver Radio (Victim)
Band 1
Band 2
Band 3
Ch 1
Ch 2
Ch 3
Ch 4
Transmitter Radio (Aggressor)
Two cells per channel combination
R
G
Performance for receiver radio for "nominal" scenario
Performance for receiver radio for "sensitivity" scenario

FIG. 5

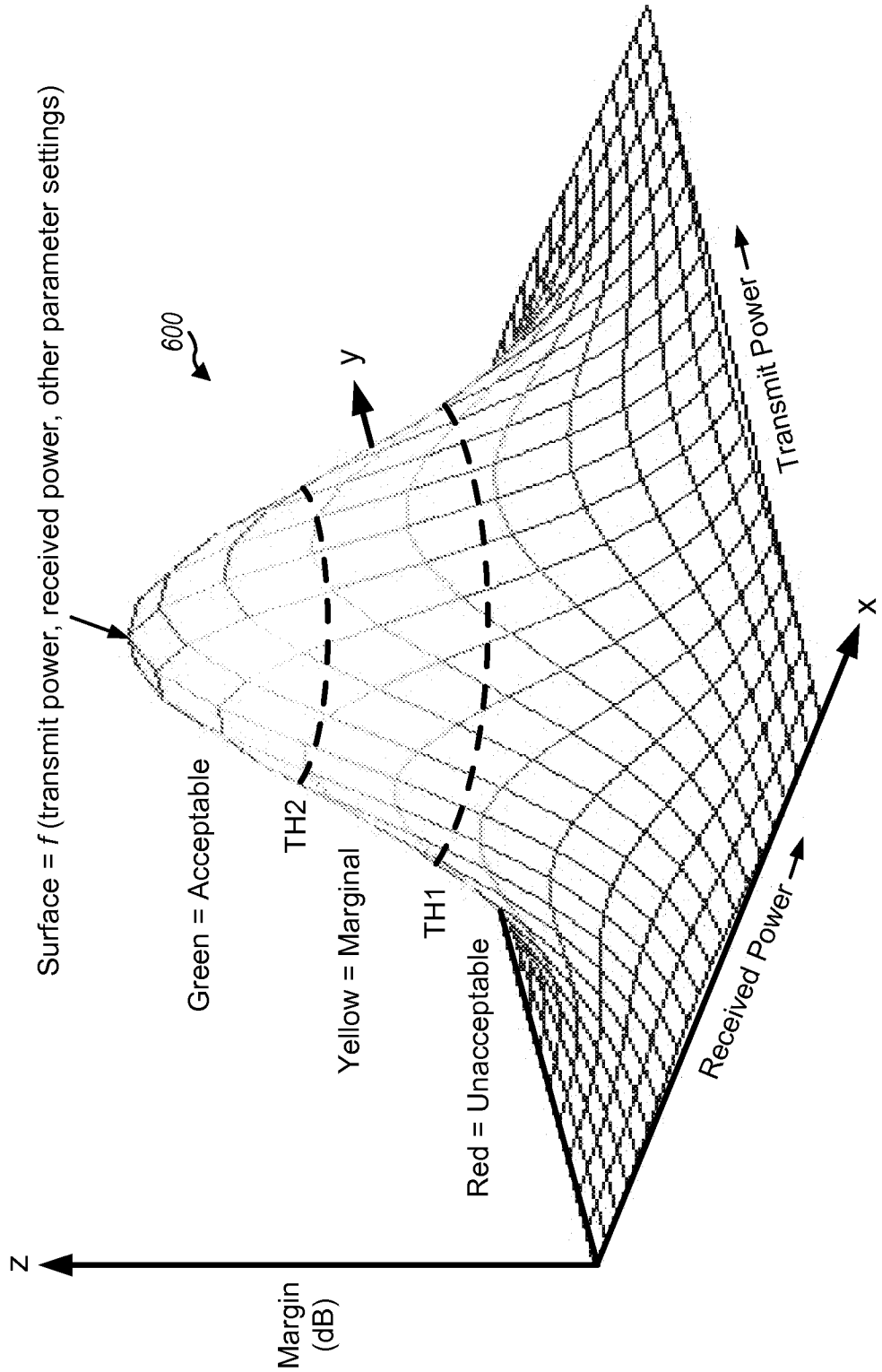
Surface = f (transmit power, received power, other parameter settings)
600
y
Transmit Power
x
Green = Acceptable
TH2
Yellow = Marginal
TH1
Red = Unacceptable
Received Power
z
Margin (dB)

FIG. 6

700

Receiver Radio (Victim)				Transmitter Radio (Aggressor)														Radio Tech
				LTE/E-UTRA								Bluetooth		FM TX		WLAN		Radio Tech
				824-849		2500-2570		2570-2620		2620-2690		2400-2484		88-108		2400-2484		Freq
Radio Tech		Freq	Perf	Sen	Nom	Sen	Nom	Sen	Nom	Sen	Nom	Sen	Nom	Sen	Nom	Sen	Nom	Scenario
	LTE/E-UTRA	2300-2400	Green									100%	100%			100%	100%	
			Yellow									0%	0%			0%	0%	
			Red									0%	0%			0%	0%	
		2570-2620	Green									100%	100%			35%	91%	
			Yellow									0%	0%			55%	0%	
			Red									0%	0%			10%	9%	
		2620-2690	Green									47%	70%			28%	47%	
			Yellow									10%	12%			19%	8%	
			Red									43%	18%			53%	45%	
	Bluetooth	2400-2484	Green			0%	89%	0%	100%	0%	72%							
			Yellow			0%	5%	0%	0%	0%	3%							
			Red			100%	6%	100%	0%	100%	25%							
	FM RX	88-108	Green															
			Yellow															
			Red															
	WLAN	2400-2484	Green			0%	84%	0%	100%	0%	80%							
			Yellow			0%	1%	0%	0%	0%	5%							
			Red			100%	15%	100%	0%	100%	15%							
	GPS	1575																
	FLO	716-722																
		722-728																

Performance for one band combination

710

FIG. 7

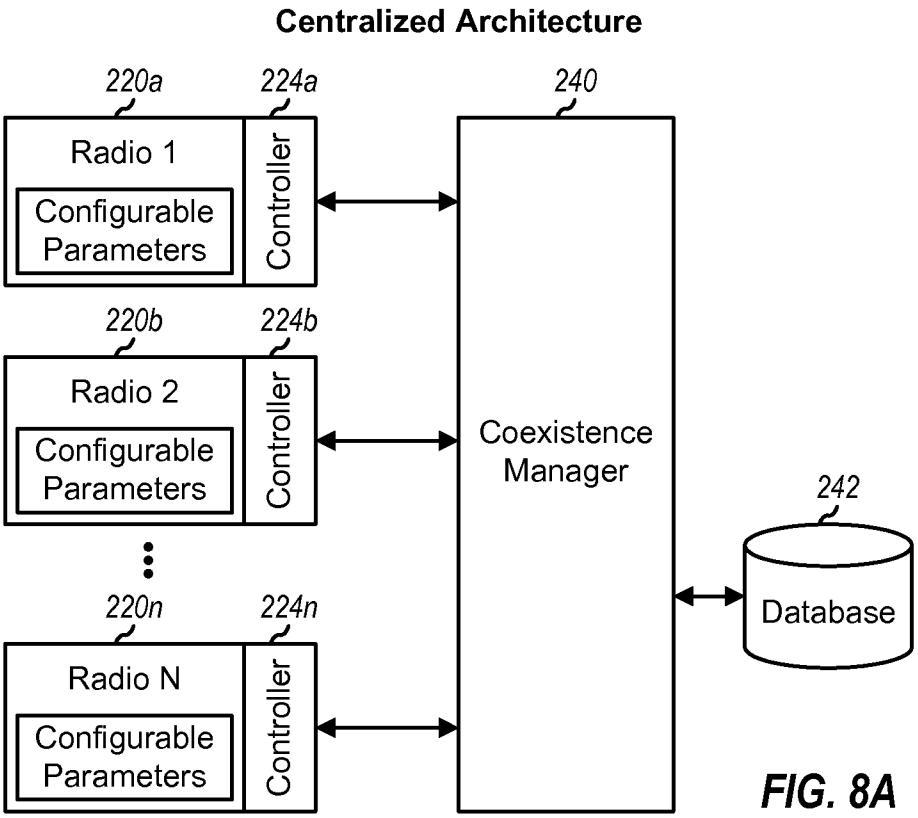
Centralized Architecture
220a
224a
240
Radio 1
Configurable Parameters
Controller
220b
224b
Radio 2
Configurable Parameters
Controller
Coexistence Manager
242
Database
220n
224n
Radio N
Configurable Parameters
Controller

FIG. 8A

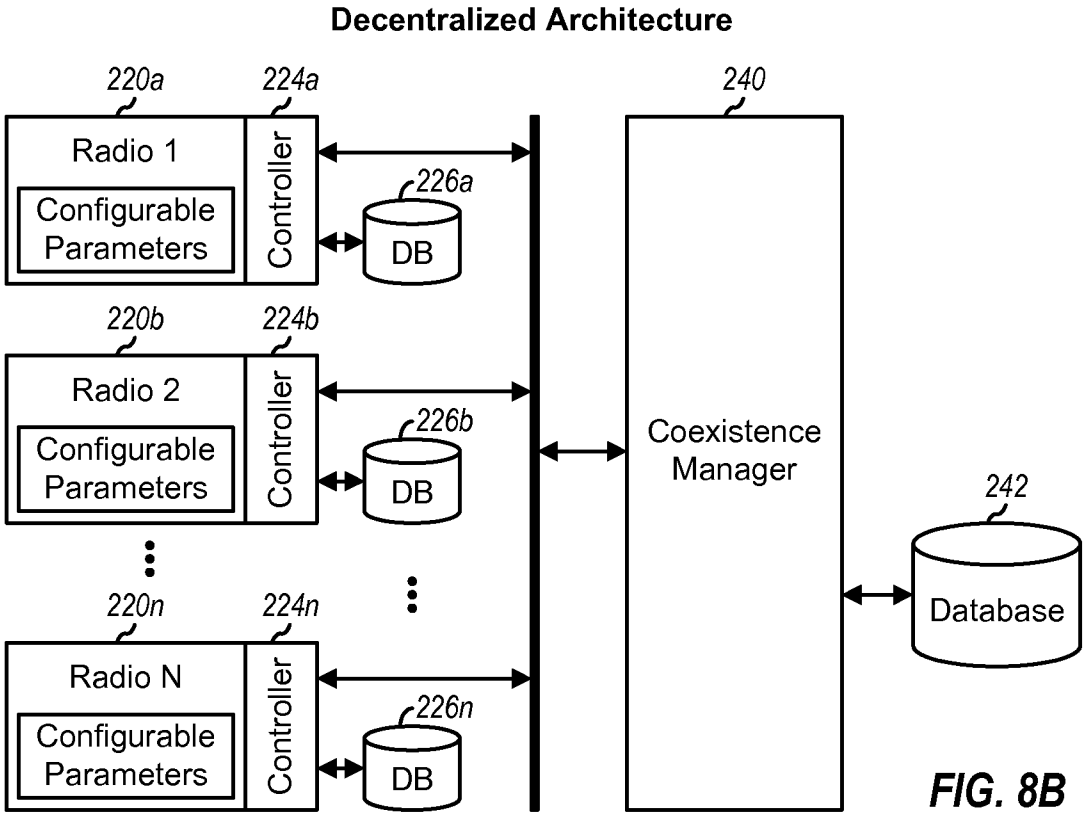
Decentralized Architecture
220a
224a
240
Radio 1
Configurable Parameters
Controller
226a
DB
220b
224b
Radio 2
Configurable Parameters
Controller
226b
DB
Coexistence Manager
242
Database
220n
224n
Radio N
Configurable Parameters
Controller
226n
DB

FIG. 8B

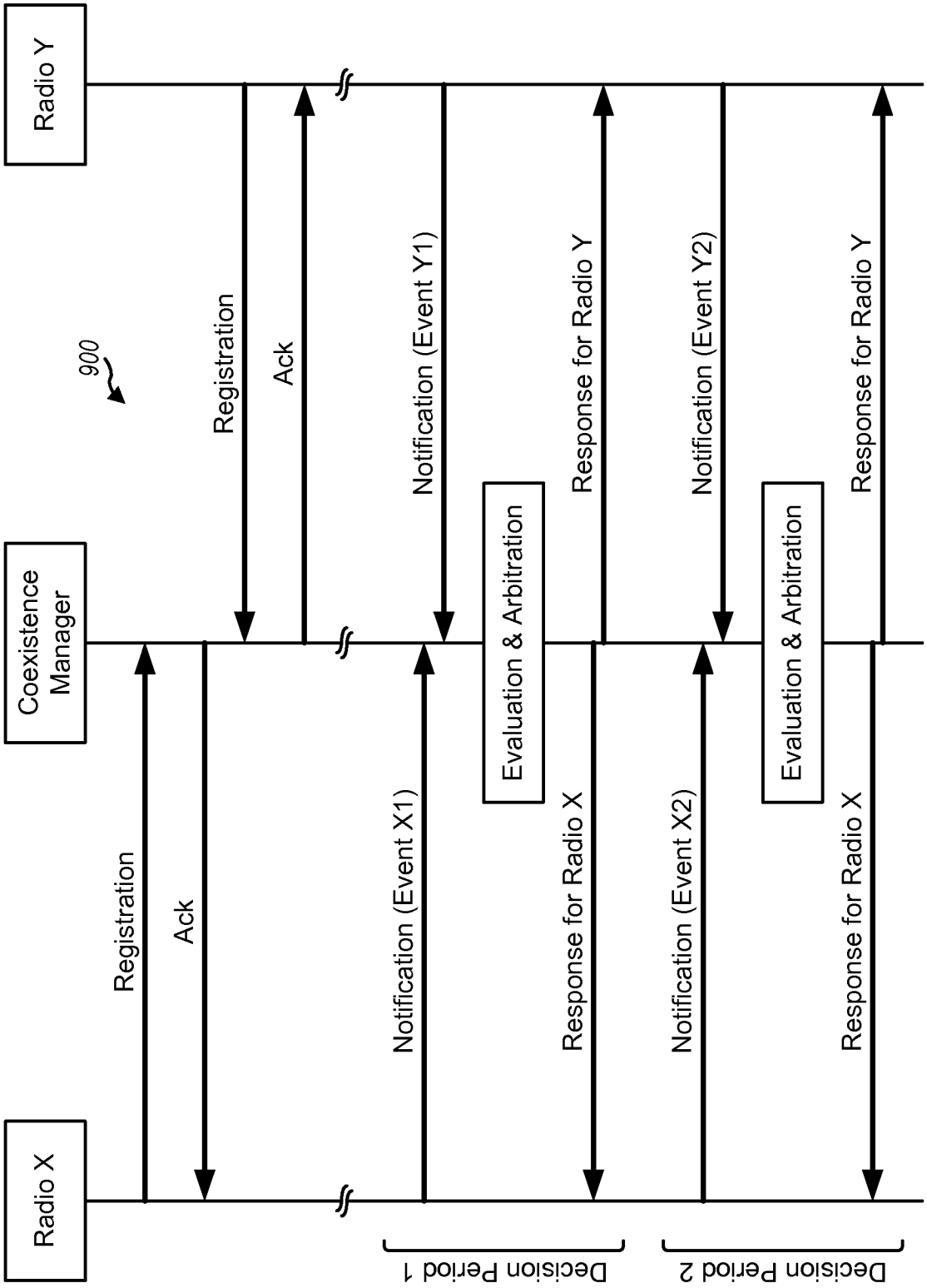
Radio Y
Coexistence Manager
Radio X
900
Registration
Ack
Notification (Event Y1)
Evaluation & Arbitration
Response for Radio Y
Notification (Event Y2)
Evaluation & Arbitration
Response for Radio Y
Registration
Ack
Notification (Event X1)
Response for Radio X
Notification (Event X2)
Response for Radio X
Decision Period 1
Decision Period 2

FIG. 9

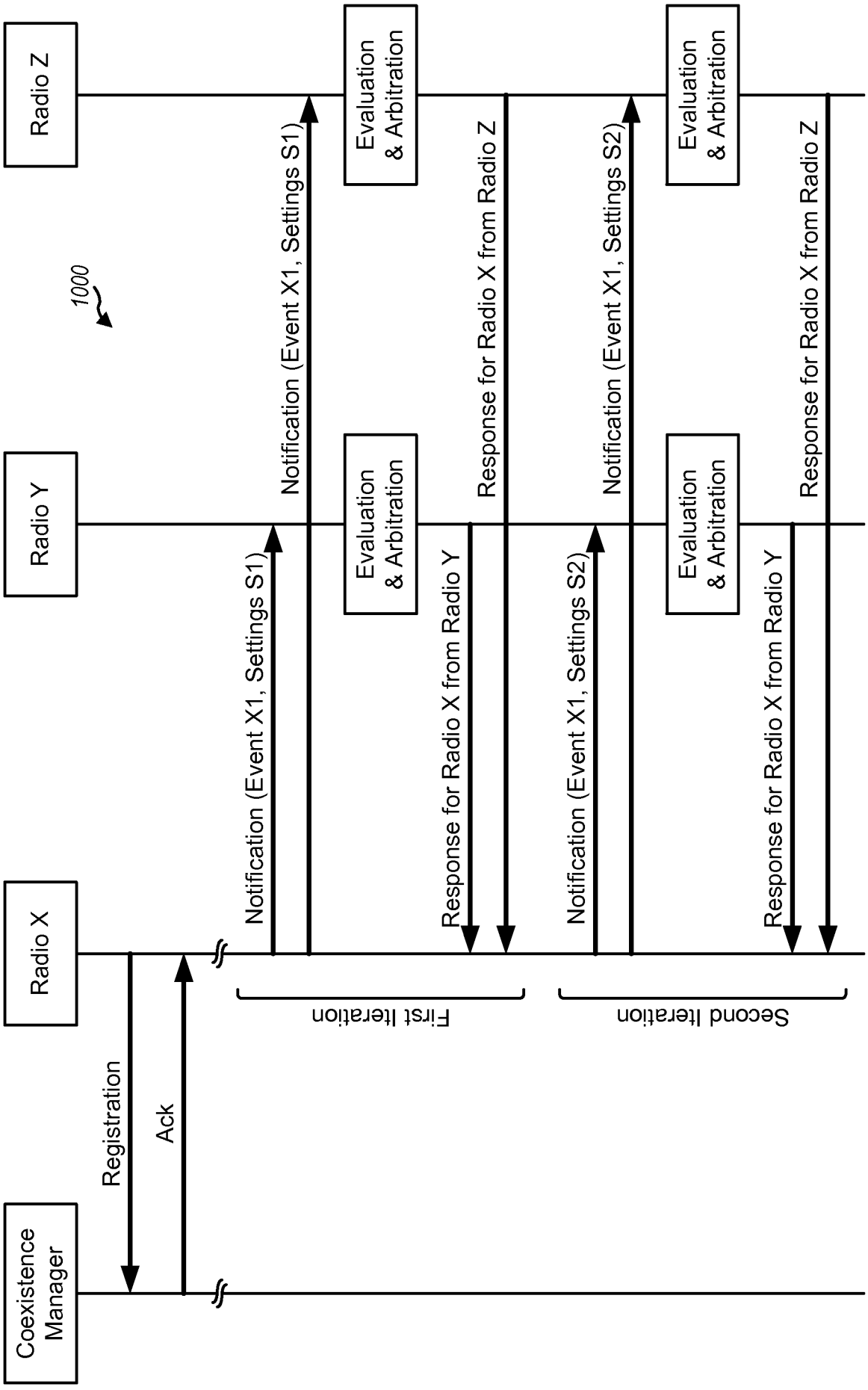
Coexistence Manager
Radio X
Radio Y
Radio Z
1000
Registration
Ack
Notification (Event X1, Settings S1)
Evaluation & Arbitration
Response for Radio X from Radio Y
Response for Radio X from Radio Z
Notification (Event X1, Settings S2)
Evaluation & Arbitration
Response for Radio X from Radio Y
Response for Radio X from Radio Z
First Iteration
Second Iteration

FIG. 10

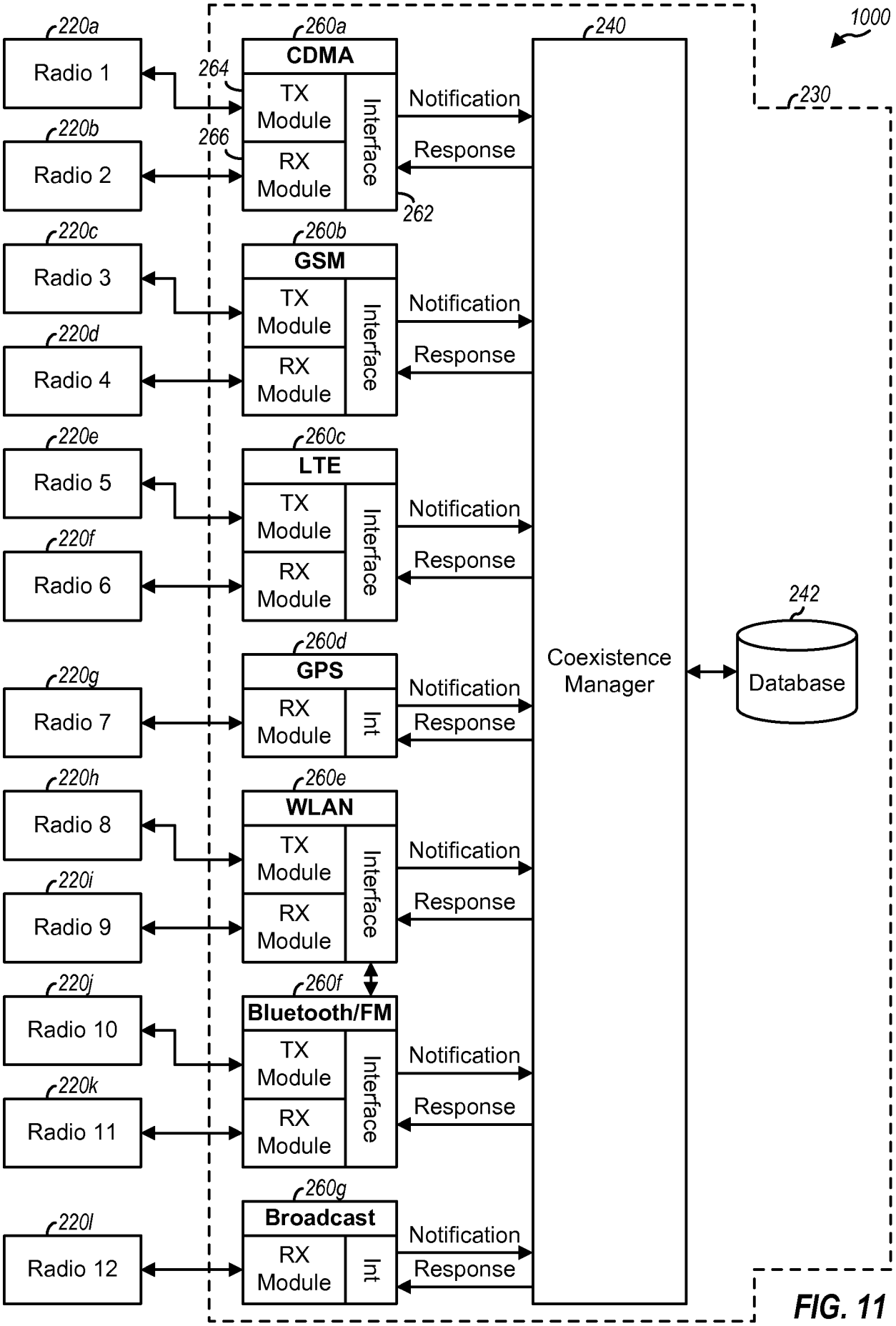
1000
230
240
220a
Radio 1
220b
Radio 2
220c
Radio 3
220d
Radio 4
220e
Radio 5
220f
Radio 6
220g
Radio 7
220h
Radio 8
220i
Radio 9
220j
Radio 10
220k
Radio 11
220l
Radio 12
260a
CDMA
TX Module
RX Module
Interface
264
266
262
260b
GSM
260c
LTE
260d
GPS
RX Module
Int
260e
WLAN
260f
Bluetooth/FM
260g
Broadcast
Notification
Response
Coexistence Manager
242
Database

FIG. 11

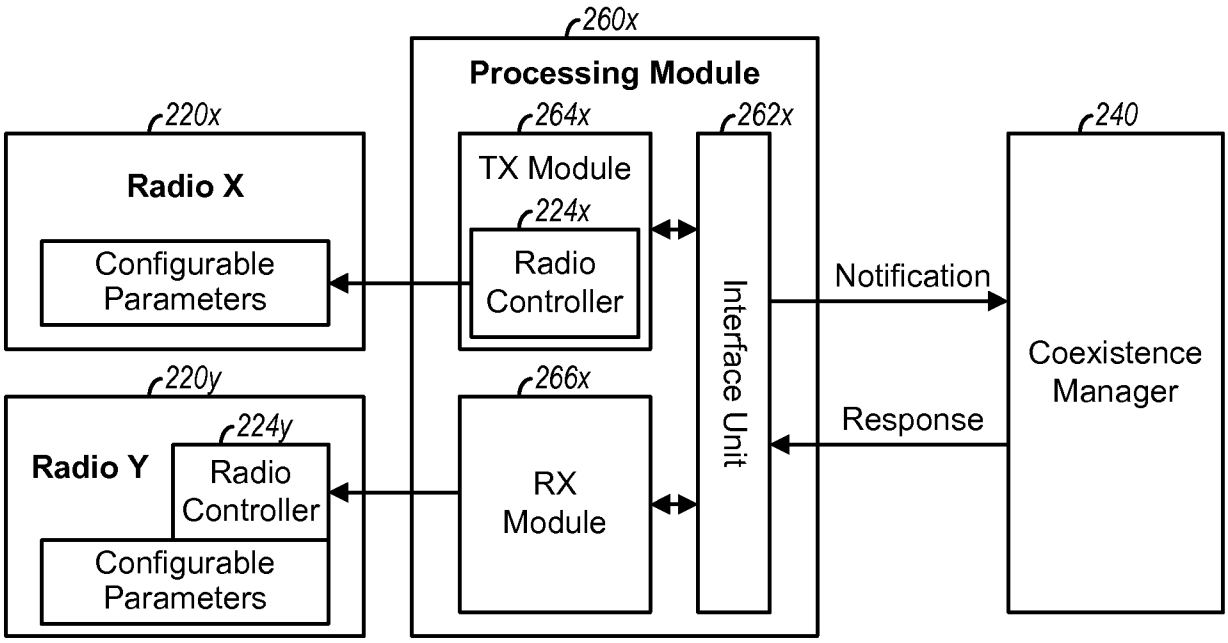

FIG. 12

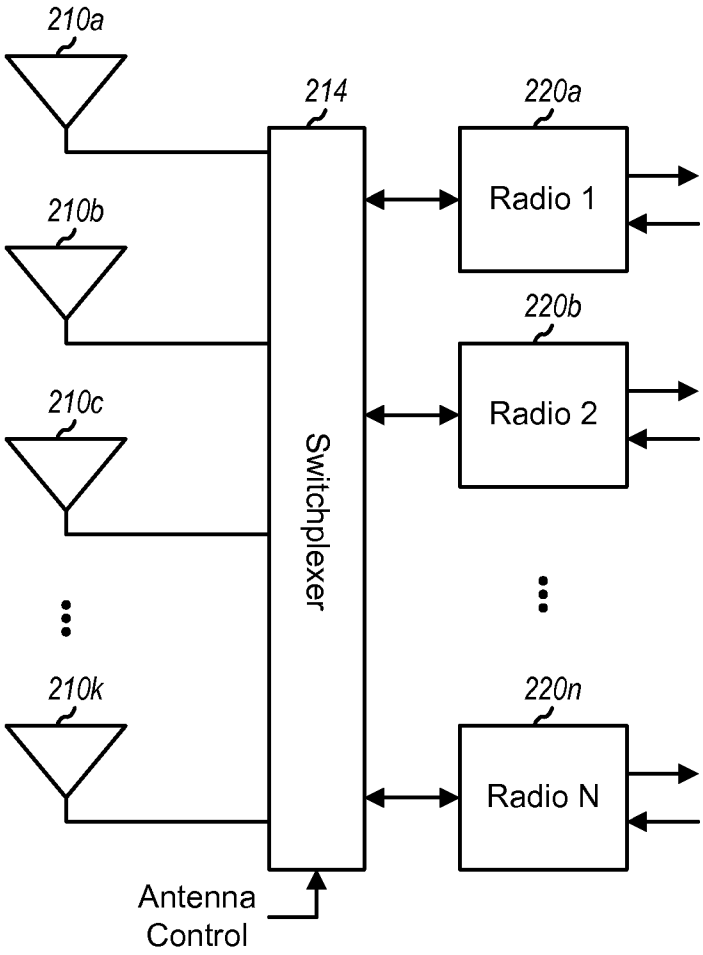

FIG. 13A

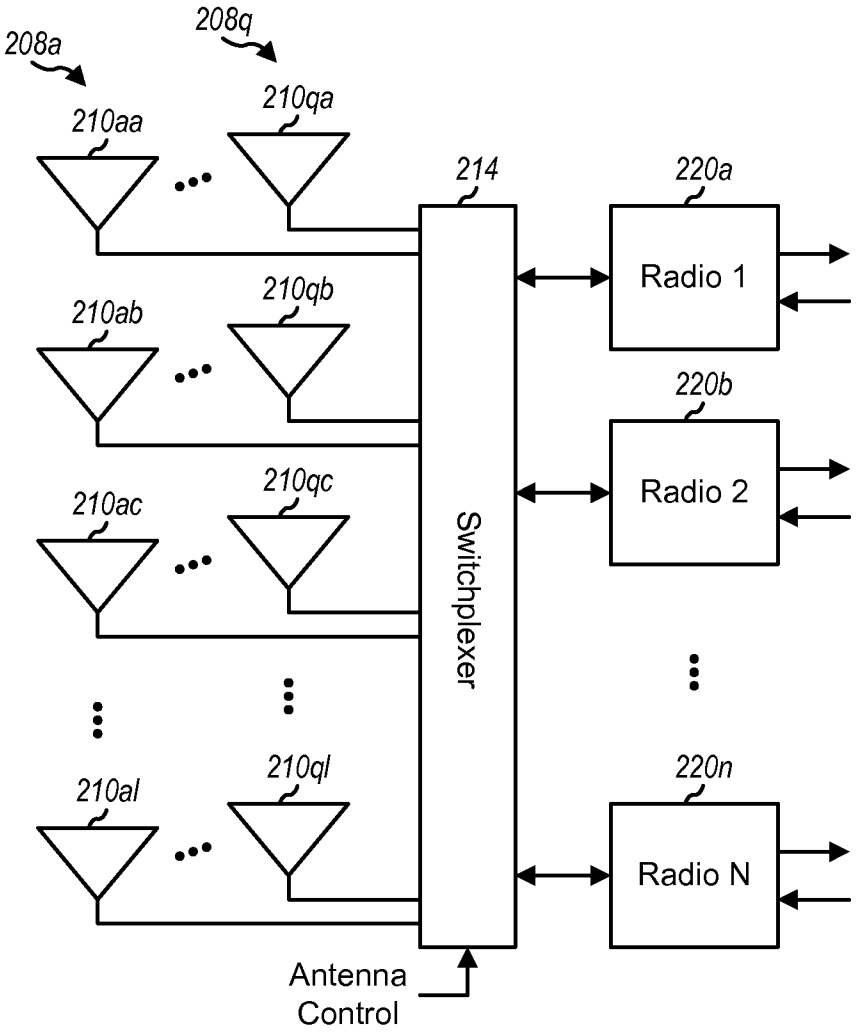
208a
208q
210aa
210qa
214
220a
Radio 1
210ab
210qb
220b
Radio 2
210ac
210qc
Switchplexer
210al
210ql
220n
Radio N
Antenna
Control

FIG. 13B

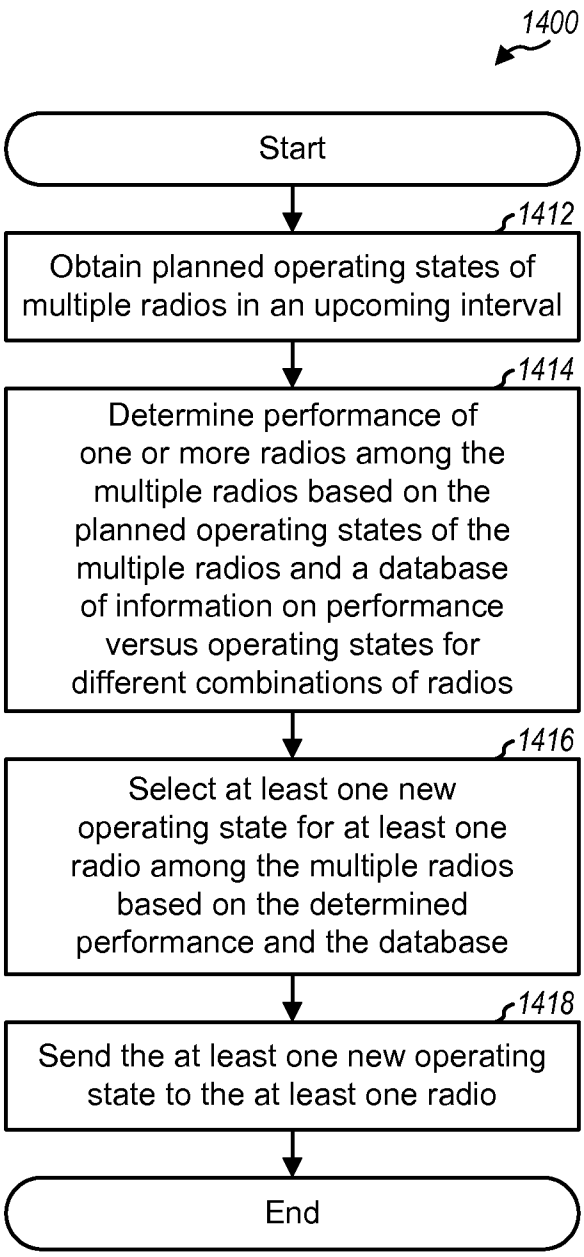
1400
Start
1412
Obtain planned operating states of multiple radios in an upcoming interval
1414
Determine performance of one or more radios among the multiple radios based on the planned operating states of the multiple radios and a database of information on performance versus operating states for different combinations of radios
1416
Select at least one new operating state for at least one radio among the multiple radios based on the determined performance and the database
1418
Send the at least one new operating state to the at least one radio
End

FIG. 14

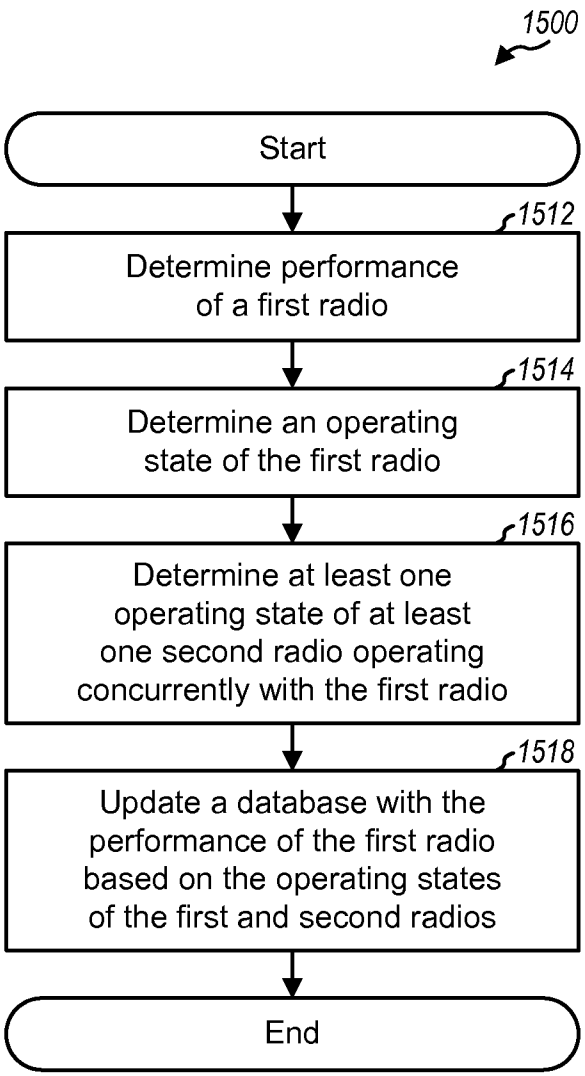
1500
Start
1512
Determine performance of a first radio
1514
Determine an operating state of the first radio
1516
Determine at least one operating state of at least one second radio operating concurrently with the first radio
1518
Update a database with the performance of the first radio based on the operating states of the first and second radios
End

FIG. 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/036882

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W88/06
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W H04Q H04L G06F

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/161041 A1 (PERNU VILLE [FI]) 3 July 2008 (2008-07-03) * abstract paragraph [0031] - paragraph [0034] paragraph [0042] - paragraph [0047]	1-46
A	WO 2008/000905 A1 (NOKIA CORP [FI]; PIIPPONEN ANTTI [FI]; PAERSSINEN AARNO [FI]) 3 January 2008 (2008-01-03) paragraph [0012] paragraph [0026] - paragraph [0055] paragraph [0080] - paragraph [0087]	1-46
A	US 2009/040937 A1 (XHAFA ARITON E [US] ET AL) 12 February 2009 (2009-02-12) * abstract	1-46

-/--

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 September 2010	16/09/2010

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, Fax: (+31-70) 340-3016	Hultsch, Wolfgang

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/036882

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 2007/206631 A1 (PARTS ULO [FI] ET AL) 6 September 2007 (2007-09-06) * abstract; figure 3 paragraph [0030] - paragraph [0046]; figures 3,4	1-46
A	WO 2008/070777 A2 (MOTOROLA INC [US]; HIDDINK GERRIT W [NL]; CHEN XIANG [US]; GEURTSEN AA) 12 June 2008 (2008-06-12) * abstract	1-46

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2010/036882

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2008161041 A1	03-07-2008	WO 2008081262 A2	10-07-2008
WO 2008000905 A1	03-01-2008	NONE	
US 2009040937 A1	12-02-2009	NONE	
US 2007206631 A1	06-09-2007	EP 2087614 A1	12-08-2009
		WO 2008053082 A1	08-05-2008
WO 2008070777 A2	12-06-2008	CN 101595683 A	02-12-2009
		EP 2090027 A2	19-08-2009
		KR 20090089373 A	21-08-2009
		US 2008139212 A1	12-06-2008