US009961565B2

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Roy et al.

(10) **Patent No.: US 9,961,565 B2**
(45) **Date of Patent: *May 1, 2018**

(54) **METHOD FOR MILLIMETER WAVE BEAM TRACKING**

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(73) Assignee: **IDAC Holdings, Inc.**, Wilmington, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days. days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **15/488,146**

(22) Filed: **Apr. 14, 2017**

(65) **Prior Publication Data**

US 2017/0223552 A1 Aug. 3, 2017

Related U.S. Application Data

(63) Continuation of application No. 14/423,362, filed as application No. PCT/US2013/057101 on Aug. 28, 2013, now Pat. No. 9,629,171.

(Continued)

(51) **Int. Cl.**

H04W 16/28 (2009.01)
H04W 24/08 (2009.01)
H04W 64/00 (2009.01)

(52) **U.S. Cl.**

CPC ***H04W 16/28*** (2013.01); ***H04W 24/08*** (2013.01); ***H04W 64/003*** (2013.01)

(58) **Field of Classification Search**

CPC H04W 16/28; H04W 24/10; H04B 7/0617; H04B 7/0602

See application file for complete search history.

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(Continued)

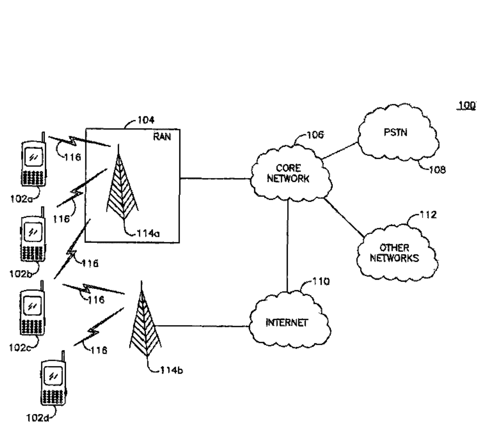
Primary Examiner — Omoniyi Obayanju

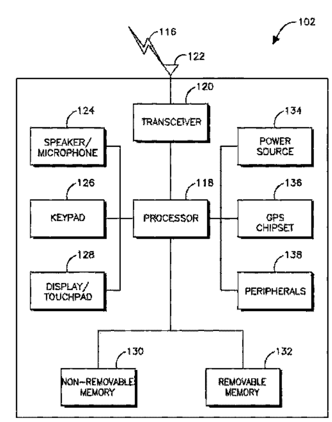
(74) *Attorney, Agent, or Firm* — Volpe and Koenig, P.C.

(57) **ABSTRACT**

A wireless transmit/receive unit (WTRU) may receive a request to perform directional signal strength measurements and provide location data associated with the WTRU. The WTRU may transmit directional signal strength measurements, based on the request and the location data associated with the WTRU, to facilitate generation of a directional radio environment map (DREM). The WTRU may receive a request to switch to a new transmission and reception beam pair based on the DREM.

13 Claims, 28 Drawing Sheets





Related U.S. Application Data

(60) Provisional application No. 61/774,979, filed on Mar. 8, 2013, provisional application No. 61/694,162, filed on Aug. 28, 2012.

(56) **References Cited**

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IEEE Standard for Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements; Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High-Rate Wireless Personal Area Networks (WPANs); Amendment 2: Millimeter-wave-based Alternative Physical Layer Extension, IEEE 802.15.3c-2009 (Oct. 2009).

* cited by examiner

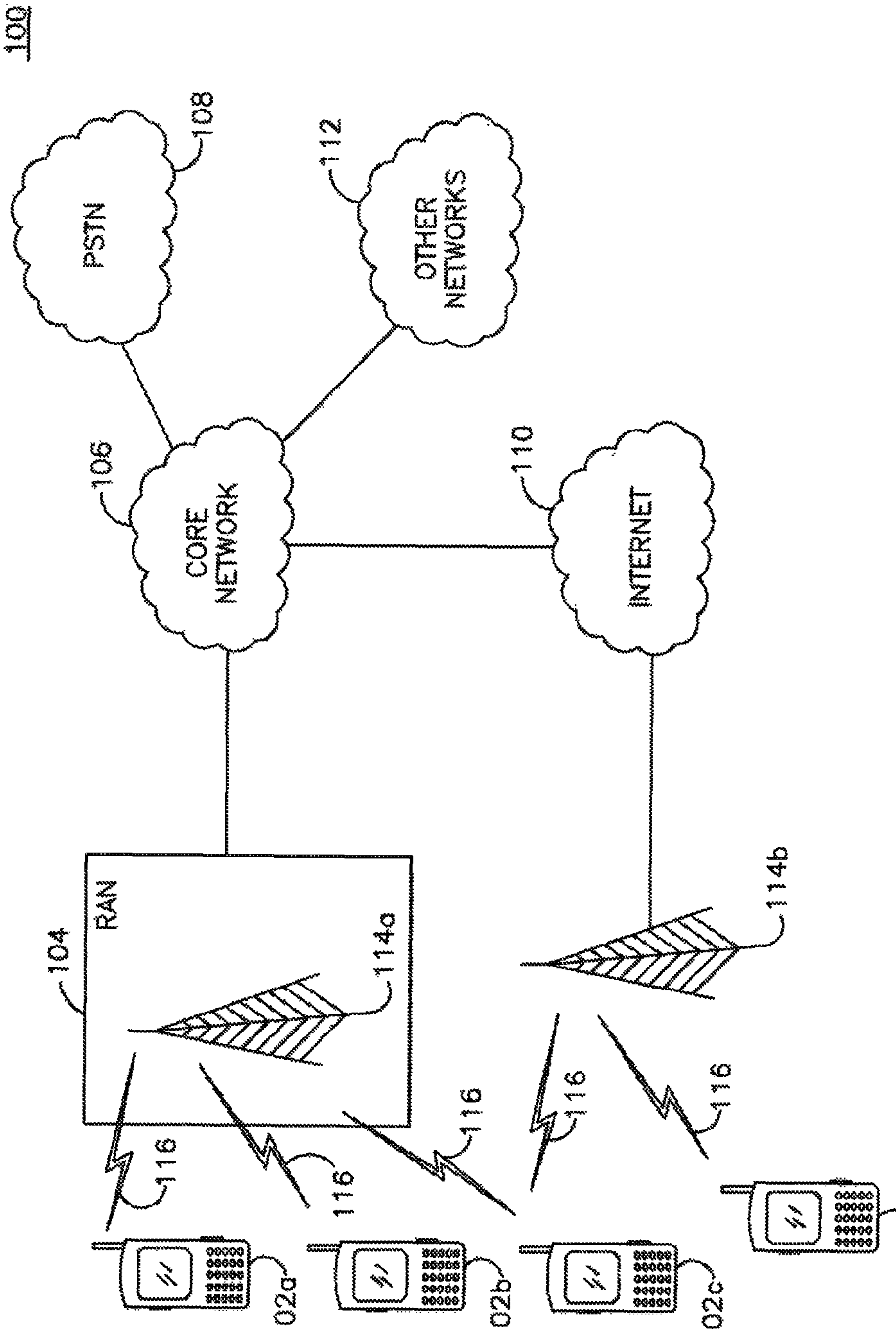

100
PSTN
108
OTHER NETWORKS
112
CORE NETWORK
106
INTERNET
110
RAN
104
114a
114b
116
102a
102b
102c
102d

FIG. 1A

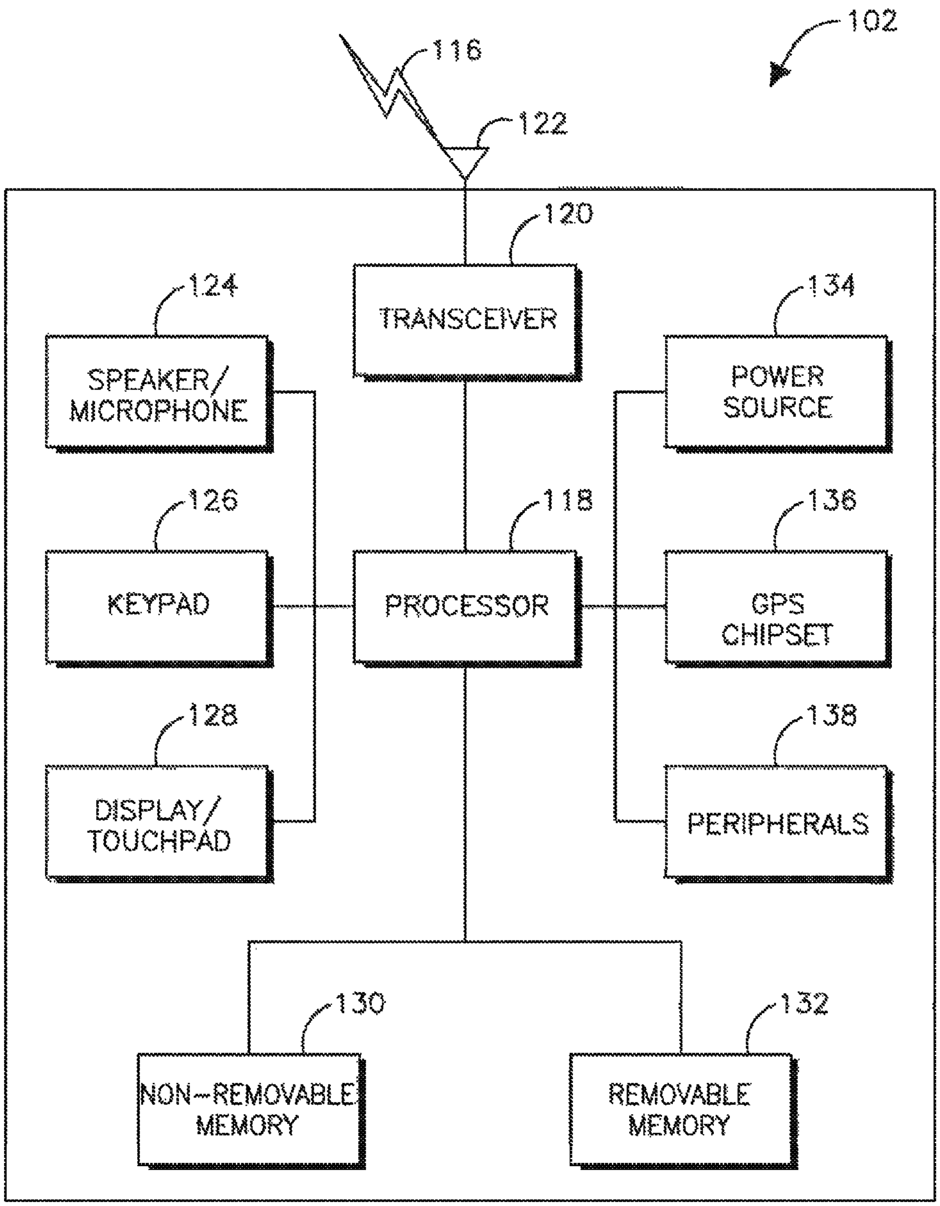
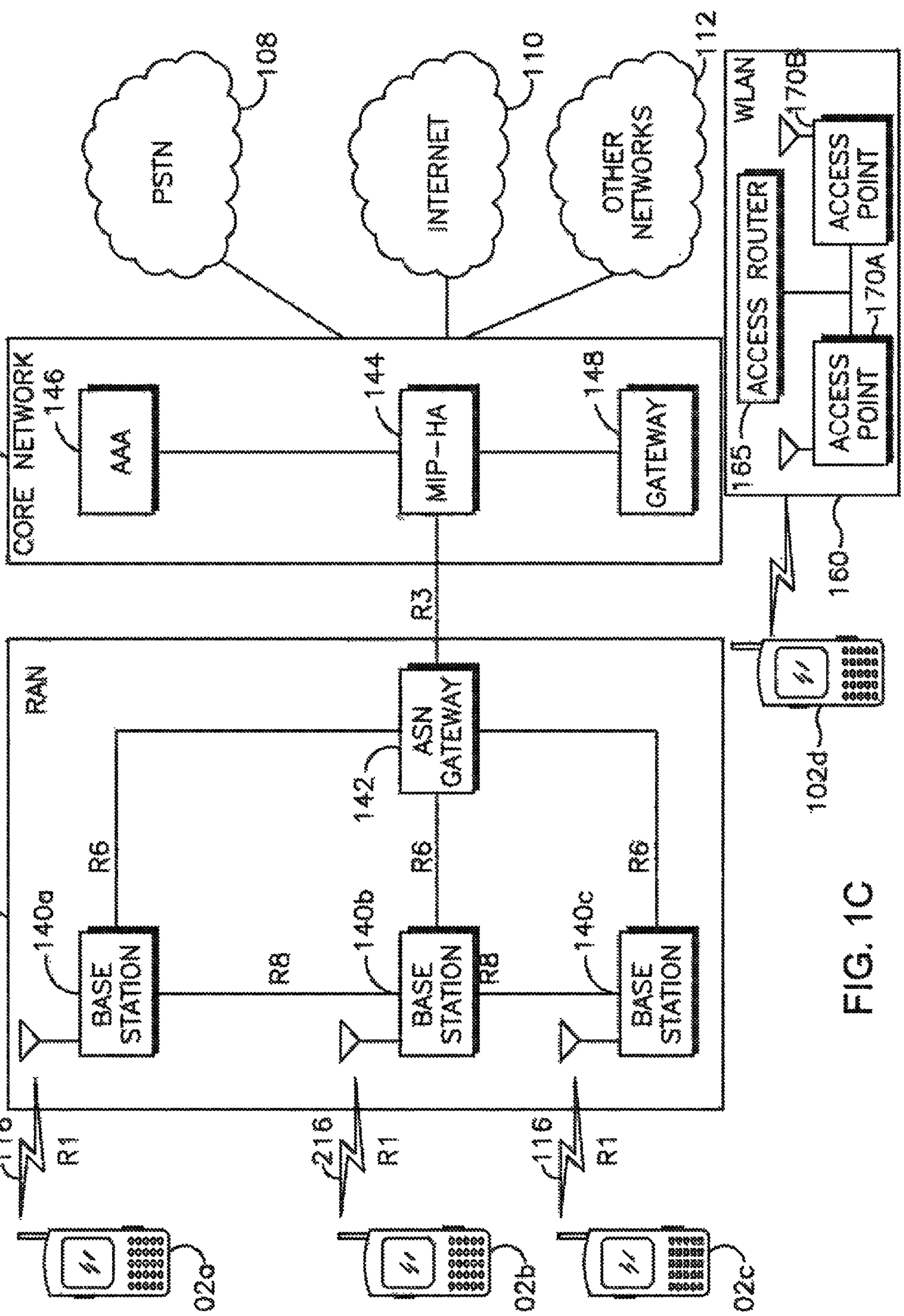

102
116
122
120
TRANSCEIVER
124
SPEAKER/
MICROPHONE
134
POWER
SOURCE
126
KEYPAD
118
PROCESSOR
136
GPS
CHIPSET
128
DISPLAY/
TOUCHPAD
138
PERIPHERALS
130
NON-REMOVABLE
MEMORY
132
REMOVABLE
MEMORY

FIG. 1B



PSTN
108
INTERNET
110
OTHER NETWORKS
112
CORE NETWORK
106
AAA
146
MIP-HA
144
GATEWAY
148
WLAN
ACCESS ROUTER
165
ACCESS POINT
ACCESS POINT
170A
170B
160
R3
RAN
104
ASN GATEWAY
142
R6
R6
R6
BASE STATION
140a
BASE STATION
140b
BASE STATION
140c
R8
R8
116
R1
216
R1
116
R1
102a
102b
102c
102d

FIG. 1C

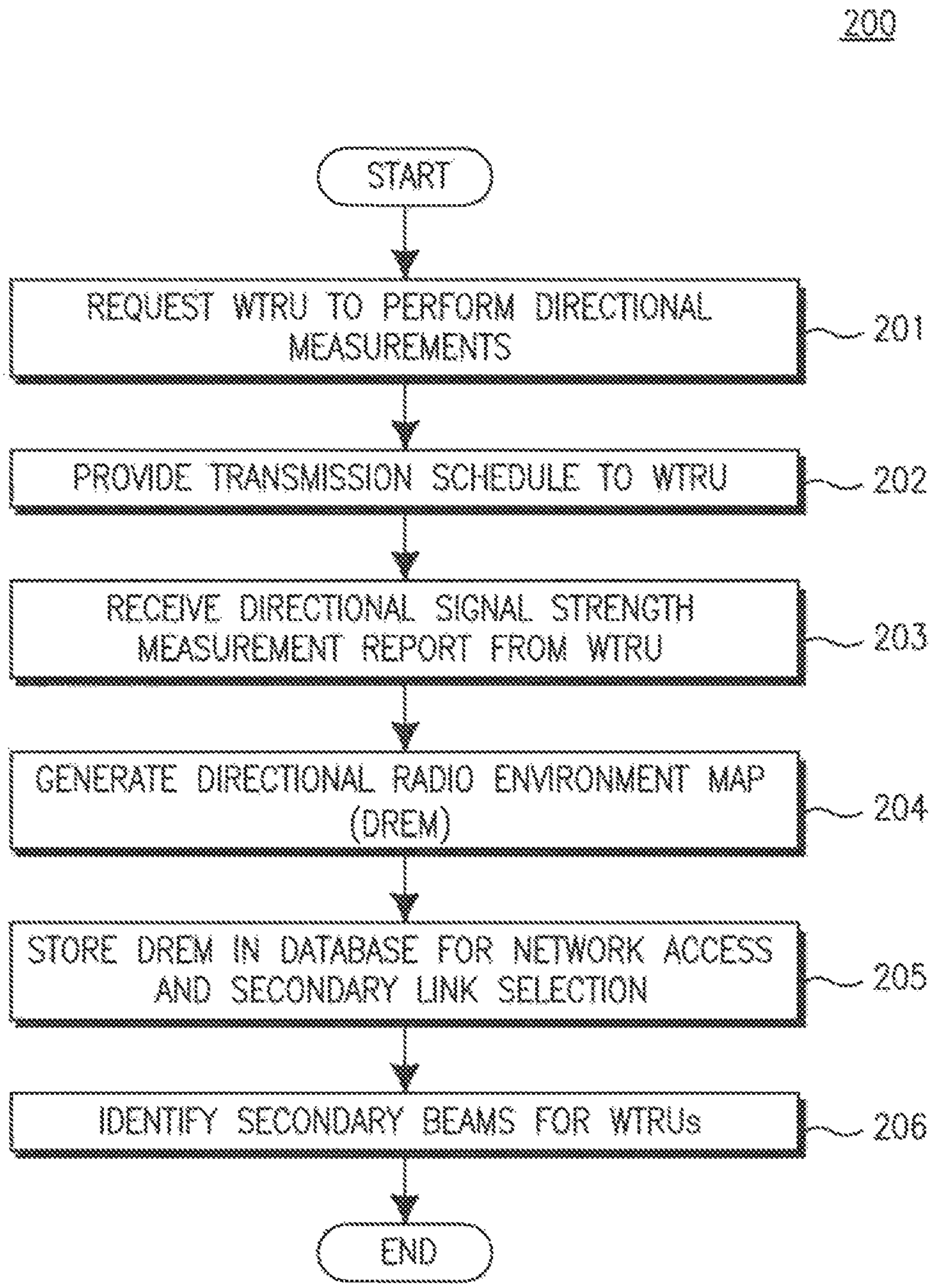

200
START
REQUEST WTRU TO PERFORM DIRECTIONAL MEASUREMENTS
201
PROVIDE TRANSMISSION SCHEDULE TO WTRU
202
RECEIVE DIRECTIONAL SIGNAL STRENGTH MEASUREMENT REPORT FROM WTRU
203
GENERATE DIRECTIONAL RADIO ENVIRONMENT MAP (DREM)
204
STORE DREM IN DATABASE FOR NETWORK ACCESS AND SECONDARY LINK SELECTION
205
IDENTIFY SECONDARY BEAMS FOR WTRUs
206
END

FIG. 2A

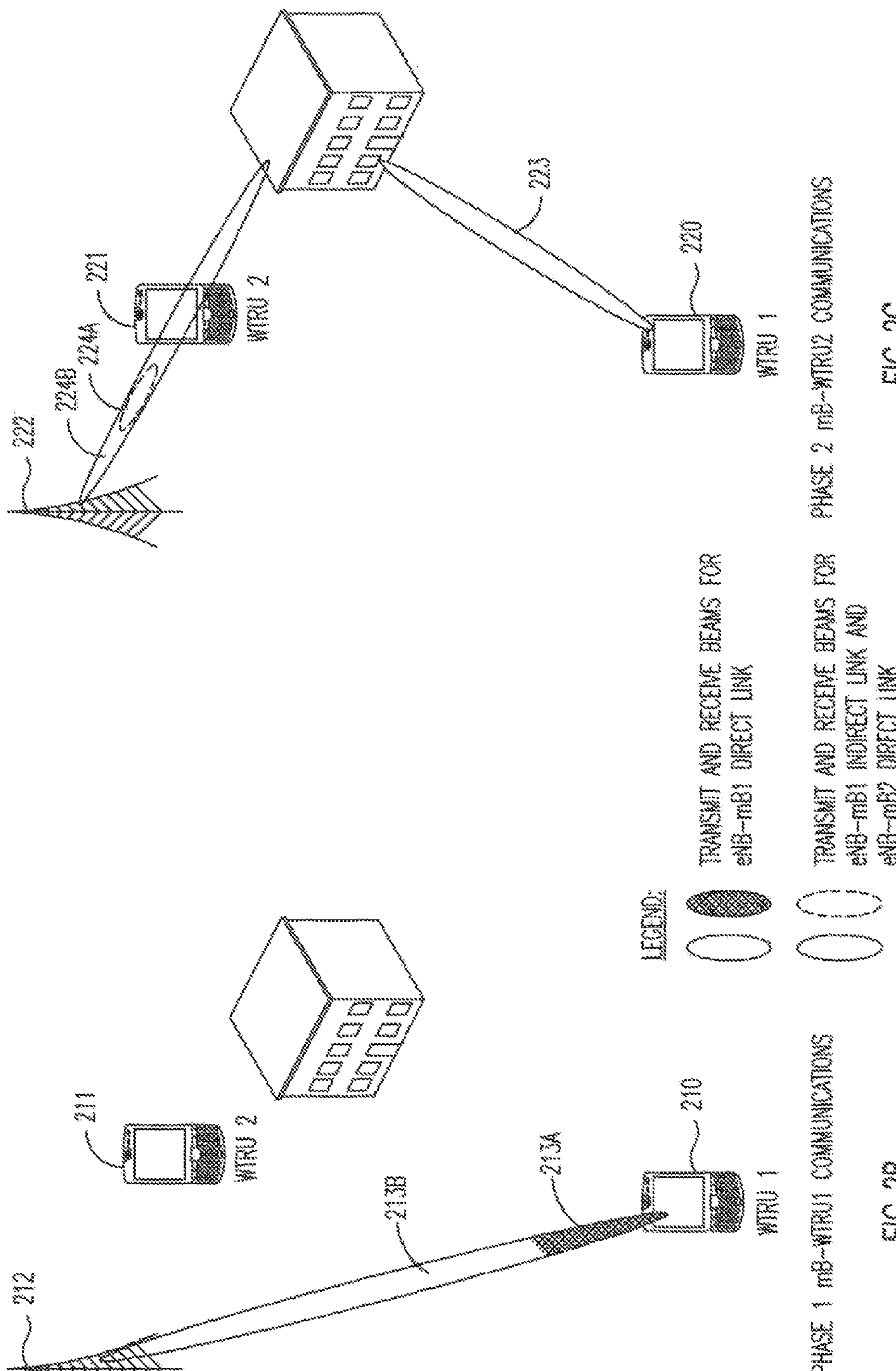
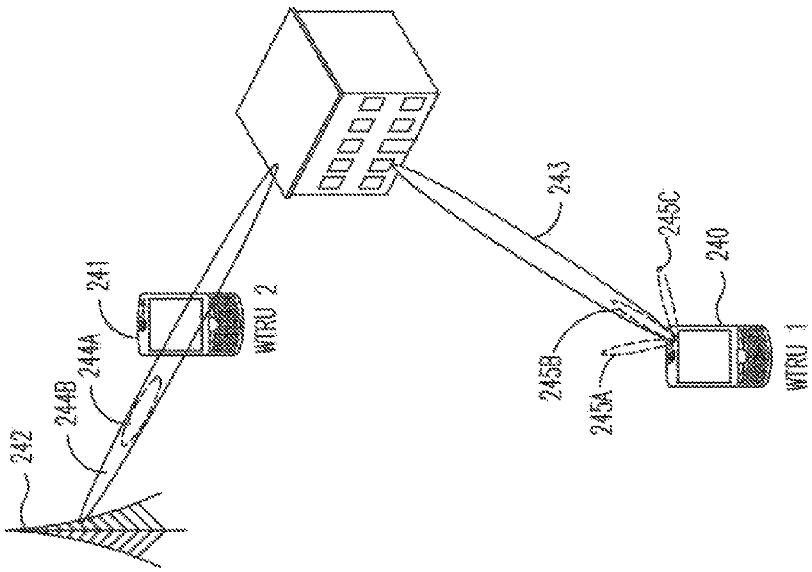

212
213B
213A
210
WTRU 1
211
WTRU 2
PHASE 1 mB-WTRU1 COMMUNICATIONS
LEGEND:
TRANSMIT AND RECEIVE BEAMS FOR eNB-mB1 DIRECT LINK
TRANSMIT AND RECEIVE BEAMS FOR eNB-mB1 INDIRECT LINK AND eNB-mB2 DIRECT LINK
222
224B
224A
221
WTRU 2
223
220
WTRU 1
PHASE 2 mB-WTRU2 COMMUNICATIONS

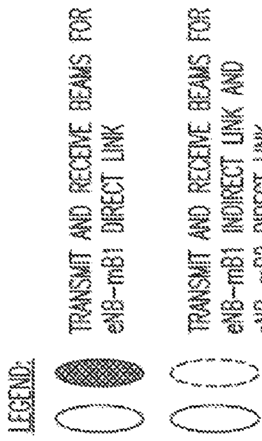
FIG. 2B

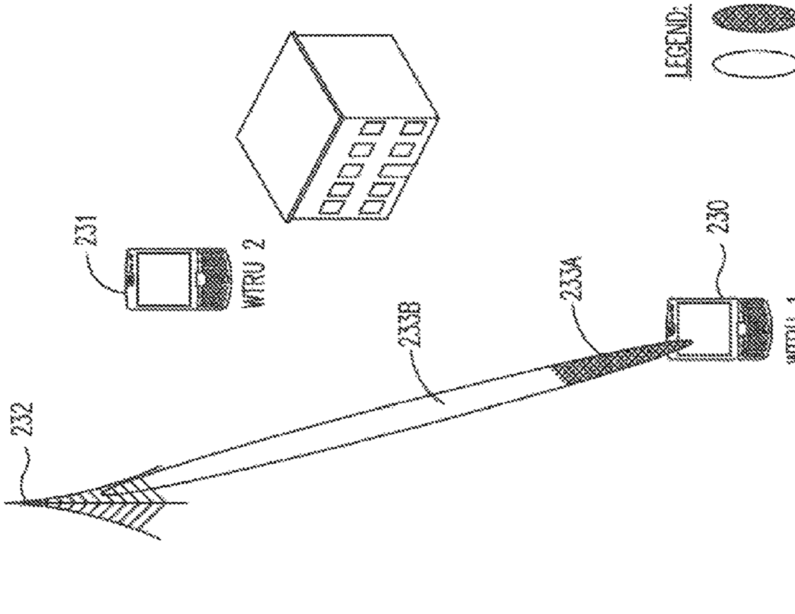
FIG. 2C



PHASE 4 WTRU1 PERFORMS MEASUREMENTS IN REQUESTED DIRECTIONS AND REPORTS RESULTS TO mB

FIG. 2E





PHASE 3 mB REQUESTS WTRU1 TO PERFORM DIRECTIONAL MEASUREMENTS IT PROVIDES mB–WTRU2 TRANSMISSION SCHEDULE AND REQUESTED MEASUREMENT DIRECTIONS

FIG. 2D

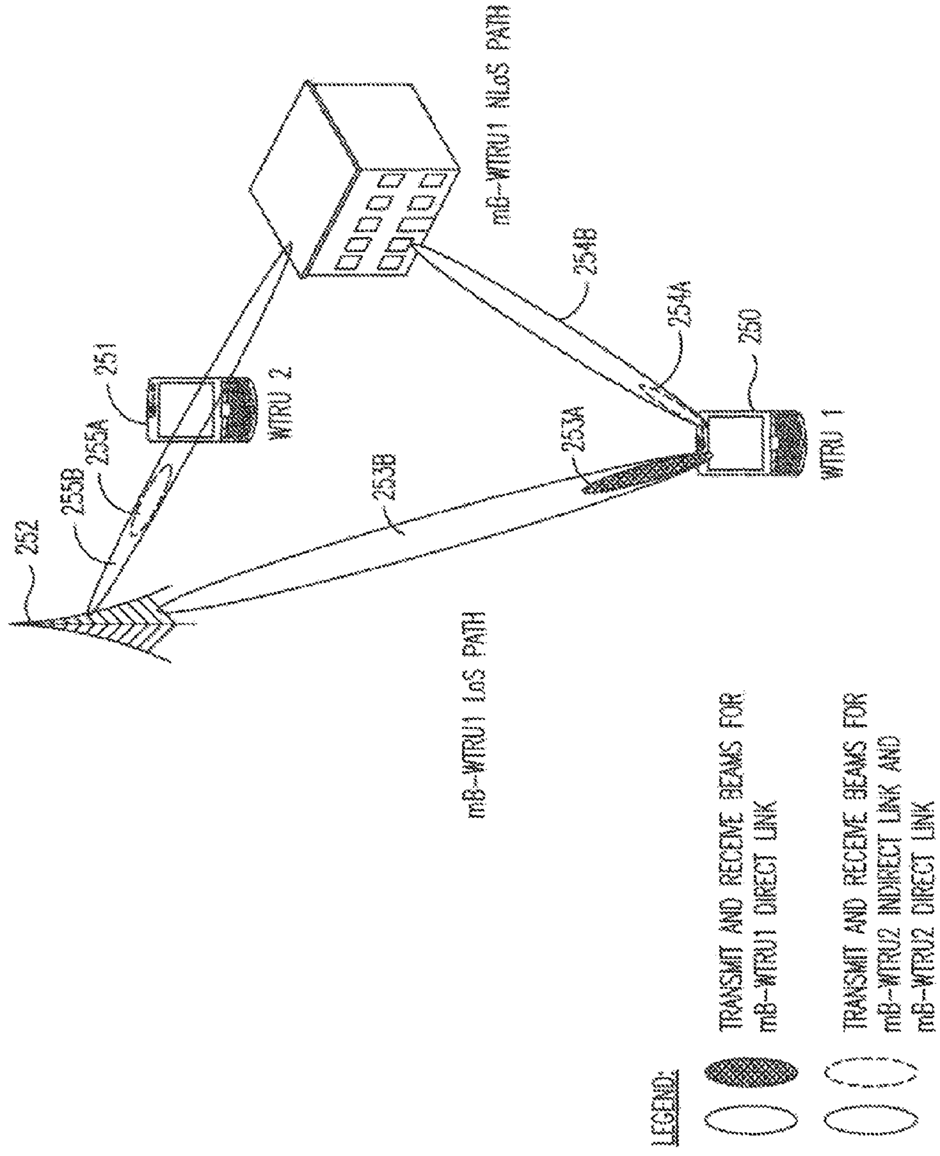

mB-WTRU1 NLoS PATH
254B
254A
250
251
WTRU 2
253A
WTRU 1
255A
255B
253B
252
mB-WTRU1 LoS PATH
LEGEND:
TRANSMIT AND RECEIVE BEAMS FOR mB-WTRU1 DIRECT LINK
TRANSMIT AND RECEIVE BEAMS FOR mB-WTRU2 INDIRECT LINK AND mB-WTRU2 DIRECT LINK

FIG. 2F

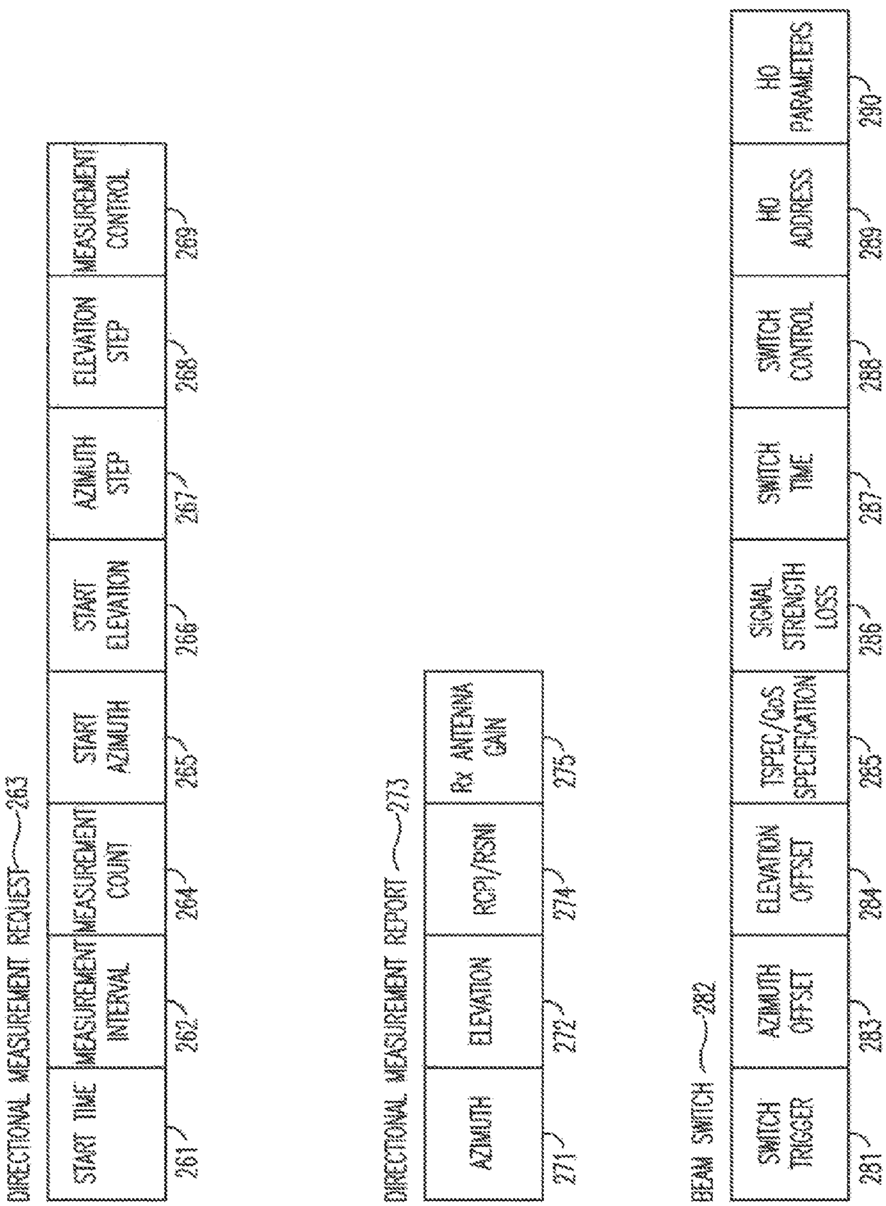

DIRECTIONAL MEASUREMENT REQUEST
263
START TIME
261
MEASUREMENT INTERVAL
262
MEASUREMENT COUNT
264
START AZIMUTH
265
START ELEVATION
266
AZIMUTH STEP
267
ELEVATION STEP
268
MEASUREMENT CONTROL
269
DIRECTIONAL MEASUREMENT REPORT
273
AZIMUTH
271
ELEVATION
272
RCPI/RSNI
274
Rx ANTENNA GAIN
275
BEAM SWITCH
282
SWITCH TRIGGER
281
AZIMUTH OFFSET
283
ELEVATION OFFSET
284
TSPEC/QoS SPECIFICATION
285
SIGNAL STRENGTH LOSS
286
SWITCH TIME
287
SWITCH CONTROL
288
HO ADDRESS
289
HO PARAMETERS
290

FIG. 2G

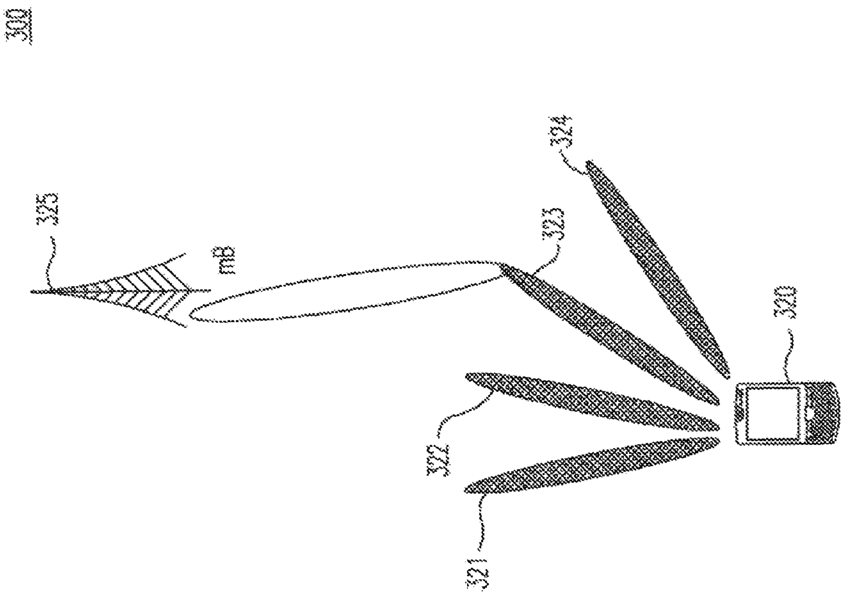


FIG. 3B

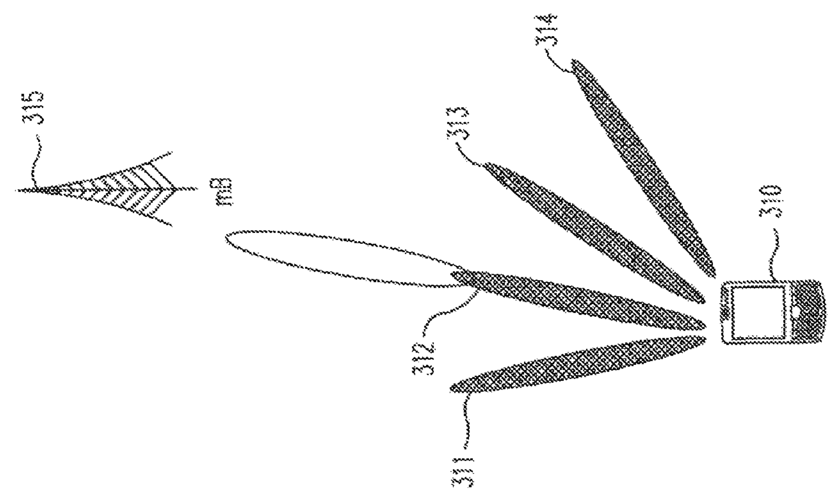


FIG. 3A

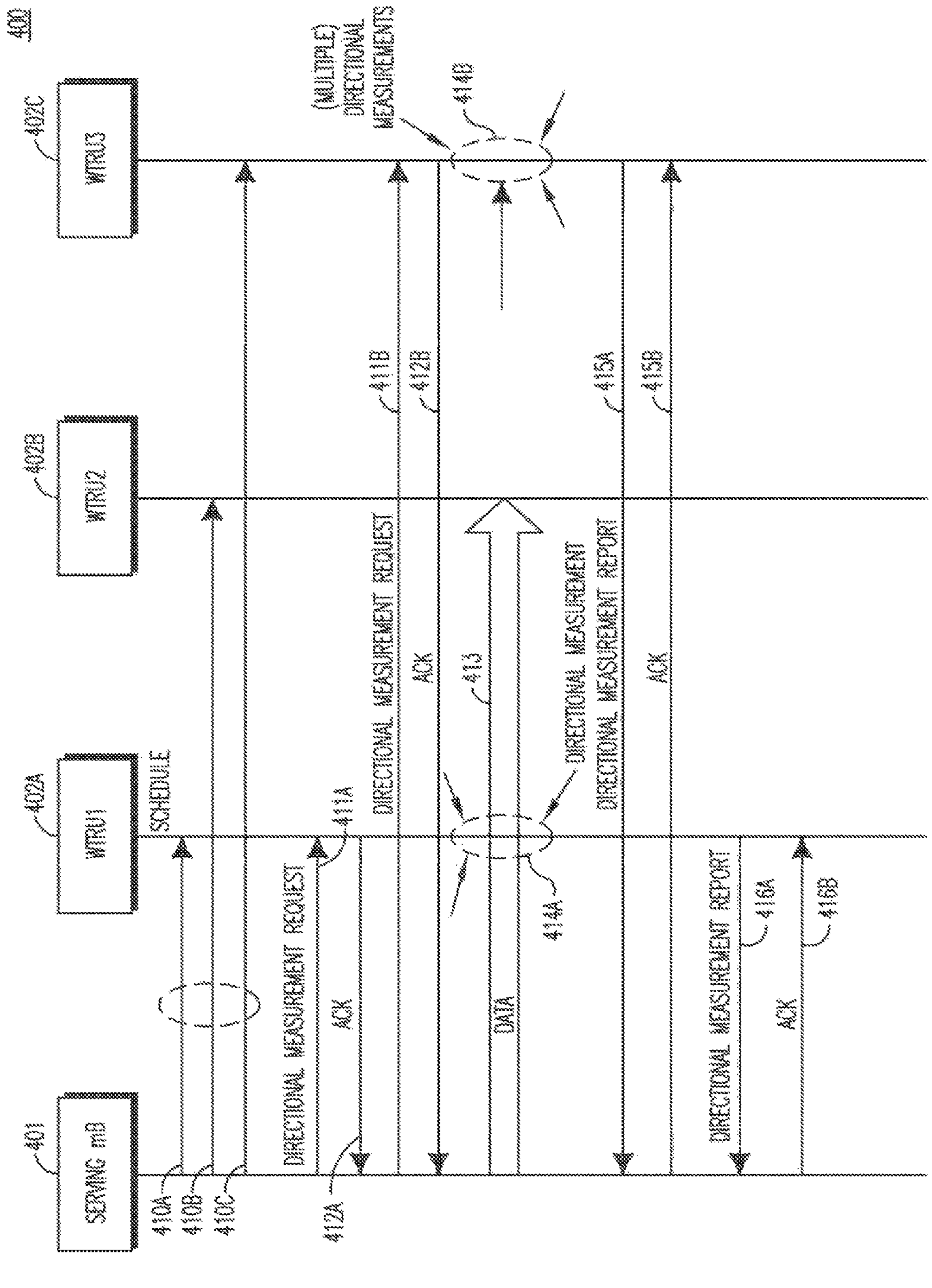

400
SERVING mB
401
WTRU1
402A
WTRU2
402B
WTRU3
402C
SCHEDULE
410A
410B
410C
DIRECTIONAL MEASUREMENT REQUEST
411A
ACK
412A
DIRECTIONAL MEASUREMENT REQUEST
411B
ACK
412B
DATA
413
DIRECTIONAL MEASUREMENT
414A
(MULTIPLE) DIRECTIONAL MEASUREMENTS
414B
DIRECTIONAL MEASUREMENT REPORT
415A
ACK
415B
DIRECTIONAL MEASUREMENT REPORT
416A
ACK
416B

FIG. 4A

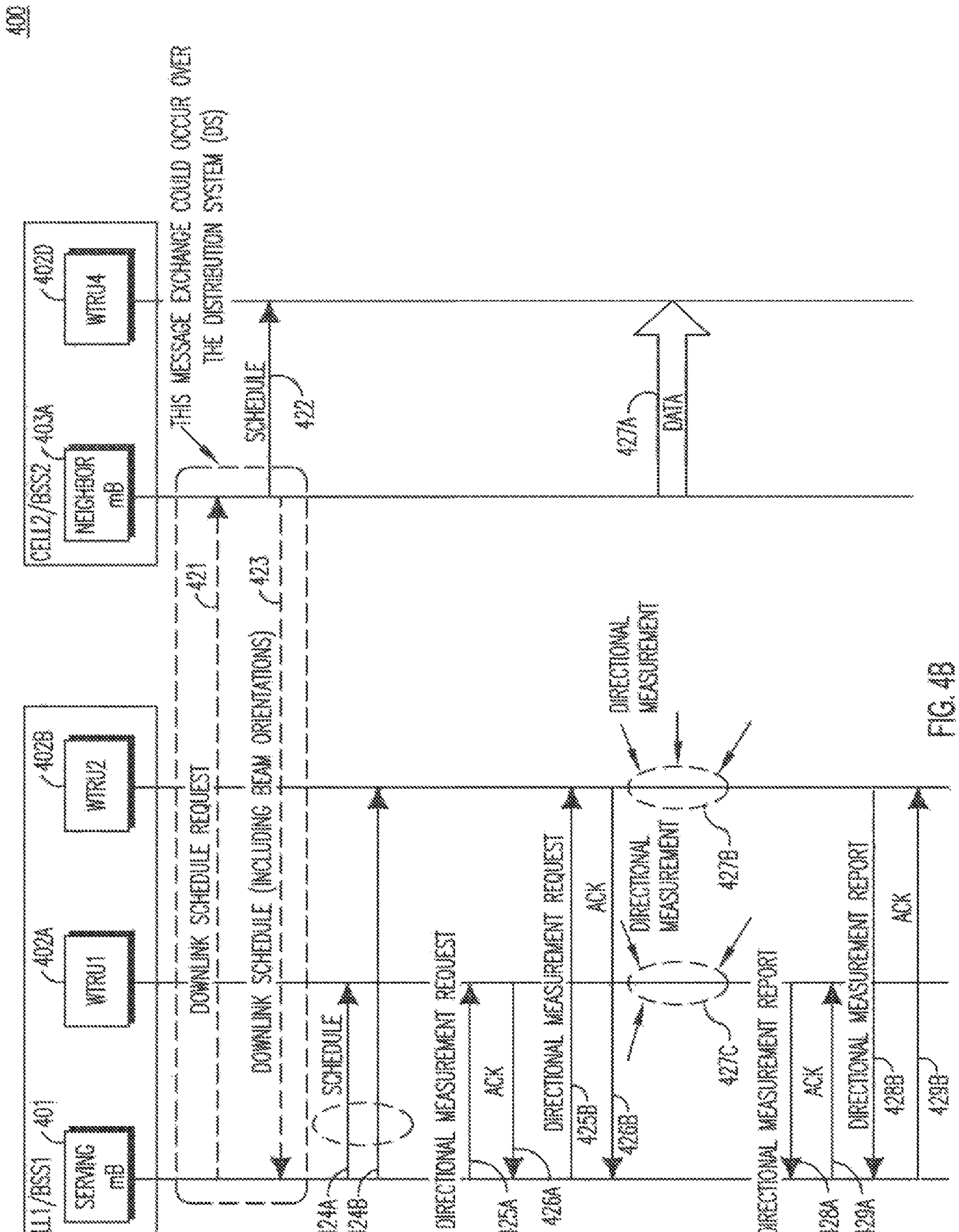

400
CELL1/BSS1
SERVING mB
401
WTRU1
402A
WTRU2
402B
CELL2/BSS2
NEIGHBOR mB
403A
WTRU4
402D
THIS MESSAGE EXCHANGE COULD OCCUR OVER THE DISTRIBUTION SYSTEM (DS)
DOWNLINK SCHEDULE REQUEST
421
DOWNLINK SCHEDULE (INCLUDING BEAM ORIENTATIONS)
423
SCHEDULE
422
SCHEDULE
424A
424B
DIRECTIONAL MEASUREMENT REQUEST
ACK
425A
426A
DIRECTIONAL MEASUREMENT REQUEST
ACK
425B
426B
DIRECTIONAL MEASUREMENT
427C
DIRECTIONAL MEASUREMENT
427B
DIRECTIONAL MEASUREMENT
DATA
427A
DIRECTIONAL MEASUREMENT REPORT
ACK
428A
429A
DIRECTIONAL MEASUREMENT REPORT
ACK
428B
429B

FIG. 4B

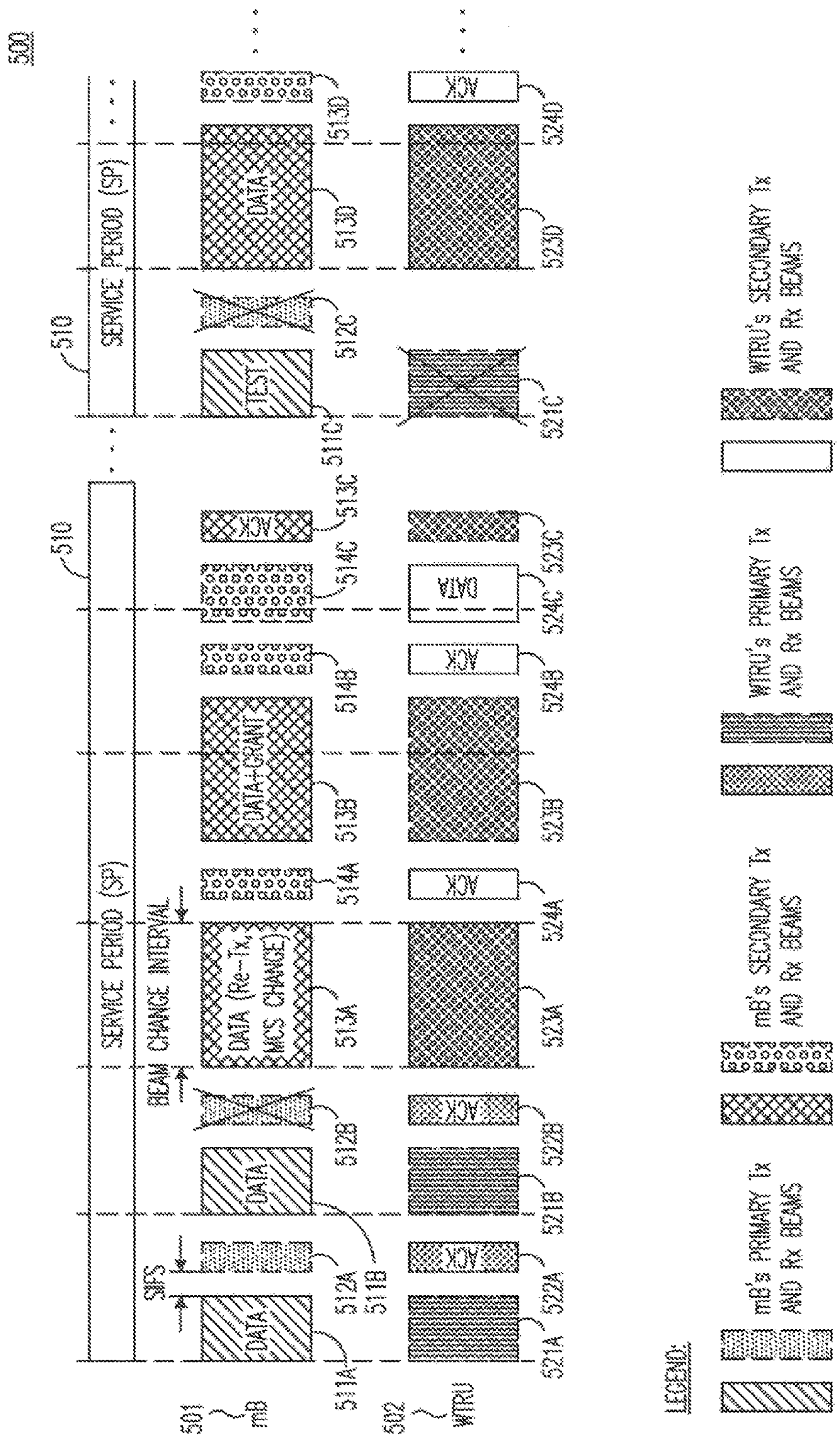

500
501
mB
502
WTRU
510
SERVICE PERIOD (SP)
SIFS
BEAM CHANGE INTERVAL
DATA
ACK
DATA (Re-Tx, MCS CHANGE)
DATA+GRANT
TEST
511A
511B
511C
512A
512B
512C
513A
513B
513C
513D
514A
514B
514C
521A
521B
521C
522A
522B
523A
523B
523C
523D
524A
524B
524C
524D
LEGEND:
mB's PRIMARY Tx AND Rx BEAMS
mB's SECONDARY Tx AND Rx BEAMS
WTRU's PRIMARY Tx AND Rx BEAMS
WTRU's SECONDARY Tx AND Rx BEAMS

FIG. 5

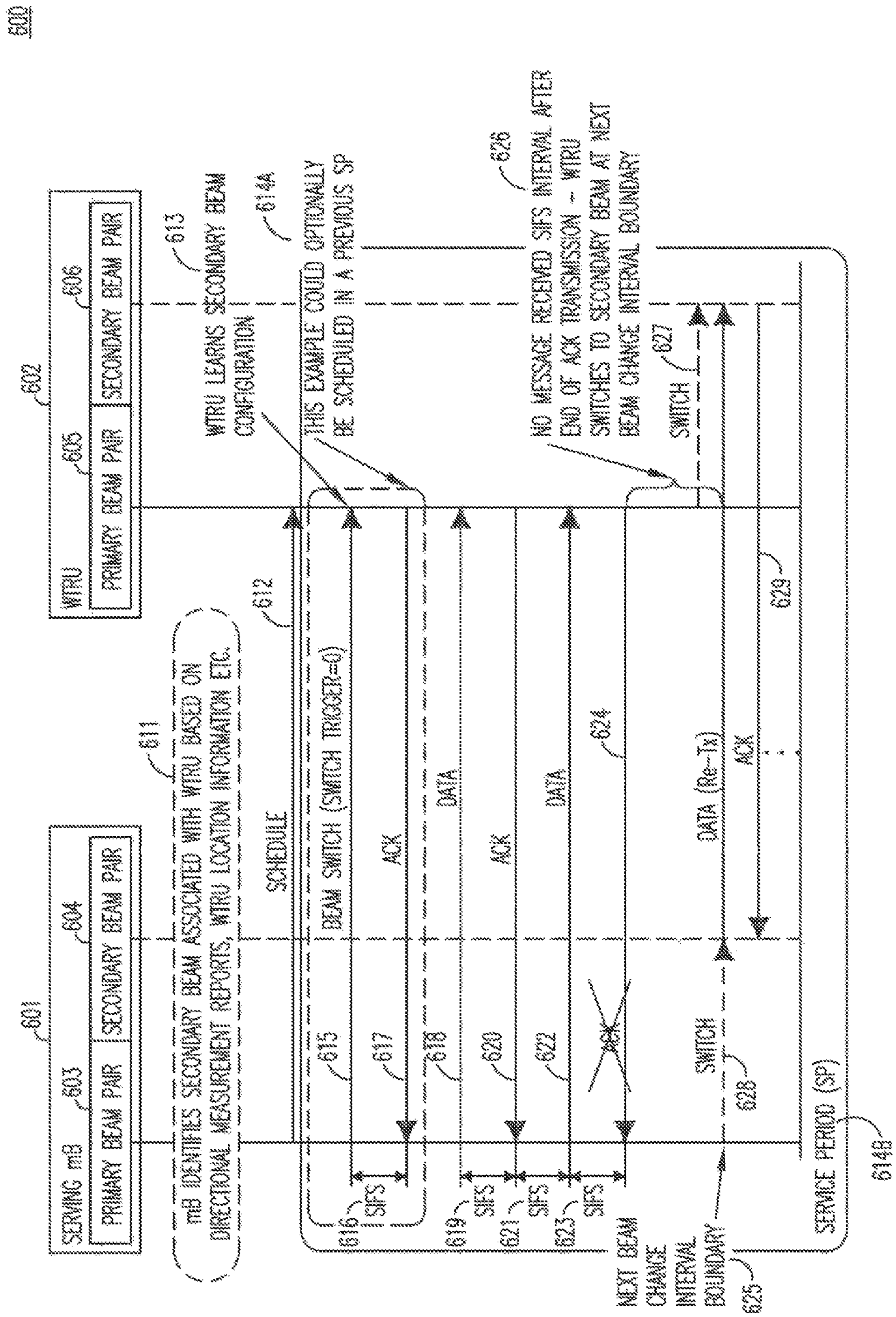

600
601
SERVING mB
PRIMARY BEAM PAIR
603
SECONDARY BEAM PAIR
604
602
WTRU
PRIMARY BEAM PAIR
605
SECONDARY BEAM PAIR
606
611
mB IDENTIFIES SECONDARY BEAM ASSOCIATED WITH WTRU BASED ON DIRECTIONAL MEASUREMENT REPORTS, WTRU LOCATION INFORMATION ETC.
612
SCHEDULE
613
WTRU LEARNS SECONDARY BEAM CONFIGURATION
614A
THIS EXAMPLE COULD OPTIONALLY BE SCHEDULED IN A PREVIOUS SP
615
BEAM SWITCH (SWITCH TRIGGER=0)
617
ACK
618
DATA
620
ACK
622
DATA
624
616
SIFS
619
SIFS
621
SIFS
623
SIFS
626
NO MESSAGE RECEIVED SIFS INTERVAL AFTER END OF ACK TRANSMISSION – WTRU SWITCHES TO SECONDARY BEAM AT NEXT BEAM CHANGE INTERVAL BOUNDARY
627
SWITCH
628
SWITCH
DATA (Re-Tx)
ACK
629
NEXT BEAM CHANGE INTERVAL BOUNDARY
625
SERVICE PERIOD (SP)
614B

FIG. 6A

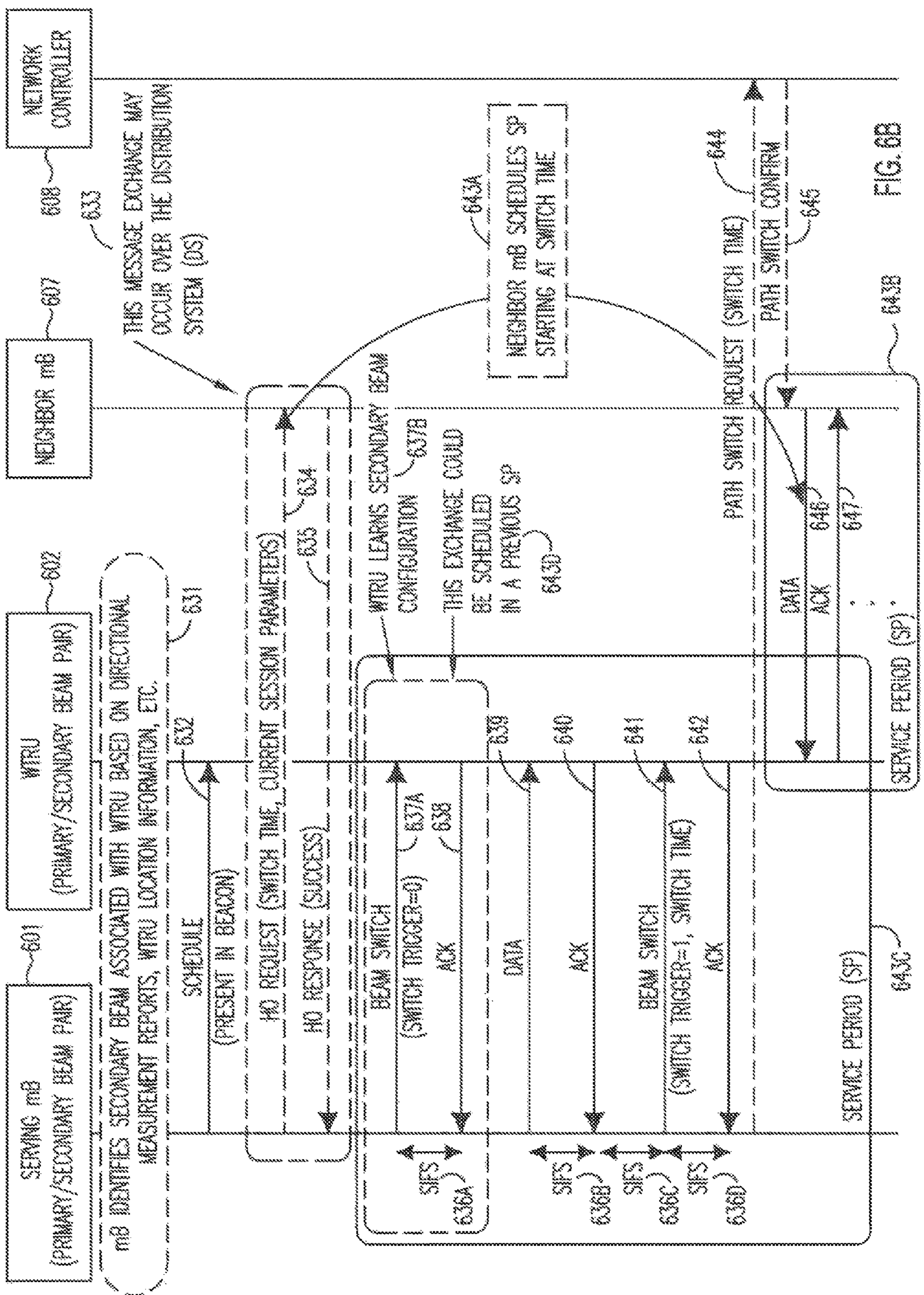

SERVING mB (PRIMARY/SECONDARY BEAM PAIR)
601
WTRU (PRIMARY/SECONDARY BEAM PAIR)
602
NEIGHBOR mB
607
NETWORK CONTROLLER
608
mB IDENTIFIES SECONDARY BEAM ASSOCIATED WITH WTRU BASED ON DIRECTIONAL MEASUREMENT REPORTS, WTRU LOCATION INFORMATION, ETC.
631
632
SCHEDULE (PRESENT IN BEACON)
THIS MESSAGE EXCHANGE MAY OCCUR OVER THE DISTRIBUTION SYSTEM (DS)
633
HO REQUEST (SWITCH TIME, CURRENT SESSION PARAMETERS)
634
HO RESPONSE (SUCCESS)
635
WTRU LEARNS SECONDARY BEAM CONFIGURATION
637B
THIS EXCHANGE COULD BE SCHEDULED IN A PREVIOUS SP
643D
BEAM SWITCH (SWITCH TRIGGER=0)
637A
ACK
638
DATA
639
ACK
640
BEAM SWITCH (SWITCH TRIGGER=1, SWITCH TIME)
641
ACK
642
SIFS
636A
SIFS
636B
SIFS
636C
SIFS
636D
SERVICE PERIOD (SP)
643C
NEIGHBOR mB SCHEDULES SP STARTING AT SWITCH TIME
643A
PATH SWITCH REQUEST (SWITCH TIME)
644
PATH SWITCH CONFIRM
645
DATA
646
ACK
647
SERVICE PERIOD (SP)
643B

FIG. 6B

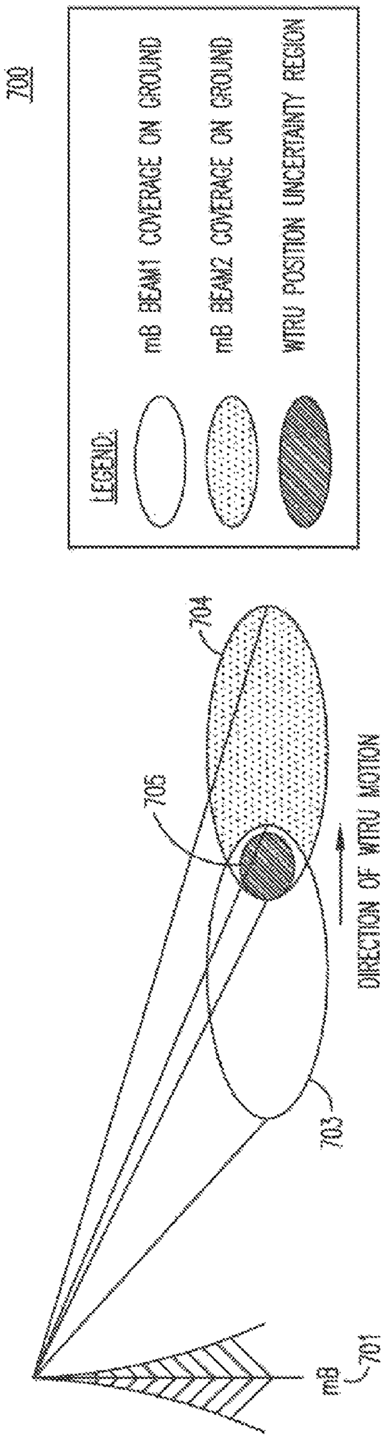

700
LEGEND:
mB BEAM1 COVERAGE ON GROUND
mB BEAM2 COVERAGE ON GROUND
WTRU POSITION UNCERTAINTY REGION
704
705
703
DIRECTION OF WTRU MOTION
702
mB
701

FIG. 7A

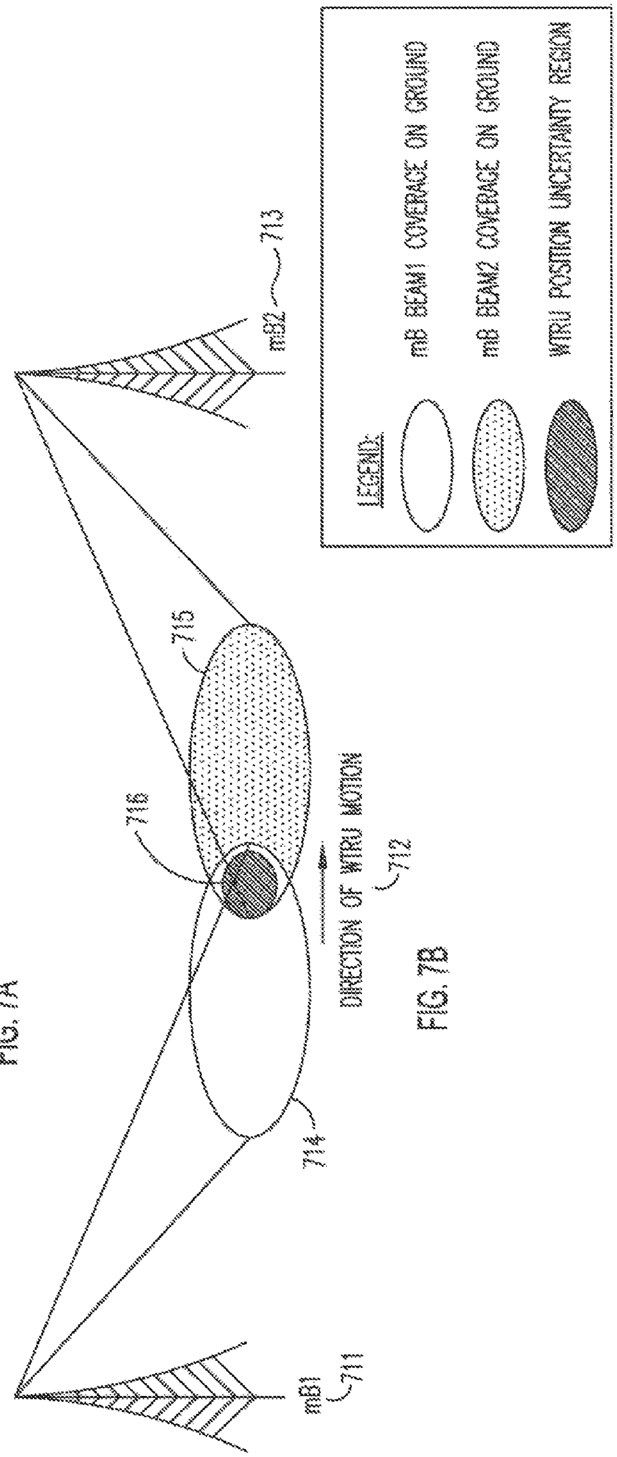

LEGEND:
mB BEAM1 COVERAGE ON GROUND
mB BEAM2 COVERAGE ON GROUND
WTRU POSITION UNCERTAINTY REGION
mB2
713
715
716
DIRECTION OF WTRU MOTION
712
714
mB1
711

FIG. 7B

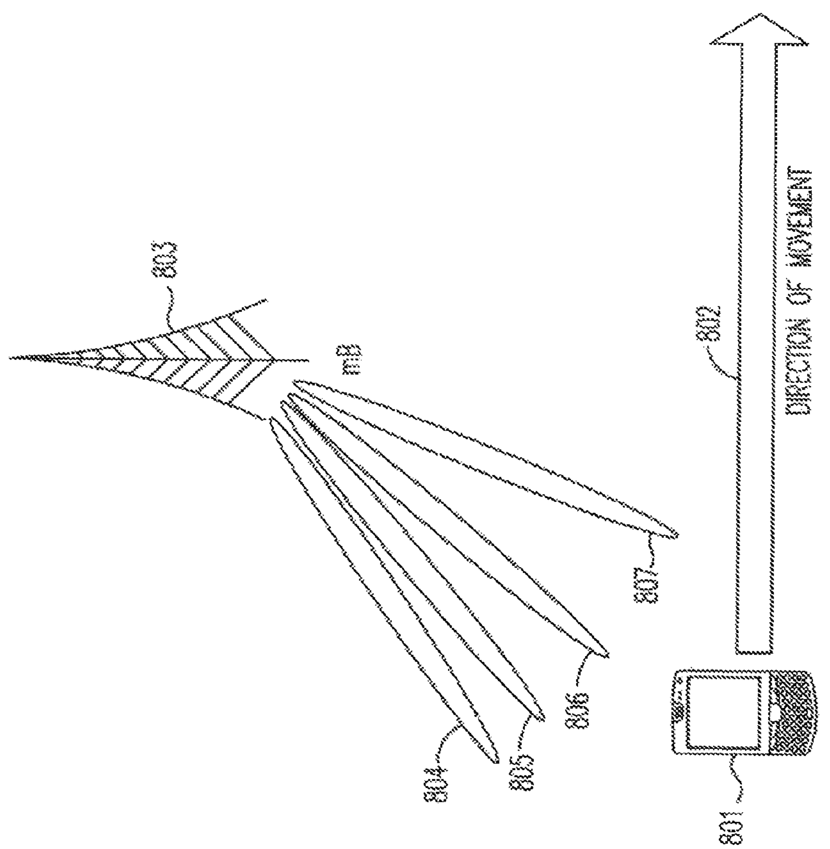


FIG. 8

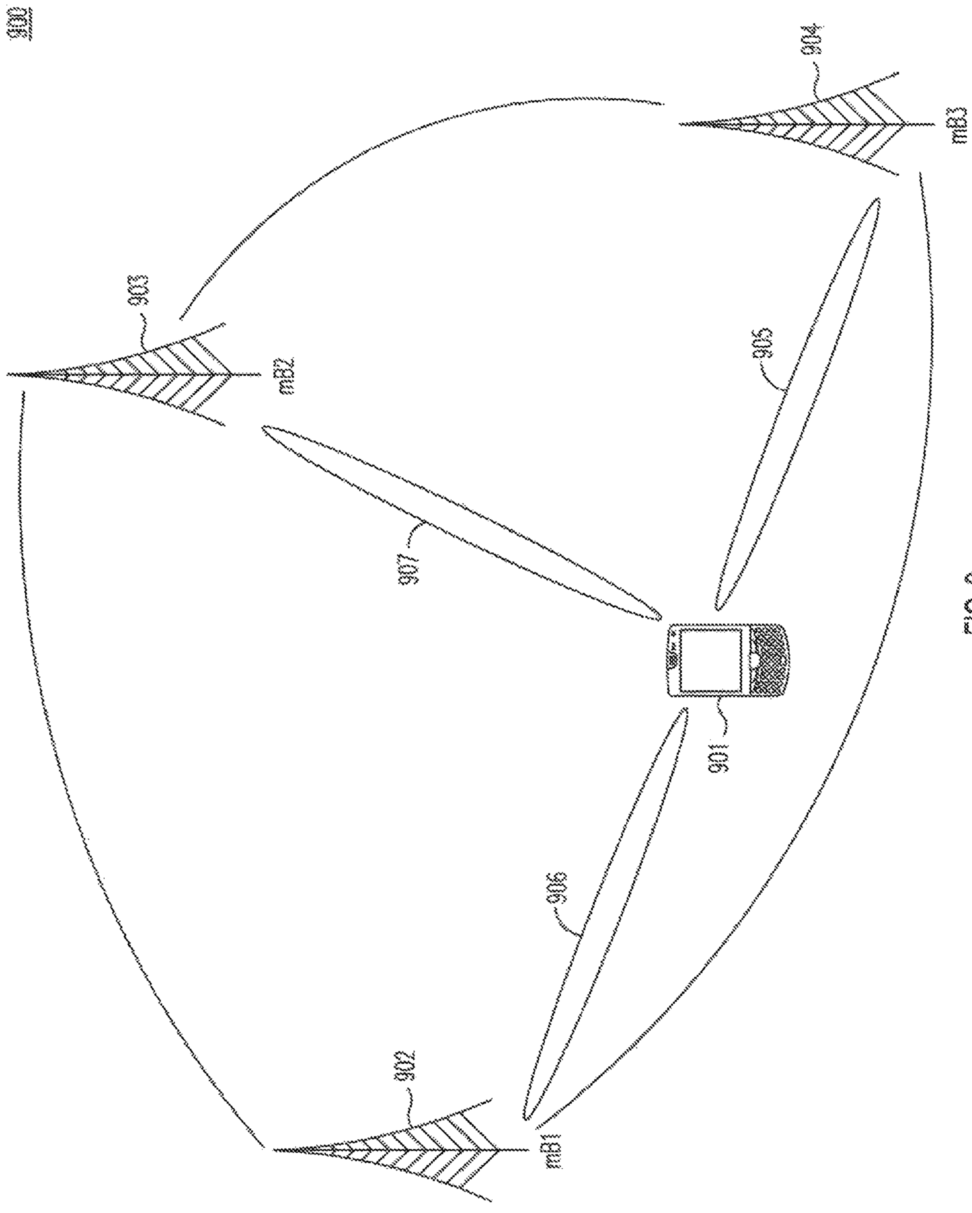


FIG. 9

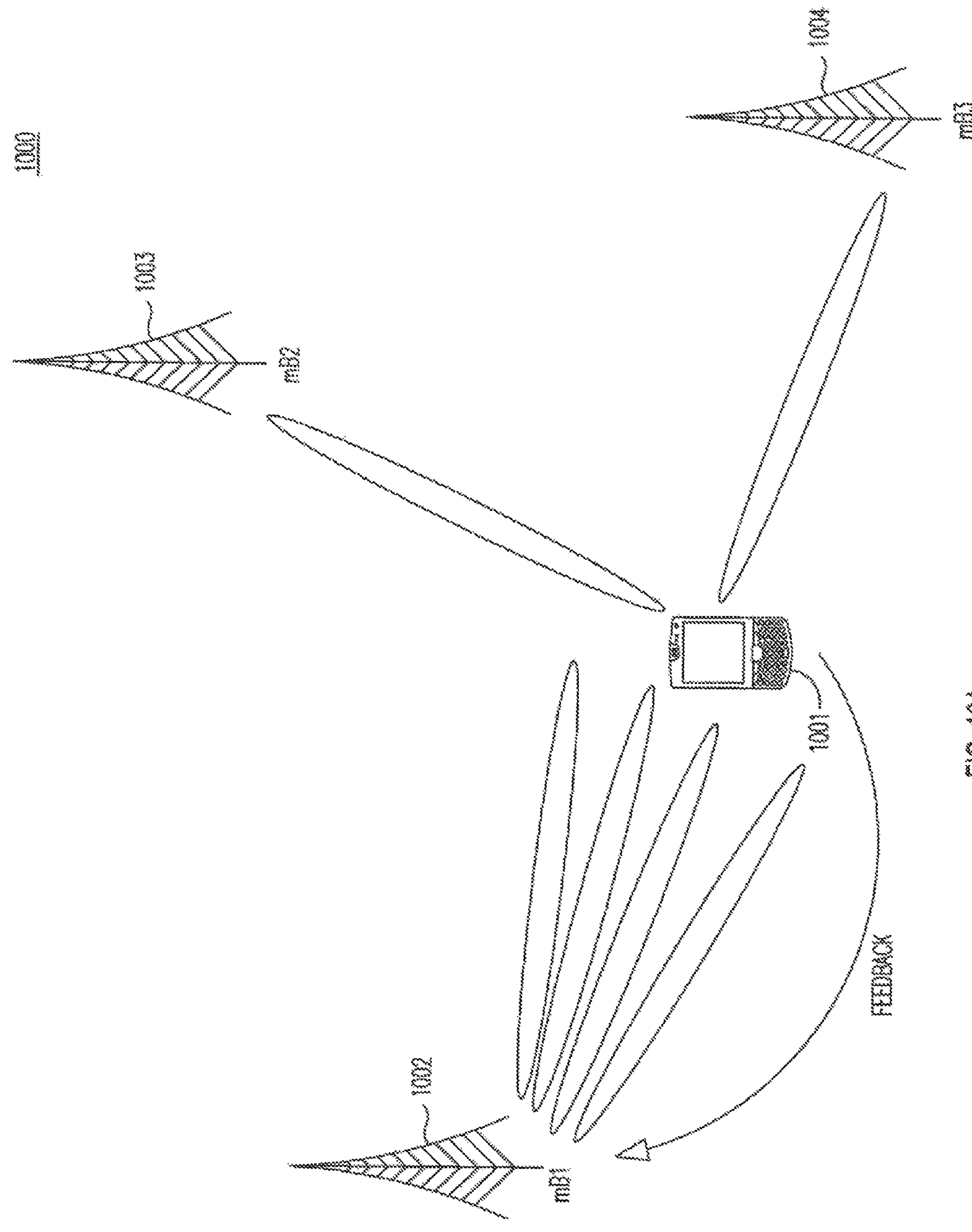


FIG. 10A

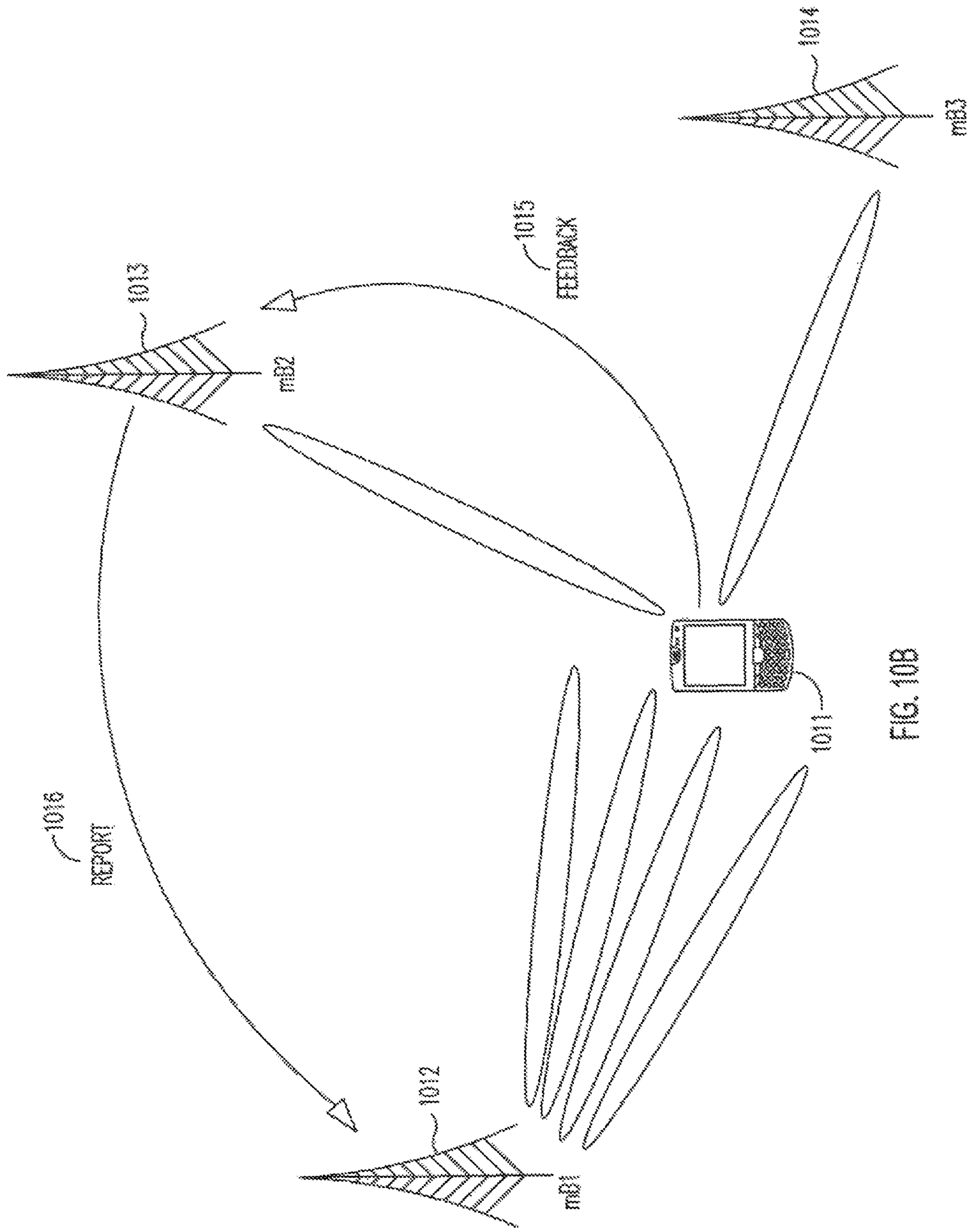


FIG. 10B

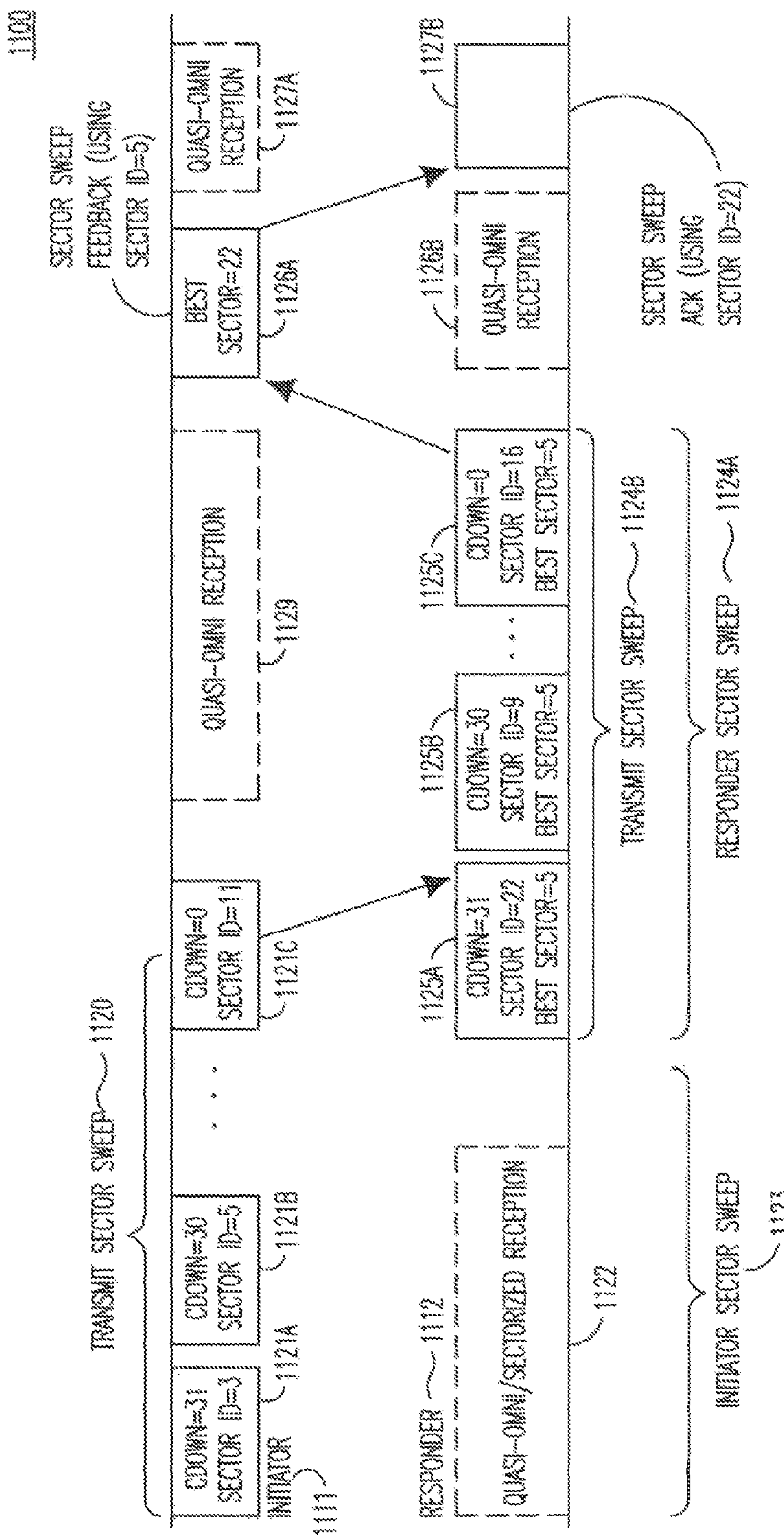

1100
INITIATOR
1111
RESPONDER
1112
CDOWN=31 SECTOR ID=3
1121A
CDOWN=30 SECTOR ID=5
1121B
CDOWN=0 SECTOR ID=11
1121C
TRANSMIT SECTOR SWEEP
1120
QUASI-OMNI/SECTORIZED RECEPTION
1122
INITIATOR SECTOR SWEEP
1123
CDOWN=31 SECTOR ID=22 BEST SECTOR=5
1125A
CDOWN=30 SECTOR ID=9 BEST SECTOR=5
1125B
CDOWN=0 SECTOR ID=16 BEST SECTOR=5
1125C
TRANSMIT SECTOR SWEEP
1124B
RESPONDER SECTOR SWEEP
1124A
QUASI-OMNI RECEPTION
1129
BEST SECTOR=22
1126A
SECTOR SWEEP FEEDBACK (USING SECTOR ID=5)
QUASI-OMNI RECEPTION
1127A
QUASI-OMNI RECEPTION
1126B
1127B
SECTOR SWEEP ACK (USING SECTOR ID=22)

FIG. 11A

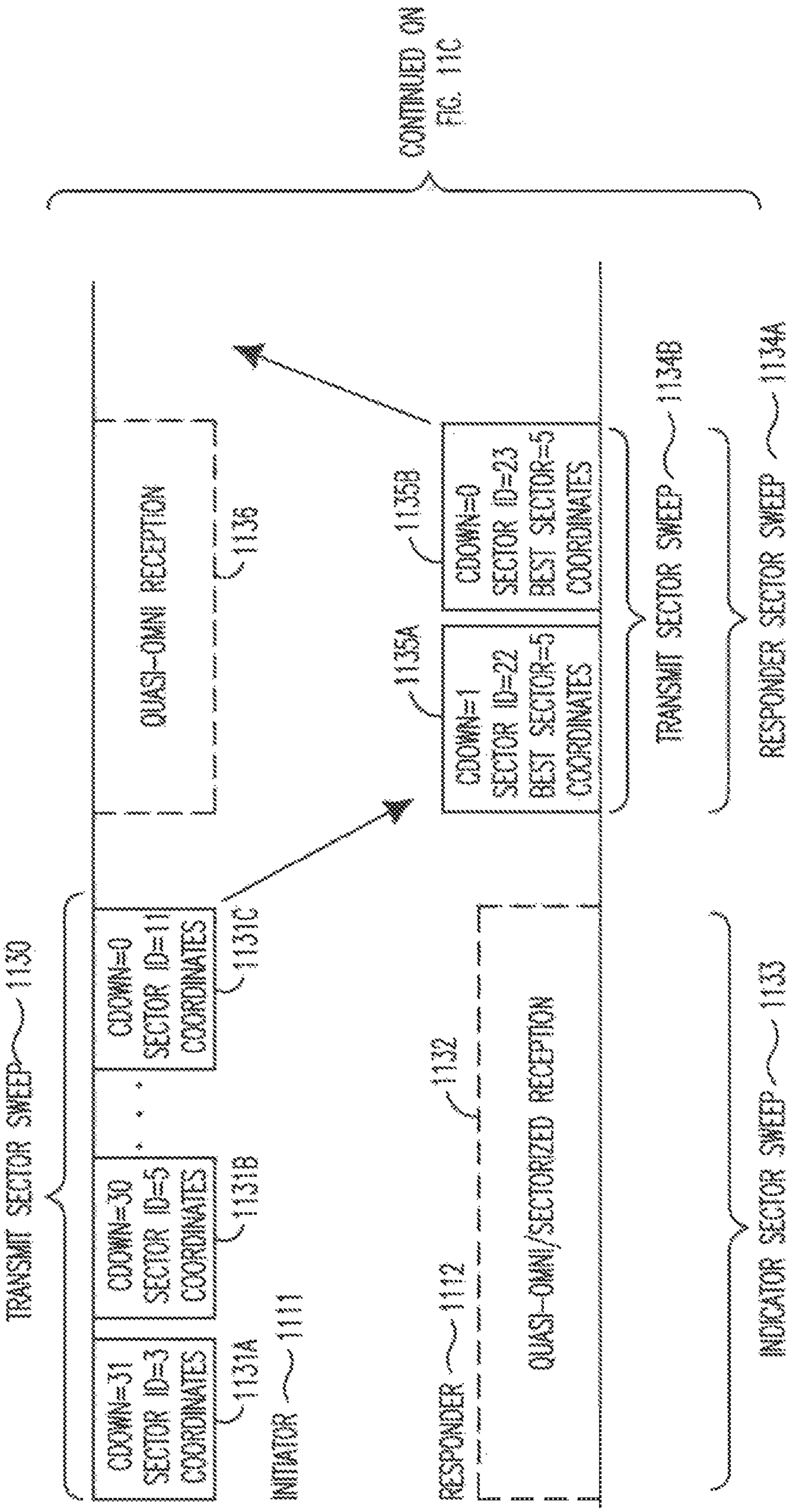
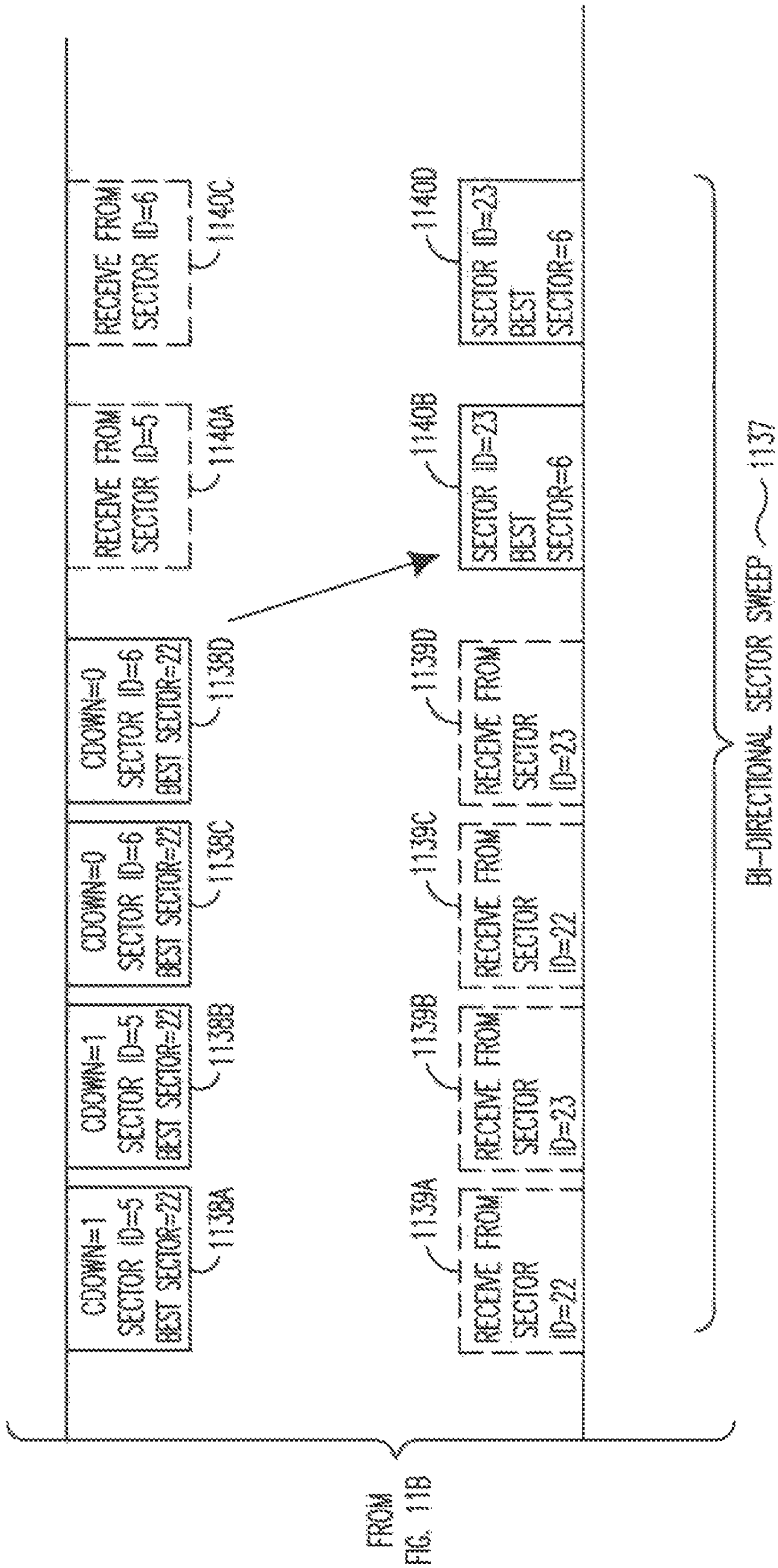

CONTINUED ON FIG. 11C
TRANSMIT SECTOR SWEEP 1130
CDOWN=31 SECTOR ID=3 COORDINATES
1131A
CDOWN=30 SECTOR ID=5 COORDINATES
1131B
CDOWN=0 SECTOR ID=11 COORDINATES
1131C
INITIATOR 1111
QUASI-OMNI RECEPTION
1136
RESPONDER 1112
QUASI-OMNI/SECTORIZED RECEPTION
1132
CDOWN=1 SECTOR ID=22 BEST SECTOR=5 COORDINATES
1135A
CDOWN=0 SECTOR ID=23 BEST SECTOR=5 COORDINATES
1135B
TRANSMIT SECTOR SWEEP 1134B
RESPONDER SECTOR SWEEP 1134A
INDICATOR SECTOR SWEEP 1133

FIG. 11B



CDOWN=1 SECTOR ID=5 BEST SECTOR=22
1138A
CDOWN=1 SECTOR ID=5 BEST SECTOR=22
1138B
CDOWN=0 SECTOR ID=6 BEST SECTOR=22
1138C
CDOWN=0 SECTOR ID=6 BEST SECTOR=22
1138D
RECEIVE FROM SECTOR ID=5
1140A
RECEIVE FROM SECTOR ID=6
1140C
RECEIVE FROM SECTOR ID=22
1139A
RECEIVE FROM SECTOR ID=23
1139B
RECEIVE FROM SECTOR ID=22
1139C
RECEIVE FROM SECTOR ID=23
1139D
SECTOR ID=23 BEST SECTOR=6
1140B
SECTOR ID=23 BEST SECTOR=6
1140D
BI-DIRECTIONAL SECTOR SWEEP
1137
FROM FIG. 11B

FIG. 11C

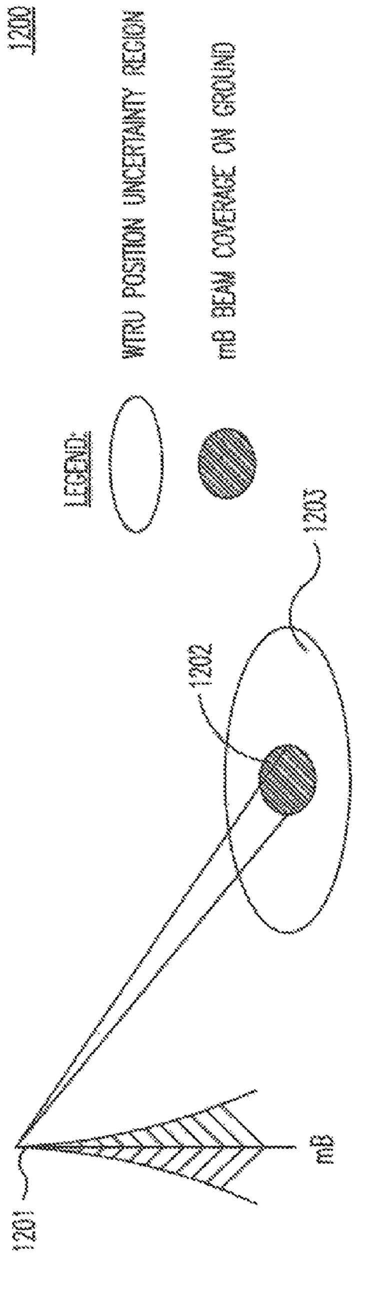

1200
LEGEND:
WTRU POSITION UNCERTAINTY REGION
mB BEAM COVERAGE ON GROUND
1201
1202
1203
mB

FIG. 12

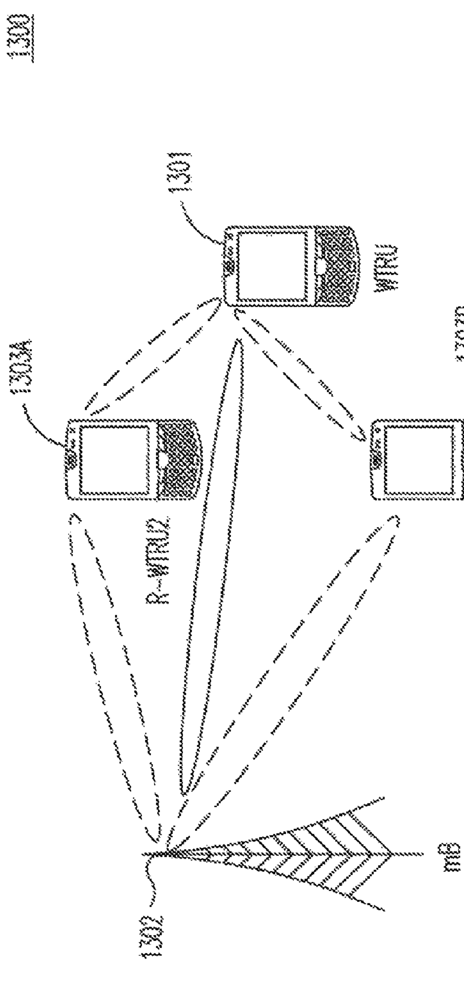

1300
1301
WTRU
1303A
R-WTRU2
1303B
R-WTRU1
1302
mB

FIG. 13

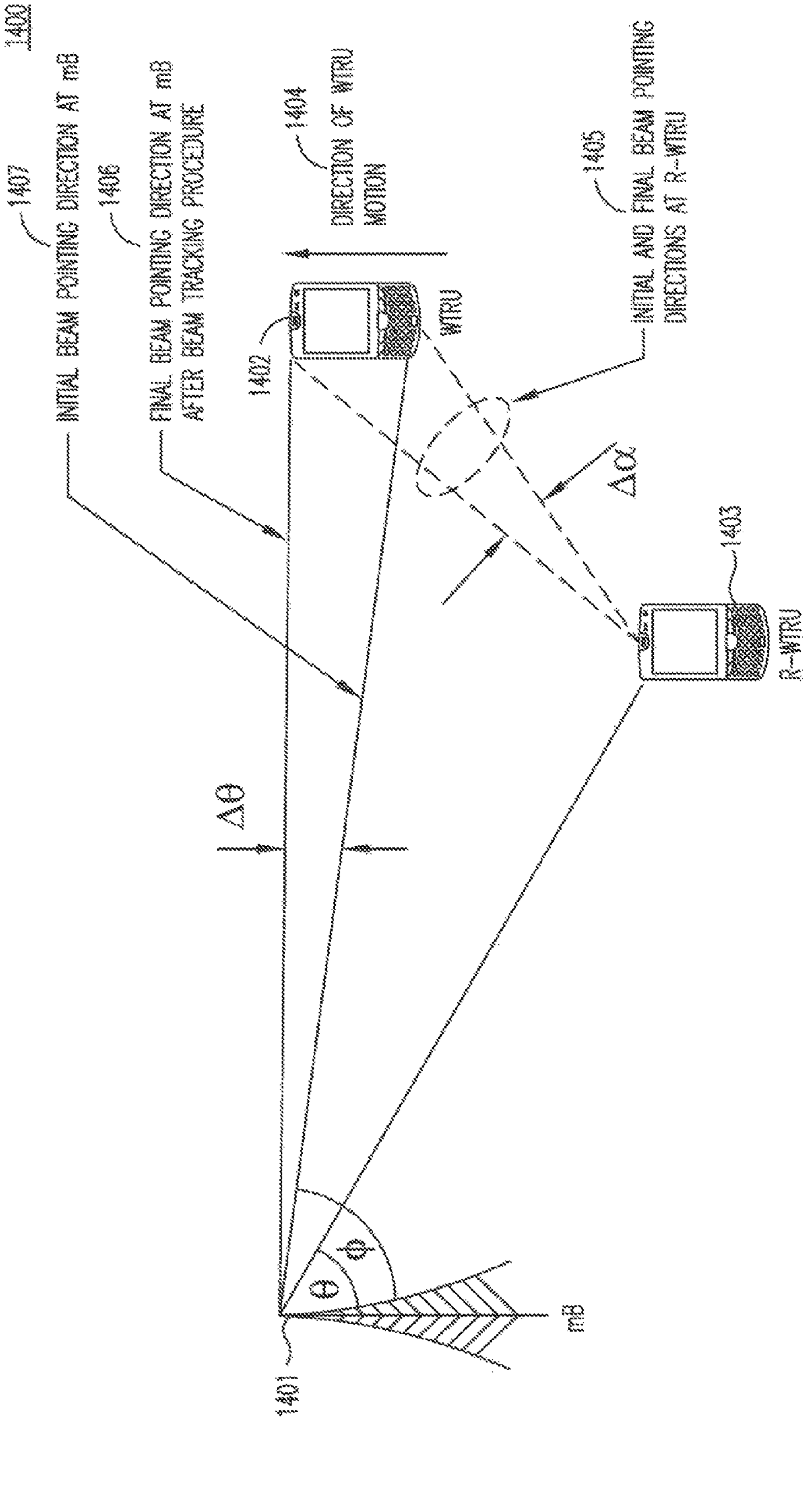

1400
1407
INITIAL BEAM POINTING DIRECTION AT mB
1406
FINAL BEAM POINTING DIRECTION AT mB
AFTER BEAM TRACKING PROCEDURE
1404
DIRECTION OF WTRU
MOTION
1405
INITIAL AND FINAL BEAM POINTING
DIRECTIONS AT R-WTRU
1402
WTRU
1403
R-WTRU
Δα
Δθ
θ
φ
mB
1401

FIG. 14A

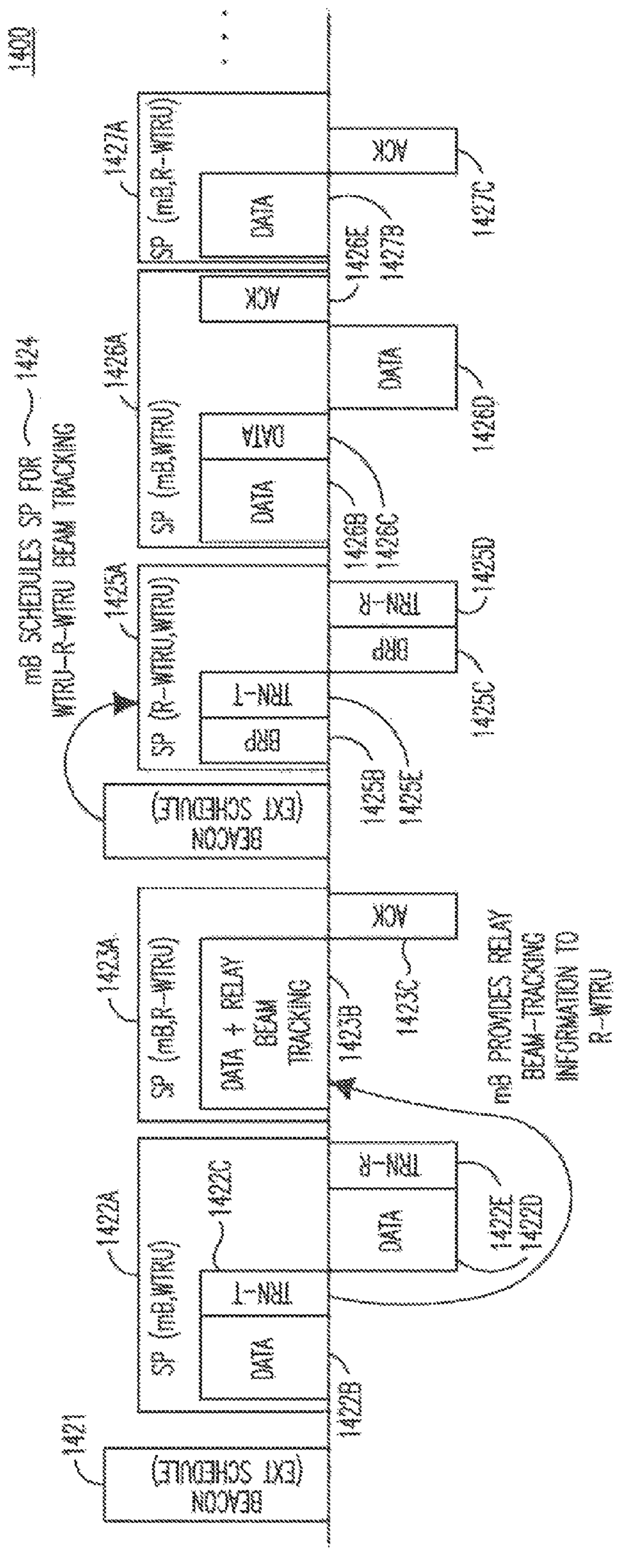


FIG. 14B

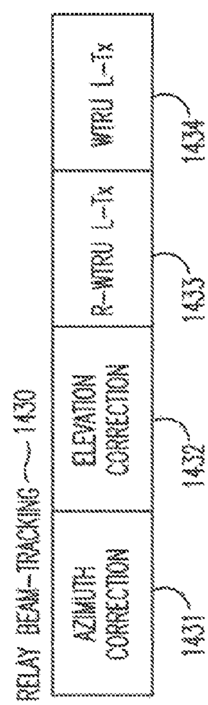


FIG. 14C

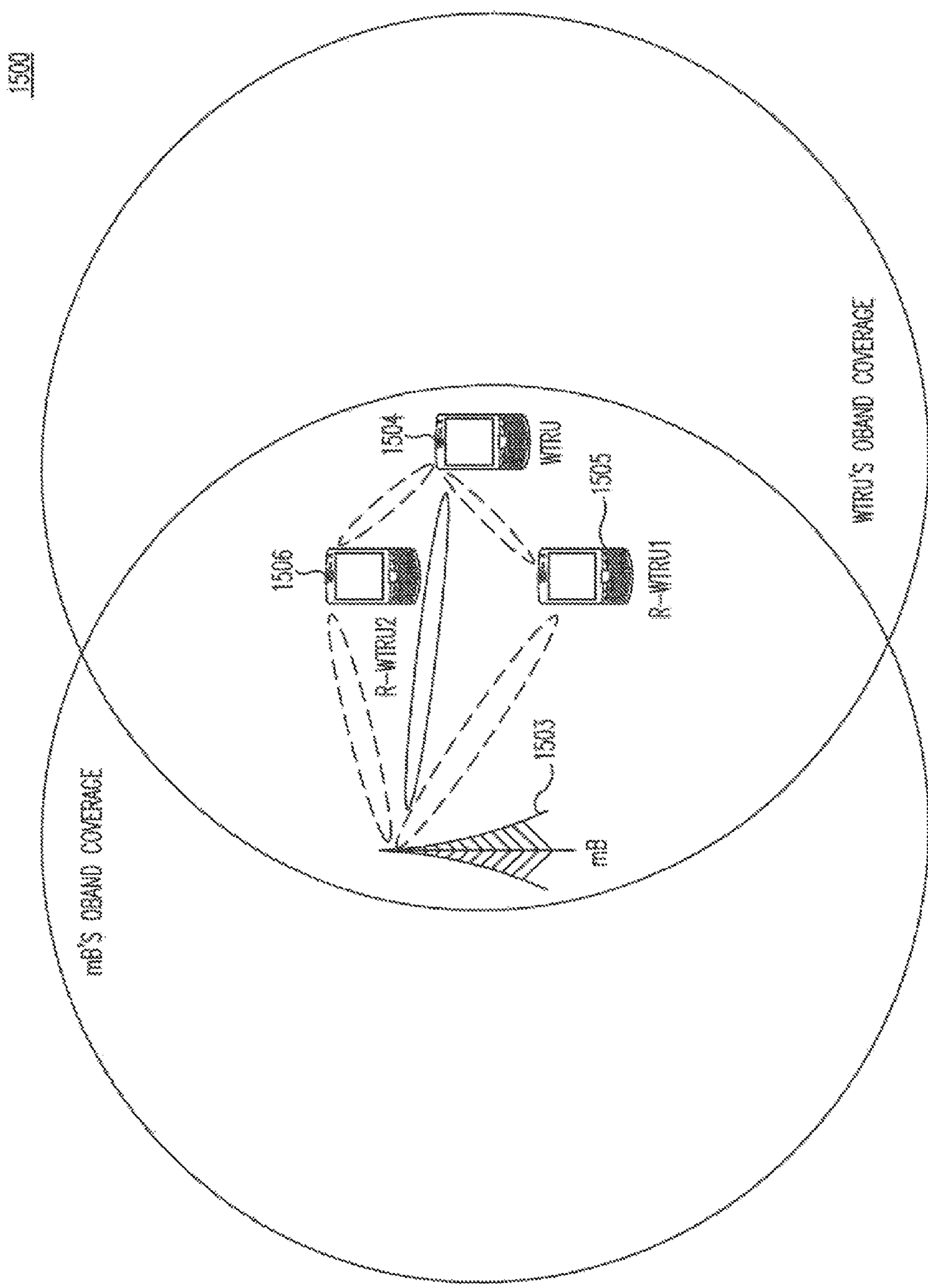

1500
WTRU'S OBAND COVERAGE
1502
1504
WTRU
1505
R-WTRU1
1506
R-WTRU2
1503
mB
mB'S OBAND COVERAGE
1501

FIG. 15

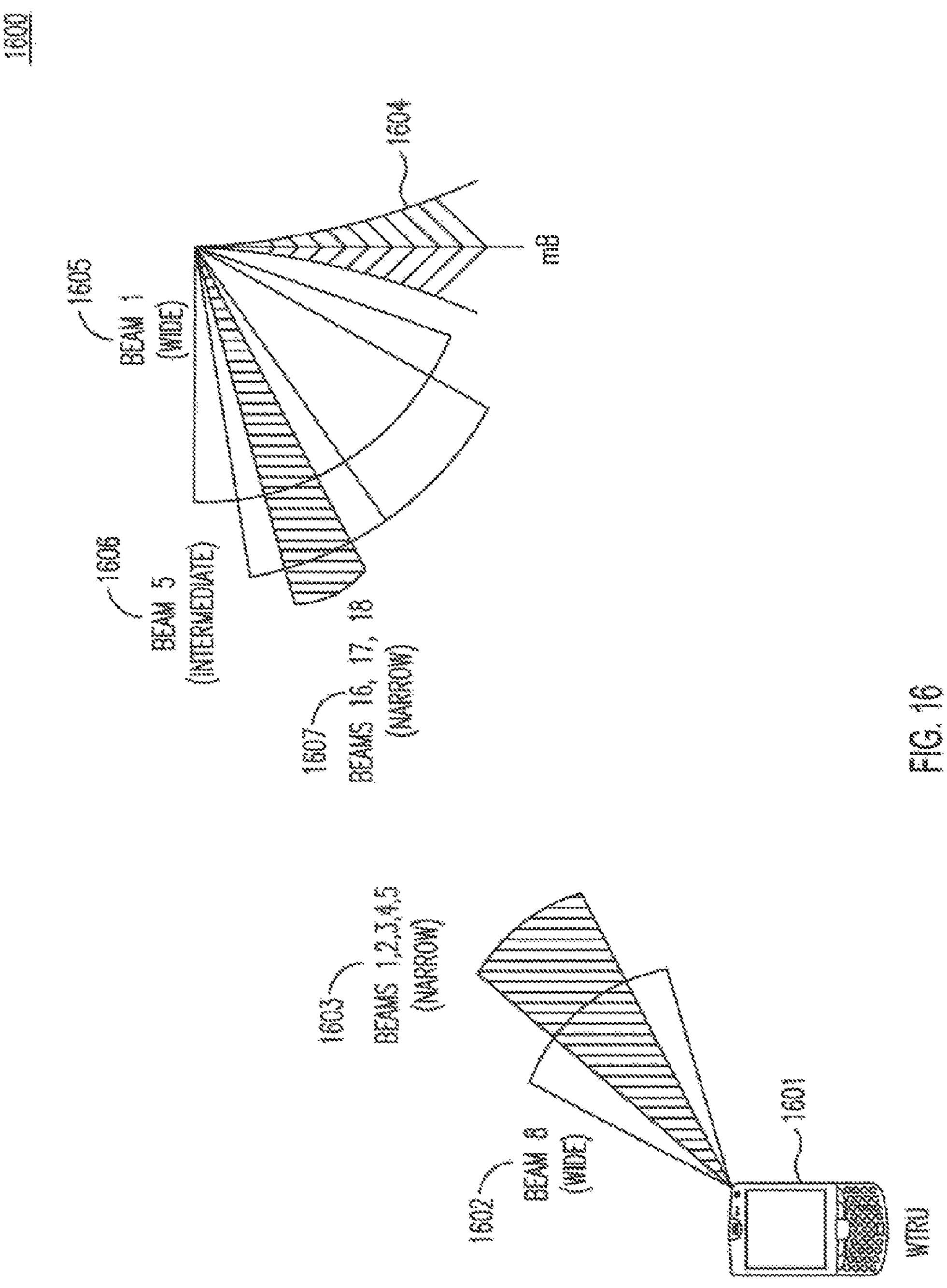

1600
1604
mB
1605
BEAM 1
(WIDE)
1606
BEAM 5
(INTERMEDIATE)
1607
BEAMS 16, 17, 18
(NARROW)
1603
BEAMS 1,2,3,4,5
(NARROW)
1602
BEAM 8
(WIDE)
1601
WTRU

FIG. 16

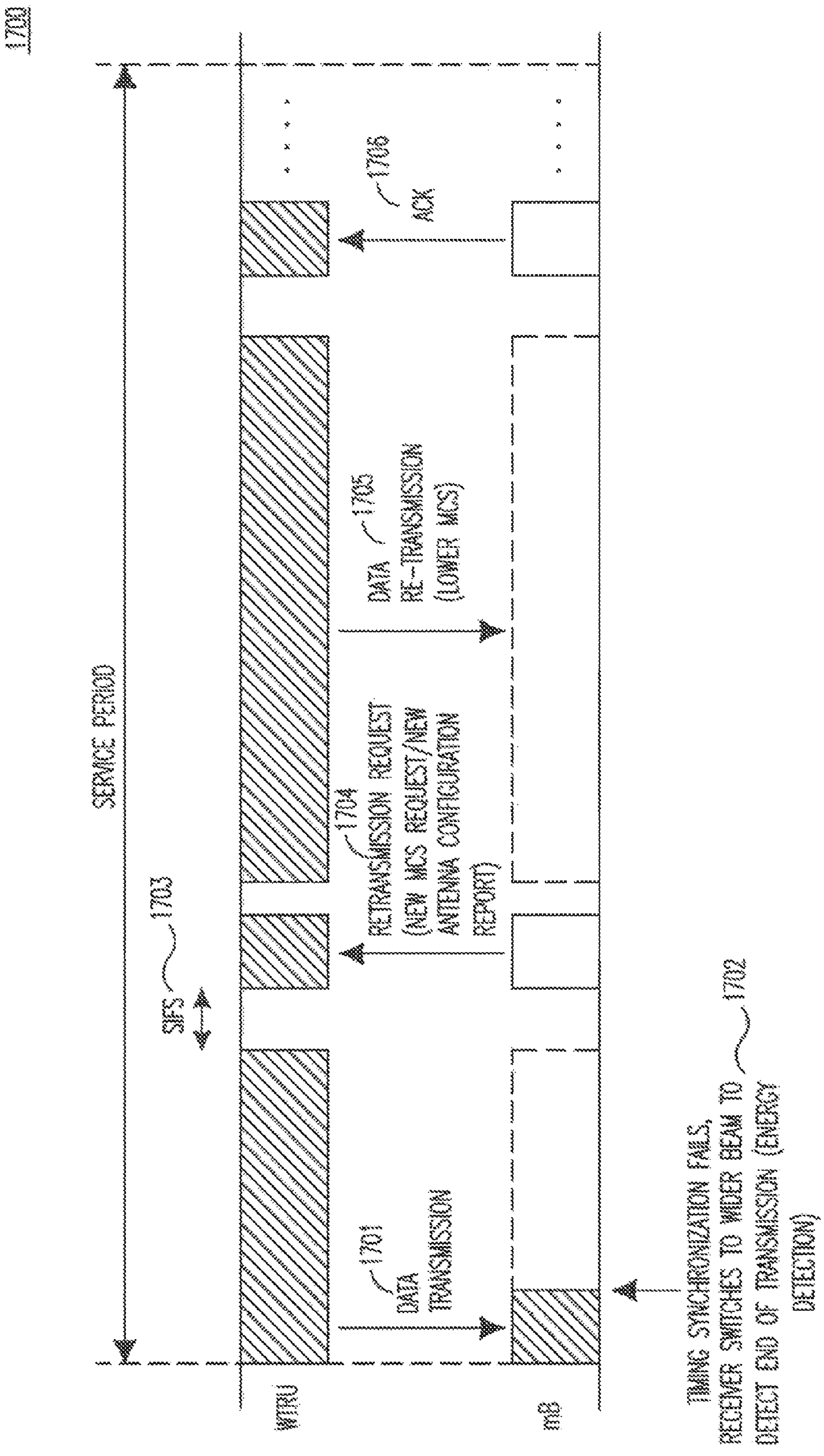

1700
SERVICE PERIOD
WTRU
mB
1701 DATA TRANSMISSION
SIFS
1703
1704 RETRANSMISSION REQUEST (NEW MCS REQUEST/NEW ANTENNA CONFIGURATION REPORT)
1705 DATA RE-TRANSMISSION (LOWER MCS)
1706 ACK
1702
TIMING SYNCHRONIZATION FAILS, RECEIVER SWITCHES TO WIDER BEAM TO DETECT END OF TRANSMISSION (ENERGY DETECTION)

FIG. 17

METHOD FOR MILLIMETER WAVE BEAM TRACKING

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. Non-Provisional application Ser. No. 14/423,362 filed Feb. 23, 2015, which is the U.S. National Stage, under 35 U.S.C. § 371, of International Application No. PCT/US2013/057101 filed Aug. 28, 2013, which claims the benefit of U.S. Provisional Application Ser. No. 61/694,162 filed Aug. 28, 2012 and U.S. Provisional Application Ser. No. 61/774,979 filed Mar. 8, 2013, the contents of which are hereby incorporated by reference herein.

BACKGROUND

High frequencies offer the potential of wide bandwidths. The narrow beamforming enabled at these frequencies (along with high penetration losses) provides high spatial containment of the transmitted signals. These frequencies may be referred to as millimeter wave (mmW) frequencies. The precise frequency range may range from approximately 28 GHz to 160 GHZ or 300 GHz with a special interest in the unlicensed V-band (60 GHz band) and E-band (70/80/90 GHz point-to-point band). Even higher frequencies, (sometimes referred to as terahertz (THz)), may be used and may be are applicable. The V-band is of particular interest due to the ~7 GHz, (depending on country) of unlicensed spectrum available and the growing ecosystem of under-development standards such as WiGig, WirelessHD and the like. Existing 60 GHz standards such as Institute of Electrical and Electronics Engineers (IEEE) 802.11ad and IEEE 802.15.3c specify procedures for initial beam acquisition and subsequent beam tracking. However, these procedures are inadequate to address more challenging wireless transmit/receive unit (WTRU) mobility scenarios in outdoor applications. Moreover, they do not leverage measurements from neighboring cells to aid WTRU tracking.

SUMMARY

Methods and apparatuses are described herein to perform and improve mmW beam tracking. Described herein are localization methods to improve predictions of the position of a WTRU, which may allow a millimeter wave base station (mB) to appropriately select a modified beam without having to perform beam acquisition every single time a WTRU moves. Localization techniques in which an mB may control a directional measurement campaign in order to generate a directional radio environment map (DREM) are described herein. The mB may request associated WTRUs to perform directional signal strength measurements, which may then be reported back to the mB. The mB may then generate a DREM based on the directional signal strength measurement reports, which may be used to identify secondary links when a primary link fails. Another application of the DREM is to determine possibilities for multiple simultaneous transmissions to different WTRUs. The mB may store the DREM in a database for network access by other mBs and for secondary link selection.

Also described herein are additional localization techniques using internal/external information for prediction. The information may be time-stamping, signal strength measurement, location information (global positioning system (GPS) coordinates), and inputs from internal devices such as gyroscopes, accelerometers, and the like. Another example method may use the previous history of used beams and other historical data such as mapped terrain information. In yet another example, data obtained from mB-mB cooperation including feedback information and reference signaling information may be used. Using group movement of WTRUs to perform beam tracking of a WTRU group is also described. Beam tracking for directional relays and initial beam training optimization methods are also described. Finally, WTRU localization precision improvement, beamwidth adaptation, and assisted beam tracking and handover methods are disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

A more detailed understanding may be had from the following description, given by way of example in conjunction with the accompanying drawings wherein:

FIG. 1A is a system diagram of an example communications system in which one or more disclosed embodiments may be implemented;

FIG. 1B is a system diagram of an example wireless transmit/receive unit (WTRU) that may be used within the communications system illustrated in FIG. 1A;

FIG. 1C is a system diagram of an example radio access network and an example core network that may be used within the communications system illustrated in FIG. 1A;

FIG. 2A is a high level flow chart in which the mB may control a directional measurement campaign in order to generate a directional radio environment map (DREM);

FIG. 2B is an example of a first phase of mB controlled directional measurements;

FIG. 2C is an example of a second phase of mB controlled directional measurements;

FIG. 2D is an example of a third phase of mB controlled directional measurements;

FIG. 2E is an example of a fourth phase of mB controlled directional measurements;

FIG. 2F is an example of secondary link discovery at a WTRU following directional signal strength measuring and reporting;

FIG. 2G is an example of a Directional Measurement frame;

FIG. 3A is an example of using data from other sources for tracking the movement of a WTRU to generate a DREM;

FIG. 3B is a second example of using data from other sources for tracking the movement of a WTRU to generate a DREM;

FIG. 4A is a call flow diagram for an example intra cell/basic service set (BSS) directional measurement procedure for DREM generation;

FIG. 4B is a call flow diagram for an example inter cell/basic service set (BSS) directional measurement procedure for DREM generation;

FIG. 5 is an example of secondary beam activation;

FIG. 6A is an example call flow of a procedure in which an implicit intra-cell switch is made to a secondary beam;

FIG. 6B is an example call flow of a procedure in which an explicit inter-cell switch is made to a secondary beam;

FIG. 7A is an example in which an mB has two beams and may select a beam based on WTRU movement;

FIG. 7B is an example of how location information may be used for improved handover decisions;

FIG. 8 is an example in which a WTRU may be tracked using historical data;

FIG. 9 is an example in which a WTRU may be tracked by multiple mBs;

FIG. 10A an example of a WTRU providing data feedback from multiple mBs to the serving mB;

FIG. 10B is an example of mB to mB communication signaling;

FIG. 11A is an example of the current IEEE 802.11ad Sector Level Sweep (SLS) procedure;

FIG. 11B is an example of a revised SLS procedure;

FIG. 11C is a continuation of the example revised SLS procedure of FIG. 11B;

FIG. 12 is an example of improved method for geo-location precision;

FIG. 13 is an example of direct and indirect mB-WTRU links;

FIG. 14A is an example of beam tracking on the R-WTRU-WTRU link triggered by WTRU movement;

FIG. 14B is an example of how an mB may provide relay beam tracking information to a relay WTRU and may schedule a SP for WTRU-R-WTRU beam tracking;

FIG. 14C is an example of a relay beam-tracking field that may be provided by the mB to the R-WTRU;

FIG. 15 is an example of beam tracking via omni-directional band (OBand) signaling;

FIG. 16 is an example of the use of variable beamwidths; and

FIG. 17 is an example of a receiver beam adaptation procedure.

DETAILED DESCRIPTION

FIG. 1A is a diagram of an example communications system **100** in which one or more disclosed embodiments may be implemented. The communications system **100** may be a multiple access system that provides content, such as voice, data, video, messaging, broadcast, etc., to multiple wireless users. The communications system **100** may enable multiple wireless users to access such content through the sharing of system resources, including wireless bandwidth. For example, the communications systems **100** may employ one or more channel access methods, such as code division multiple access (CDMA), time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), single-carrier FDMA (SC-FDMA), and the like.

As shown in FIG. 1A, the communications system **100** may include wireless transmit/receive units (WTRUs) **102***a*, **102***b*, **102***c*, **102***d*, a radio access network (RAN) **104**, a core network **106**, a public switched telephone network (PSTN) **108**, the Internet **110**, and other networks **112**, though it will be appreciated that the disclosed embodiments contemplate any number of WTRUs, base stations, networks, and/or network elements. Each of the WTRUs **102***a*, **102***b*, **102***c*, **102***d* may be any type of device configured to operate and/or communicate in a wireless environment. By way of example, the WTRUs **102***a*, **102***b*, **102***c*, **102***d* may be configured to transmit and/or receive wireless signals and may include user equipment (UE), a mobile station, a fixed or mobile subscriber unit, a pager, a cellular telephone, a personal digital assistant (PDA), a smartphone, a laptop, a netbook, a personal computer, a wireless sensor, consumer electronics, and the like.

The communications systems **100** may also include a base station **114***a* and a base station **114***b*. Each of the base stations **114***a*, **114***b* may be any type of device configured to wirelessly interface with at least one of the WTRUs **102***a*, **102***b*, **102***c*, **102***d* to facilitate access to one or more communication networks, such as the core network **106**, the Internet **110**, and/or the other networks **112**. By way of example, the base stations **114***a*, **114***b* may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, a site controller, an access point (AP), a wireless router, and the like. While the base stations **114***a*, **114***b* are each depicted as a single element, it will be appreciated that the base stations **114***a*, **114***b* may include any number of interconnected base stations and/or network elements.

The base station **114***a* may be part of the RAN **104**, which may also include other base stations and/or network elements (not shown), such as a base station controller (BSC), a radio network controller (RNC), relay nodes, etc. The base station **114***a* and/or the base station **114***b* may be configured to transmit and/or receive wireless signals within a particular geographic region, which may be referred to as a cell (not shown). The cell may further be divided into cell sectors. For example, the cell associated with the base station **114***a* may be divided into three sectors. Thus, in one embodiment, the base station **114***a* may include three transceivers, i.e., one for each sector of the cell. In another embodiment, the base station **114***a* may employ multiple-input multiple-output (MIMO) technology and, therefore, may utilize multiple transceivers for each sector of the cell.

The base stations **114***a*, **114***b* may communicate with one or more of the WTRUs **102***a*, **102***b*, **102***c*, **102***d* over an air interface **116**, which may be any suitable wireless communication link (e.g., radio frequency (RF), microwave, infrared (IR), ultraviolet (UV), visible light, etc.). The air interface **116** may be established using any suitable radio access technology (RAT).

More specifically, as noted above, the communications system **100** may be a multiple access system and may employ one or more channel access schemes, such as CDMA, TDMA, FDMA, OFDMA, SC-FDMA, and the like. For example, the base station **114***a* in the RAN **104** and the WTRUs **102***a*, **102***b*, **102***c* may implement a radio technology such as Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access (UTRA), which may establish the air interface **116** using wideband CDMA (WCDMA). WCDMA may include communication protocols such as High-Speed Packet Access (HSPA) and/or Evolved HSPA (HSPA+). HSPA may include High-Speed Downlink Packet Access (HSDPA) and/or High-Speed Uplink Packet Access (HSUPA).

In another embodiment, the base station **114***a* and the WTRUs **102***a*, **102***b*, **102***c* may implement a radio technology such as Evolved UMTS Terrestrial Radio Access (E-UTRA), which may establish the air interface **116** using Long Term Evolution (LTE) and/or LTE-Advanced (LTE-A).

In other embodiments, the base station **114***a* and the WTRUs **102***a*, **102***b*, **102***c* may implement radio technologies such as IEEE 802.16 (i.e., Worldwide Interoperability for Microwave Access (WiMAX)), CDMA2000, CDMA2000 1X, CDMA2000 EV-DO, Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), GSM EDGE (GERAN), and the like.

The base station **114***b* in FIG. 1A may be a wireless router, Home Node B, Home eNode B, or access point, for example, and may utilize any suitable RAT for facilitating wireless connectivity in a localized area, such as a place of business, a home, a vehicle, a campus, and the like. In one embodiment, the base station **114***b* and the WTRUs **102***c*, **102***d* may implement a radio technology such as IEEE 802.11 to establish a wireless local area network (WLAN). In another embodiment, the base station **114***b* and the WTRUs **102***c*, **102***d* may implement a radio technology such as IEEE 802.15 to establish a wireless personal area network (WPAN). In yet another embodiment, the base station **114***b* and the WTRUs **102***c*, **102***d* may utilize a cellular-based RAT (e.g., WCDMA, CDMA2000, GSM, LTE, LTE-A, etc.) to establish a picocell or femtocell. As shown in FIG. **1**A, the base station **114***b* may have a direct connection to the Internet **110**. Thus, the base station **114***b* may not be required to access the Internet **110** via the core network **106**.

The RAN **104** may be in communication with the core network **106**, which may be any type of network configured to provide voice, data, applications, and/or voice over internet protocol (VoIP) services to one or more of the WTRUs **102***a*, **102***b*, **102***c*, **102***d*. For example, the core network **106** may provide call control, billing services, mobile location-based services, pre-paid calling, Internet connectivity, video distribution, etc., and/or perform high-level security functions, such as user authentication. Although not shown in FIG. **1**A, it will be appreciated that the RAN **104** and/or the core network **106** may be in direct or indirect communication with other RANs that employ the same RAT as the RAN **104** or a different RAT. For example, in addition to being connected to the RAN **104**, which may be utilizing an E-UTRA radio technology, the core network **106** may also be in communication with another RAN (not shown) employing a GSM radio technology.

The core network **106** may also serve as a gateway for the WTRUs **102***a*, **102***b*, **102***c*, **102***d* to access the PSTN **108**, the Internet **110**, and/or other networks **112**. The PSTN **108** may include circuit-switched telephone networks that provide plain old telephone service (POTS). The Internet **110** may include a global system of interconnected computer networks and devices that use common communication protocols, such as the transmission control protocol (TCP), user datagram protocol (UDP) and the internet protocol (IP) in the TCP/IP internet protocol suite. The networks **112** may include wired or wireless communications networks owned and/or operated by other service providers. For example, the networks **112** may include another core network connected to one or more RANs, which may employ the same RAT as the RAN **104** or a different RAT.

Some or all of the WTRUs **102***a*, **102***b*, **102***c*, **102***d* in the communications system **100** may include multi-mode capabilities, i.e., the WTRUs **102***a*, **102***b*, **102***c*, **102***d* may include multiple transceivers for communicating with different wireless networks over different wireless links. For example, the WTRU **102***c* shown in FIG. **1**A may be configured to communicate with the base station **114***a*, which may employ a cellular-based radio technology, and with the base station **114***b*, which may employ an IEEE 802 radio technology.

FIG. **1**B is a system diagram of an example WTRU **102**. As shown in FIG. **1**B, the WTRU **102** may include a processor **118**, a transceiver **120**, a transmit/receive element **122**, a speaker/microphone **124**, a keypad **126**, a display/touchpad **128**, non-removable memory **130**, removable memory **132**, a power source **134**, a global positioning system (GPS) chipset **136**, and other peripherals **138**. It will be appreciated that the WTRU **102** may include any sub-combination of the foregoing elements while remaining consistent with an embodiment.

The processor **118** may be a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Array (FPGAs) circuits, any other type of integrated circuit (IC), a state machine, and the like. The processor **118** may perform signal coding, data processing, power control, input/output processing, and/or any other functionality that enables the WTRU **102** to operate in a wireless environment. The processor **118** may be coupled to the transceiver **120**, which may be coupled to the transmit/receive element **122**. While FIG. **1**B depicts the processor **118** and the transceiver **120** as separate components, it will be appreciated that the processor **118** and the transceiver **120** may be integrated together in an electronic package or chip.

The transmit/receive element **122** may be configured to transmit signals to, or receive signals from, a base station (e.g., the base station **114***a*) over the air interface **116**. For example, in one embodiment, the transmit/receive element **122** may be an antenna configured to transmit and/or receive RF signals. In another embodiment, the transmit/receive element **122** may be an emitter/detector configured to transmit and/or receive IR, UV, or visible light signals, for example. In yet another embodiment, the transmit/receive element **122** may be configured to transmit and receive both RF and light signals. It will be appreciated that the transmit/receive element **122** may be configured to transmit and/or receive any combination of wireless signals.

In addition, although the transmit/receive element **122** is depicted in FIG. **1**B as a single element, the WTRU **102** may include any number of transmit/receive elements **122**. More specifically, the WTRU **102** may employ MIMO technology. Thus, in one embodiment, the WTRU **102** may include two or more transmit/receive elements **122** (e.g., multiple antennas) for transmitting and receiving wireless signals over the air interface **116**.

The transceiver **120** may be configured to modulate the signals that are to be transmitted by the transmit/receive element **122** and to demodulate the signals that are received by the transmit/receive element **122**. As noted above, the WTRU **102** may have multi-mode capabilities. Thus, the transceiver **120** may include multiple transceivers for enabling the WTRU **102** to communicate via multiple RATs, such as UTRA and IEEE 802.11, for example.

The processor **118** of the WTRU **102** may be coupled to, and may receive user input data from, the speaker/microphone **124**, the keypad **126**, and/or the display/touchpad **128** (e.g., a liquid crystal display (LCD) display unit or organic light-emitting diode (OLED) display unit). The processor **118** may also output user data to the speaker/microphone **124**, the keypad **126**, and/or the display/touchpad **128**. In addition, the processor **118** may access information from, and store data in, any type of suitable memory, such as the non-removable memory **130** and/or the removable memory **132**. The non-removable memory **130** may include random-access memory (RAM), read-only memory (ROM), a hard disk, or any other type of memory storage device. The removable memory **132** may include a subscriber identity module (SIM) card, a memory stick, a secure digital (SD) memory card, and the like. In other embodiments, the processor **118** may access information from, and store data in, memory that is not physically located on the WTRU **102**, such as on a server or a home computer (not shown).

The processor **118** may receive power from the power source **134**, and may be configured to distribute and/or control the power to the other components in the WTRU **102**. The power source **134** may be any suitable device for powering the WTRU **102**. For example, the power source **134** may include one or more dry cell batteries (e.g., nickel-cadmium (NiCd), nickel-zinc (NiZn), nickel metal hydride (NiMH), lithium-ion (Li-ion), etc.), solar cells, fuel cells, and the like.

The processor **118** may also be coupled to the GPS chipset **136**, which may be configured to provide location information (e.g., longitude and latitude) regarding the current location of the WTRU **102**. In addition to, or in lieu of, the information from the GPS chipset **136**, the WTRU **102** may receive location information over the air interface **116** from a base station (e.g., base stations **114***a*, **114***b*) and/or determine its location based on the timing of the signals being received from two or more nearby base stations. It will be appreciated that the WTRU **102** may acquire location information by way of any suitable location-determination method while remaining consistent with an embodiment.

The processor **118** may further be coupled to other peripherals **138**, which may include one or more software and/or hardware modules that provide additional features, functionality and/or wired or wireless connectivity. For example, the peripherals **138** may include an accelerometer, an e-compass, a satellite transceiver, a digital camera (for photographs or video), a universal serial bus (USB) port, a vibration device, a television transceiver, a hands free headset, a Bluetooth® module, a frequency modulated (FM) radio unit, a digital music player, a media player, a video game player module, an Internet browser, and the like.

FIG. **1**C is a system diagram of the RAN **104** and the core network **106** according to an embodiment. The RAN **104** may be an access service network (ASN) that employs IEEE 802.16 radio technology to communicate with the WTRUs **102***a*, **102***b*, **102***c* over the air interface **116**. As will be further discussed below, the communication links between the different functional entities of the WTRUs **102***a*, **102***b*, **102***c*, the RAN **104**, and the core network **106** may be defined as reference points.

As shown in FIG. **1**C, the RAN **104** may include base stations **140***a*, **140***b*, **140***c*, and an ASN gateway **142**, though it will be appreciated that the RAN **104** may include any number of base stations and ASN gateways while remaining consistent with an embodiment. The base stations **140***a*, **140***b*, **140***c* may each be associated with a particular cell (not shown) in the RAN **104** and may each include one or more transceivers for communicating with the WTRUs **102***a*, **102***b*, **102***c* over the air interface **116**. The base stations **140***a*, **140***b*, **140***c* may be a base transceiver station (BTS), a Node-B, an eNode B, a Home Node B, a Home eNode B, a site controller, an access point (AP), a wireless router, and the like. In one embodiment, the base stations **140***a*, **140***b*, **140***c* may implement MIMO technology. Thus, the base station **140***a*, for example, may use multiple antennas to transmit wireless signals to, and receive wireless signals from, the WTRU **102***a*. The base stations **140***a*, **140***b*, **140***c* may also provide mobility management functions, such as handoff triggering, tunnel establishment, radio resource management, traffic classification, quality of service (QoS) policy enforcement, and the like. The ASN gateway **142** may serve as a traffic aggregation point and may be responsible for paging, caching of subscriber profiles, routing to the core network **106**, and the like.

The air interface **116** between the WTRUs **102***a*, **102***b*, **102***c* and the RAN **104** may be defined as an R1 reference point that implements the IEEE 802.16 specification. In addition, each of the WTRUs **102***a*, **102***b*, **102***c* may establish a logical interface (not shown) with the core network **106**. The logical interface between the WTRUs **102***a*, **102***b*, **102***c* and the core network **106** may be defined as an R2 reference point, which may be used for authentication, authorization, IP host configuration management, and/or mobility management.

The communication link between each of the base stations **140***a*, **140***b*, **140***c* may be defined as an R8 reference point that includes protocols for facilitating WTRU handovers and the transfer of data between base stations. The communication link between the base stations **140***a*, **140***b*, **140***c* and the ASN gateway **142** may be defined as an R6 reference point. The R6 reference point may include protocols for facilitating mobility management based on mobility events associated with each of the WTRUs **102***a*, **102***b*, **102***c*.

As shown in FIG. **1**C, the RAN **104** may be connected to the core network **106**. The communication link between the RAN **104** and the core network **106** may defined as an R3 reference point that includes protocols for facilitating data transfer and mobility management capabilities, for example. The core network **106** may include a mobile IP home agent (MIP-HA) **144**, an authentication, authorization, accounting (AAA) server **146**, and a gateway **148**. While each of the foregoing elements are depicted as part of the core network **106**, it will be appreciated that any one of these elements may be owned and/or operated by an entity other than the core network operator.

The MIP-HA **144** may be responsible for IP address management, and may enable the WTRUs **102***a*, **102***b*, **102***c* to roam between different ASNs and/or different core networks. The MIP-HA **144** may provide the WTRUs **102***a*, **102***b*, **102***c* with access to packet-switched networks, such as the Internet **110**, to facilitate communications between the WTRUs **102***a*, **102***b*, **102***c* and IP-enabled devices. The AAA server **146** may be responsible for user authentication and for supporting user services. The gateway **148** may facilitate interworking with other networks. For example, the gateway **148** may provide the WTRUs **102***a*, **102***b*, **102***c* with access to circuit-switched networks, such as the PSTN **108**, to facilitate communications between the WTRUs **102***a*, **102***b*, **102***c* and traditional land-line communications devices. In addition, the gateway **148** may provide the WTRUs **102***a*, **102***b*, **102***c* with access to the networks **112**, which may include other wired or wireless networks that are owned and/or operated by other service providers.

Although not shown in FIG. **1**C, it will be appreciated that the RAN **104** may be connected to other ASNs and the core network **106** may be connected to other core networks. The communication link between the RAN **104** and the other ASNs may be defined as an R4 reference point, which may include protocols for coordinating the mobility of the WTRUs **102***a*, **102***b*, **102***c* between the RAN **104** and the other ASNs. The communication link between the core network **106** and the other core networks may be defined as an R5 reference, which may include protocols for facilitating interworking between home core networks and visited core networks.

An access router (AR) **165** of a wireless local area network (WLAN) **160** may be in communication with other networks **112** including the Internet **110** via the core network **106**. The AR **165** may facilitate communications between APs **170***a* and **170***b*. The APs **170***a* and **170***b* may be in communication with WTRU **102***d*, which may provide the WTRU **102***d* with access to packet-switched networks, such as the Internet **110**, to facilitate communications between the WTRUs **102***a*, **102***b*, **102***c* and IP-enabled devices.

Communication systems using highly directional links require their beams to be oriented in a way such that they point towards each other. This process is generally referred as beam acquisition. This may use the exchange of special signal bursts or sounding frames between the nodes. Beam acquisition establishes the initial beam configuration between corresponding nodes, enabling them to initiate communications. However, the initial antenna configuration discovered after beam acquisition may be rendered non-optimum due to substantial relative motion between the communicating nodes. Therefore, the optimum pair of beams between the nodes may be improved by being constantly updated based on their relative motion. This process is called beam tracking and is usually a simpler procedure than initial beam acquisition, with the beam search space restricted to a few candidates that are closely related to the last known optimum beam in some sense. Beam tracking enhancements that involve directional measurements and message exchanges between the millimeter wave base station (mB) and WTRU and between mBs are described herein.

Beam tracking enables directional communications between nodes while subject to relative motion and orientation data changes and follows initial beam acquisition, where initial beam orientation between nodes is determined. The aim of the beam tracking function is to adapt the transmission and reception beam patterns at both ends of a communication link, starting from the initial beamforming training configuration. Enhancements to the IEEE 802.11ad standard to suit high-mobility outdoor deployments of future millimeter wave systems are described herein as an example. However, the described procedures can be applied to any other directional communication system. The terms millimeter wave Base station (mB) and WTRU used herein correspond to an access point (AP) and station (STA) in IEEE 802.11ad standard, respectively. Alternately, it could refer to Piconet Controller (PNC) and Device (DEV) in an IEEE 802.15.3c system, respectively. An mB may also be any type of wireless device capable of operating AP/BS likes features. For example, an mB may refer to a WTRU used for tethering so that other mobile devices may share an internet connection with the WTRU. An mB may also refer to any WTRU used as a mobile hotspot.

Localization methods to improve the prediction of the positions of a WTRU, which may allow an mB to appropriately select a modified beam, are described herein in accordance with one embodiment. The methods described may be applied to determine the location of the WTRU and to help track the WTRUs movement without having to perform beam acquisition every single time a WTRU moves. The methods described herein may be applied in collaboration in order to increase the accuracy of the predictions of the position of the WTRU and therefore improve secondary beam selection.

Measuring signal strength for example may be one technique used for improving beam tracking. The measurement of signal strength of a beacon signal may be done using factors including but not limited to the frequency and power of a signal. The concept of the Doppler Effect may be used to accomplish this task. The Doppler Effect occurs when an object, such as a WTRU, moves with respect to another stationary object (mB). The received frequency of the waves emitted from the stationary object change according to the moving object's motion. As a result, when a WTRU moves with respect to a stationary object, the frequency of the waves transmitted from the WTRU may change. These relative changes in frequency occur because as the WTRU is moving toward a stationary observer, each successive wave crest may be emitted from a position closer to the stationary observer than the previous wave and may take less time to reach the observer than the previous wave. This reduction in the time between the arrivals of successive wave crests may cause an increase in the frequency. While the WTRU is moving, the distance between successive wave fronts may be reduced, so the waves appear to bunch together. Similarly, if the WTRU is moving away from the stationary observer, each wave may be emitted from a position farther from the stationary observer than the previous wave, and as a result, the arrival time between successive waves is increased, which reduces the frequency. The distance between successive wave fronts is increased, so the waves appear to spread out.

An observation similar to the Doppler Effects may be made when the power of beacon signals received from an mB is observed. When the moving WTRU gets closer to the stationary mB, the measured power of the signal may increase, and as the WTRU moves away, the power may decrease because the signal has traveled a longer distance to reach the WTRU and may have deteriorated. The WTRU may also measure the power of any other mBs within listening range, and the WTRU may then use for example, a triangulation technique with the collected information to determine its location.

By measuring the difference in power due to the movement of the WTRU with respect to all the possible mBs in range, the movement of the WTRU may be tracked. The beam direction may be changed accordingly to facilitate the strongest link between the WTRU and mB. Therefore, measurement, reporting, and prediction techniques may be used to establish the strongest link at various positions of the WTRU in movement. The WTRU may make measurements that record changes in the frequency or power of a received signal that may be used by the mB to determine the position of the WTRU.

FIG. **2**A provides a high level flow chart in which the mB may control a directional measurement campaign in order to generate a directional radio environment map (DREM) for use in improved beam tracking and simplified handovers in accordance with one embodiment **200**. The mB may request associated WTRUs to perform directional signal strength measurements **201** on signals addressed to them. An mB may also request that associated WTRUs report directional signal measurements **201** on messages addressed to other WTRUs. The mB may either specify the receive directions from which to request measurements **201**, and also the associated antenna configuration (beamwidth, gain, and the like) to use, or may let the WTRU decide the measurement directions. Alternatively or additionally, the mB may request the WTRU perform directional signal strength measurements **201** when nodes such as other WTRUs and/or mBs belonging to other networks are transmitting. These directional signal strength measurements **201** may apply to the broadcast beacon messages in the IEEE 802.11ad standard, 802.11aj, 802.15.3c or other similar standards. The WTRU directional signal strength measurements **201** may be performed either using a quasi-omni antenna pattern corresponding to Control PHY reception or with directional reception if it is already associated.

The mB may also provide a transmission schedule **202** to the WTRU. This may include the measurement schedule (including but not limited to time and frequency information) and the direction and antenna configuration for these measurements. This may enable the WTRU to make multiple directional signal strength measurements when data transmission is scheduled between another WTRU in the network and the mB.

The mB then may receive directional signal strength measurement reports **203** from the WTRU. The WTRU may report **203** the measured signal strength of received transmissions from the mB in terms of a Received Signal Strength Indicator (RSSI). This may be time-averaged over an appropriate duration to counter signal fading. The averaging interval used may capture WTRU dynamics when it is short enough. Additionally, the WTRU may be required to report **203** its antenna configuration such as receive beamwidth, antenna gain, and the like to the mB along with measurement results. The WTRU may report **203** the measurement results either to its serving mB or to neighbor mBs if it is associated with them. Also, when the WTRU determines the measuring directions, the measurement report **203** may include the directions covered and the antenna configuration used along with the measurements. From the signal strength measurement reports **203**, the serving mB may estimate the WTRU range and may modify its associated beam.

The mB may then generate **204** a directional radio environment map (DREM) based on the directional signal strength measurement reports. The measurement reports may enable the mB to generate **204** DREM, which may include data about its surroundings including measurements on intra-cell and inter-cell signals. Note that DREM may also include historical information gathered from previous measurement reports and possibly from different WTRUs. Antenna configurations resulting in received signal strength at the WTRU larger than a configurable or predetermined threshold may be retained as secondary WTRU-mB**1** links that may get activated when the primary line-of-sight (LoS) link may become obstructed or experiences interference without conducting a complete beam training procedure. Based on these reports the mB may perform beam tracking and identification of non line-of-sight (nLoS) communication possibilities. Another application of the DREM is to determine possibilities for multiple simultaneous transmissions to different WTRUs. The mBs may be expected to have capabilities to transmit to multiple WTRUs at the same time, either in the same direction or in distinct directions using Space Division Multiplexing (SDM) and Multi-User Multiple Input Multiple Output (MU-MIMO) techniques. Multiple simultaneous transmissions based on SDM techniques may identify WTRUs with small cross-interference between their individual beams. WTRUs in MU-MIMO systems sharing the same mB beam may also identify the WTRUs.

The mB may store **205** the DREM in a database for network access by other mBs or a central network entity and for secondary link selection. The mB may then identify **206** secondary beams for WTRUs based on the DREM. The mB may handover from the primary beam to the secondary beams based on the DREM when the primary beam becomes disrupted.

FIGS. **2**B-**2**F provide an example of mB controlled directional measurements that may be used to generate a DREM, in which an mB directs a WTRU to make directional signal strength measurements.

FIG. **2**B provides an example of a first phase of mB controlled directional measurements. WTRU**1 210** may be communicating with mB **212** over a direct LoS link with receive beam **213***a* and transmit beam **213***b*. WTRU2 **211** may not be communicating.

FIG. **2**C provides an example of a second phase of mB controlled directional measurements. In this phase, mB **222** may not have a direct LoS link with WTRU**1 220**, but a viable alternate reflected link may exist **223**. WTRU**2 221** may be communicating over a direct LoS link with receive beam **224***a* and transmit beam **224***b*.

FIG. **2**D provides an example of a third phase of mB controlled directional measurements. To identify any existing secondary links, mB **232** may request WTRU**1 230** make directional signal strength measurements while communicating over a direct LoS link with receive beam **233***a* and transmit beam **233***b*. WTRU**2 231** may not be communicating. mB **232** may also direct WTRU**1 230** to make multiple directional signal strength measurements when data transmission is scheduled on the mB**1 232** to WTRU**2 231** link.

FIG. **2**E provides an example of a fourth phase of mB controlled directional measurements. Following the request to make directional signal strength measurements, WTRU**1 240** may perform measurements in the requested directions **245***a*, **245***b*, and **245***c* and may report results to mB **242**. This may include making measurements when data transmission is scheduled on the mB **242** to WTRU**2 241** link. In this phase, WTRU**1 240** may have an indirect or reflected link **243** with mB **242**. WTRU**2 241** may be communicating with mB **242** over a direct LoS link with receive beam **244***a* and transmit beam **244***b*.

FIG. **2**F provides an example of secondary link discovery at a WTRU following directional signal strength measuring and reporting. WTRU**1 250** may communicate with mB **252** over a direct LoS link with receive beam **253***a* and transmit beam **253***b*. Alternatively, WTRU**1 250** may communicate over a non-LoS link comprising receive beam **254***a* and transmit beam **254***b* which may have been established based on the directional signal strength measurements. Communication between WTRU**2 251** and mB **252** over a direct LoS link with receive beam **255***a* and transmit beam **255***b* may remain undisturbed.

mB controlled directional measurements for generating a DREM and determining WTRU location may also involve sending extra data in beacon frames. FIG. **2**G shows an example of a Directional Measurement frame, which may contain a directional measurement request **263** field, a directional measurement report **273** field, and a beam switch **282** field.

The directional measurement request **263** field may include but is not limited to the following information: a start time **261**, measurement interval **262**, measurement count **264**, start azimuth **265**, start elevation **266**, azimuth step **267**, elevation step **268**, and measurement control **269**.

The directional measurement report **273** field shown in FIG. **2**G may include but is not limited to the following information: azimuth **271**, elevation **272**, received channel power indicator (RCPI)/received signal to noise indicator (RSNI) **274**, and Rx antenna gain **275**.

The beam switch **282** field shown in FIG. **2**G may include but is not limited to the following information: switch trigger **281**, azimuth offset **283**, elevation offset **284**, traffic specification (TSPEC)/QoS specification **285**, signal strength loss **286**, switch time **287**, switch control **288**, handover (HO) address **289**, and HO parameters **290**.

As stated above the directional measurement request **263** field includes a start time **261** timestamp, which may define the exact time of the frame. This start time **261** timestamp may also be used to calculate the Round Trip Time (RTT) after the acknowledgement (ACK) is sent back. By obtaining the RTT, the location of a WTRU may be identified independently from the directional signal strength measurements reported by the WTRU by calculating the distance traveled by the beacon to reach the WTRU. Calculating the distance traveled by the beacon to reach the WTRU using Time of Arrival (ToA) or Time Difference of Arrival (TDoA) may also be performed when system clocks are synchronized. The accuracy of the WTRU's position may be improved by calculating the distance of the WTRU from more than one mB.

The WTRU may receive periodic beacons from a mB as shown in the example of FIG. 2G. The WTRU may then synchronize its internal clock based on the received start time **261** timestamp. The WTRU may then respond to the mB with a control message containing the exact transmission instant of the WTRU response. From the timestamp received from the WTRU, the mB may estimate the range of the WTRU using time-of-flight calculations. Based on the range estimate and other received information, the mB may determine the best beam to use for communicating with the WTRU. The mB may also transmit the range estimate to the WTRU.

The WTRU may respond with its timing response upon receiving the beacon or some other message from the mB with a timestamp to avoid timing errors due to clock drift. For an mB with multiple associated WTRUs, a schedule for collecting WTRU timing responses may be established by the mB, and should shortly follow the beacon transmissions.

FIGS. **3**A-**3**B provide examples of using data from other sources for tracking the movement of a WTRU to generate a DREM and perform beam tracking **300**. In FIG. **3**A, the WTRU **310** may have a communication link with mB **315** using beam **312**, but WTRU **310** may also know the signal strengths of beams **311**, **313**, and **314**. This information may be used to determine which beam would be the best to use in the event that the orientation data of WTRU **310** changes.

In FIG. **3**B, it is shown that once the orientation data of WTRU **320** may have changed, the WTRU **320** may start using beam **323** to sustain the communication link with mB **325**. After the beam has been adjusted, WTRU **320** may contact mB **325** to notify mB **325** that because the orientation of WTRU **320** has changed, beam **323** may be used in case beam **322** is no longer strong enough to sustain the communication link. Consequently, mB **325** may update the current beam orientation and DREM associated with WTRU **320**. If WTRU **320** changes orientation drastically a different mB may be used to continue the connection. Alternatively or additionally, WTRU **320** and mB **325** may feed back the alternative beam **323** to an eNB, either through the overlaying LTE connection or a viable mmW link.

WTRU **320** may use various methods to determine and report its movement and/or changed orientation to the mB **325**. One approach is for the WTRU **320** to use internal compass signals. Additionally, the orientation change signaled by the internal sensors may be used by WTRU **320** to maintain its beam orientation towards mB **325**, by modifying its beam configuration to use alternative beam **323**.

In another example, GPS coordinates may be used to track the movement of WTRU **320**. Coordinates may be obtained using GPS, Assisted-GPS (A-GPS) or the like. This method may reduce the resources used for beam acquisition and training because the location of WTRU **320** may be established within a smaller range as the mB filters the directional signal strength measurements received based on the GPS coordinates or time information. GPS is a space-based satellite navigation system that provides location and time information in all weather and anywhere on or near the Earth where there may be an unobstructed line of sight to four or more GPS satellites. Using these coordinates may enable the identification of the position of WTRU **320** with the accuracy of 10 meters or less. This may be used by mB **325** in order to perform a beam training procedure within a particular area (of a 10 meter radius) rather than the wider range. After mmW links are formed regular feedback may be sent with the position of WTRU **320** according to the GPS coordinates to mB **325** and additionally to the eNB. For efficiency, WTRU **320** may report only the change in readings from the previous instance. Using this information, a prediction may be made as to which direction WTRU **320** may be moving and with what speed, narrowing the possibilities of beams that may be used to make a link, which may enable mB **325** to determine the best beam **323** for communicating with WTRU **320**.

Another approach for performing beam tracking of WTRU **320** may include the use of other devices internal to WTRU **320** such as by using a gyroscope/accelerometer. A gyroscope is a device that may be used for measuring orientation using angular momentum, thereby allowing it to maintain the orientation. A gyroscope may comprise a spinning wheel or disk in which the axle is free to assume any orientation. This orientation, which is not fixed, may keep changing in response to an external torque much less and in a different direction than it would without the large angular momentum associated with the disk's high rate of spin and moment of inertia. When the device is mounted on gimbals, external torque is minimized, but its orientation remains nearly fixed, regardless of any motion of the platform on which it is mounted. Because gyroscopes allow the calculation of orientation and rotation designers have incorporated them into many devices. The integration of the gyroscope has allowed for more accurate recognition of movement within a 3D space than previous methods using a lone accelerometer within a number of smart phones. A further recent innovation is an electronic gyroscope, which is present in vehicles like Segway scooters and the Honda UNI-CUB, which ensures that the vehicle remains upright and balanced.

WTRU **320** may have an integrated gyroscope, accelerometer, compass and other orientation sensing devices. Outputs from such internal sensors may be fed back to mB **325** to facilitate beam tracking. These readings, when available with high precision, along with other information, may enable mB **325** to determine the precise location and orientation of WTRU **320**. For efficiency, WTRU **320** may report only the change in readings from the previous instance. These devices may also be used advantageously by measuring the signal strength readings from the beacons, such that whatever position WTRU **320** is in WTRU **320** remains in contact with the strongest beam.

Group movement of WTRUs may also be tracked using the methods described above. This situation may apply when multiple WTRUs move together in the same direction, for example, in a vehicle. The WTRU tracking may be aided in such a situation because multiple measurements covering several WTRUs may be leveraged for WTRU location estimation. A collection of WTRUs covered by the same or adjoining mB beams constitute a group. Members of a group maintain a constant spatial relation with respect to each other, which facilitates efficient tracking. This enhancement may manifest itself in several ways including but not limited to the following: the mB may reduce WTRU tracking measurements by denoting one or a few of the WTRUs in the group, identifying one or more of the WTRUs as a group head or heads and using those measurements for the entire group, or it may manifest itself in the form of a denser sampling of WTRU tracking measurements leading to better location prediction.

For tracking purposes, a group may comprise of WTRUs sharing the same mB beam. A feature of a group may include that the members maintain a constant spatial relation with respect to each other, which facilitates efficient tracking.

This may allow group members to reduce their location reporting periodicity. The WTRUs may be informed of group membership or may infer group membership using methods including but not limited to the following: the mB may inform the WTRU about group membership and a lower location reporting periodicity, or the WTRU may determine group membership via monitoring location information of other WTRUs reported via OBand signaling. In the second case, the WTRU may infer that it is part of a group when it finds other WTRUs with similar coordinates, and may automatically reduce its position reporting periodicity.

FIG. **4**A is a call flow diagram for an example intra cell/basic service set (BSS) directional measurement procedure for DREM generation **400**. Serving mB **401** may transmit a measurement schedule **410***a*, **410***b*, and **410***c* to WTRU**1** **402***a*, WTRU**2** **402***b*, and WTRU**3** **402***c* respectively. The schedule may be transmitted in a beacon frame as described above. Serving mB **401** may then transmit directional measurement request **411***a* to WTRU**1** **402***a* and directional measurement request **411***b* to WTRU**3** **402***c*. WTRU**1** **402***a* and WTRU**3** **402***c* may respond by transmitting ACK **412***a* and **412***b* respectively to serving mB **401**. Then while serving mB **401** is transmitting data **413** to WTRU**2** **402***b*, WTRU**1** **402***a* and WTRU**3** **402***c* may make directional measurements **414***a* and **414***b*. WTRU**3** **402***c* may then transmit a directional measurement report **415***a* to serving mB **401**, which transmits an ACK **415***b* back to WTRU**3** **402***c* in response. Similarly WTRU**1** **402***a* may then transmit directional measurement report **416***a* to serving mB **401**, which transmits an ACK **416***b* back to WTRU**1** **402***a* in response.

FIG. **4**B is a call flow diagram for an example inter cell/basic service set (BSS) directional measurement procedure for DREM generation. Serving mB **401** may transmit a downlink schedule request **421** to neighbor mB **403***a*. Neighbor mB **403***a* may then transmit a measurement schedule **422** to WTRU**4** **402***d*. Then neighbor mB **403***a* may transmit a downlink schedule request **423** to serving mB **401**, which may include beam orientations. Serving **401** mB may then transmit a measurement schedule **424***a* to WTRU**1** **402***a* and transmit a measurement schedule **424***b* to WTRU**2** **402***b*. Serving mB **401** may then transmit directional measurement request **425***a* to WTRU**1** **402***a* and directional measurement request **425***b* to WTRU**2** **402***b*. WTRU**1** **402***a* and WTRU**2** **402***b* may respond by transmitting ACK **426***a* and **426***b* to serving mB **401**. Then while neighbor mB **403***a* is transmitting data **427***a* to WTRU**4** **402***d*, WTRU**1** **402***a* and WTRU**2** **402***b* may make directional measurements **427***b* and **427***c*. WTRU**1** **402***a* may then transmit directional measurement report **428***a* to serving mB **401**, which may transmit an ACK **429***a* back to WTRU**1** **402***a*. Similarly WTRU**2** **402***b* may then transmit a directional measurement report **428***b* to serving mB **401**, which transmits an ACK **429***b* back to WTRU**2** **402***b* in response.

As aforementioned, once an mB has generated a DREM in accordance with any of the methods described herein, the mB may identify secondary beams for use by a WTRU. FIG. **5** provides an example of secondary beam activation **500**. FIG. **5** shows the use of DREM to identify a secondary beam during service period **510**. In this example, mB **501** may transmit data on its primary transmission (Tx) beam **511***a* and **511***b* and may receive on its primary reception (Rx) beam **512***a* and **512***b* while WTRU **502** may be transmitting ACKs on its primary Tx beam **522***a* and **522***b* and may be receiving data on its primary Rx beam **521***a* and **521***b*. When the primary Rx beam **512***b* of mB is blocked, mB **501** switches to a secondary beam as identified using DREM and may continue to transmit data on secondary Tx beam **513***a*, **513***b*, and **513***c*. mB **501** may receive on secondary Rx beam **514***a*, **514***b*, and **514***c*. Similarly, WTRU **502** is transmitting on its secondary Tx beam **524***a*, **524***b*, and **524***c* and receives on its secondary Rx beam **523***a*, **523***b*, and **523***c*.

mB **501** may then test the primary Tx beam **511***c*, which may result in WTRU **502** having its primary Rx beam **521***c* blocked and mB **501** having its primary Rx beam **512***c* blocked. As a result mB **501** and WTRU **502** may continue communicating on their respective secondary beams: mB **501** transmits on its secondary Tx beam **513***d* and secondary Rx beam **513***e* while WTRU **502** transmits on its secondary Tx beam **523***d* and secondary Rx beam **524***d*.

FIG. **6**A shows an example call flow of a procedure in which an implicit intra-cell switch is made to a secondary beam **600**. Serving mB **601** may identify a secondary beam **611** associated with WTRU **602** based on DREM which includes but is not limited to directional measurement reports, WTRU location information, and/or WTRU orientation based on any of the methods described herein. While communicating on a primary beam **603**, the serving mB **601** may transmit a schedule **612** to WTRU **602** on its primary beam **605**, and WTRU **602** may be notified of the secondary beam configuration **613**. Serving mB **601** may then send a beam switch **615** to WTRU **602** over their respective primary beams **603** and **605**. Within a short interframe space (SIFS) **616**, WTRU **602** may respond with an ACK **617**. Serving mB **601** may then transmit data **618** to WTRU **602**. Again, within a SIFS **619**, WTRU **602** may respond with an ACK **620**. Following SIFS **621**, serving mB **601** may transmit data **622** to WTRU **602**. WTRU **602** may then respond with an ACK **624**, which is blocked and not received by serving mB **601** during SIFS **623**. As a result WTRU **602** may switch to a secondary beam **626**, and serving mB **601** may also switch to a secondary beam **628** following a beam change interval **625**. Serving mB **601** may then retransmit data **627** to WTRU **602** on their respective secondary beams **604** and **606**. WTRU **602** may then respond with an ACK **629**. This procedure may occur within a service period (SP) **614***b* or within more than one SP such as a previous SP **614***a*.

FIG. **6**B shows an example call flow of a procedure in which an explicit inter-cell switch is made to a secondary beam. Serving mB **601** may identify a secondary beam **631** associated with WTRU **602** based on DREM which includes but is not limited to directional measurement reports, WTRU location information, and/or WTRU orientation based on any of the methods described herein. While communicating on a primary beam, the serving mB **601** may transmit a schedule **632** to WTRU **602**. Serving mB **601** may then transmit a handover (HO) request **634** to a neighbor mB **607**, and the neighbor mB may respond with a HO response **635** indicating success. The HO request **634** and HO response **635** exchange may occur over the distribution system (DS) **633**. Serving mB **601** may then send a beam switch **637***a* to WTRU **602**, and WTRU **602** may learn of the secondary beam configuration **637***b*. Within a short interframe space (SIFS) **636***a*, WTRU **602** may respond with an ACK **638**. Serving mB **601** may then transmit data **639** to WTRU **602**. Again, within a SIFS **636***b*, WTRU **602** may respond with an ACK **640**. Following SIFS **636***c*, serving mB **601** may transmit a beam switch **641** to WTRU **602**, which may respond with ACK **642**. Serving mB **601** may then transmit a path switch request **644** to a network controller **608**, and the network controller **608** may respond with a path switch confirmation **645**. Then neighbor mB **607** may transmit data

646 to WTRU 602 on a secondary beam, and WTRU 602 may respond with an ACK 647. The message exchange as detailed herein may occur within the same SP 643c or within more than one SP 643b such as a previous SP 643d. The message exchange between neighbor mB and WTRU 602 may occur within a separate SP 643a.

FIG. 7A shows an example in which an mB has two beams and may select a beam based on WTRU movement 700. The directional signal strength measurements and location and orientation information fed back by WTRU 702 in accordance with any of the methods described herein may enhance the tracking performance at the mB 701. mB 701 may combine any of the aforementioned information reported by the WTRU 702 to estimate the position of WTRU 702 with high accuracy. The information may be used by mB 701 to choose the appropriate beam from its two beams 703 and 704 which provide overlapping coverage. In this example the WTRU location uncertainty region 705 is smaller than the beam 703 coverage and 704 respectively. Based on the illustrated WTRU 702 location estimate, mB 701 may switch from beam 703 to beam 704 for the next data transmission. Location based beam tracking may also be used in examples where there is no overlapping coverage between adjoining beams.

FIG. 7B shows an example of how location information may be used for improved handover decisions. Again, the directional signal strength measurements and location and orientation information fed back by WTRU 712 in accordance with any of the methods described herein may enhance the tracking performance at the mB1 711 and mB2 713, which may provide overlapping coverage as in this example. Also in this example, the location uncertainty region 716 of WTRU 712 is smaller than the beam coverage provided by 714 and 715. Initially, mB1 711 may be the serving mB. Based on the WTRU 712 location estimate and knowledge of adjacent beam coverage based on for example the DREM, mB1 711 may determine that handover of WTRU 712 to mB2 713 may be needed. Location based handover decisions may also be used in examples where there is no overlapping coverage between adjoining beams.

In addition to the directional signal strength measurements and location and orientation information fed back by a WTRU historical data may also be used for WTRU tracking and may allow logical predictions to be made as to the direction that a WTRU may move. FIG. 8 shows an example in which a WTRU may be tracked using historical data 800. WTRU 801 may be currently communicating with mB 803 using beam 805, while moving in the direction shown 802. At the current position, beam 805 may be determined to be in fact the strongest and thereby, the optimal beam to use. However, information including the corresponding beam strengths of beams 804, 806, and 807 may also be present. The direction in which WTRU 801 is moving may be calculated using the differences among the beam strengths of beams 804, 806, and 807 and the rate in which the beam strengths change. This calculation may further be improved by using other factors like timestamps, GPS data, gyroscope measurements, and the like using any of the methods described herein. Historical data may be maintained in a database such as a DREM database. This database may contain data such as for example, recent history of beams used (according to mB and beam ID) by WTRU 801, history of the terrain in which mB 803 is deployed, previous history of similar movements of WTRU 801, and any related historical information pertaining to the nearest neighboring mBs of mB 803. Terrain information in which mB 803 is deployed and the terrain of neighboring cells may further narrow down predictions as it may reduce the number of attempts for a beam training procedure to be performed because the possible paths of movement by WTRU 801 are known. This database may be constantly updated using information received from WTRU 801. mB 803 may also store the route in which WTRU 801 is moving in a database. Storing and retrieving such historical data may enable mB 803 to predict the movement of WTRU 801 allowing mB 803 to track WTRU 801 more accurately. By retrieving recent history of previous beams stored in the database of mB 803, a more accurate prediction may be made to determine the position of WTRU 802.

By using any of the tracking techniques disclosed herein and/or historical data, mB 803 may more efficiently handover the signal to a new mB because mB 803 may be able to determine the closest mB to which WTRU 801 is moving. When the WTRU reaches the edge of the cell, it is able to listen or communicate with multiple mBs. mB 803 may then handover the signal to a new mB by immediately informing the eNB in the network and the new mB the details of the movement of WTRU 802.

FIG. 9 shows an example in which a WTRU may be tracked by multiple mBs 900. In this example, WTRU 901 may be at all times situated in between mB1 902, mB2 903, and mB3 904. When WTRU 901 is within listening distance of mB1 902, mB2 903, and mB3 904 as shown by their respective beams 906, 907, and 905. mB1 902, mB2 903, and mB3 904 may use tracking information to locate the position of WTRU 901 by performing any of the methods described herein. By using multiple mBs, the WTRU may be tracked with improved precision or accuracy using method such as a triangulation technique.

Data tracked by mB2 903 and mB3 904 may be fed back to mB1 902 when mB 902 is the serving mB. This may allow mB1 902 to know the details tracked by mB2 903 and mB3 904 from WTRU 901. For example, by getting the distances of WTRU 901 from mB2 903 and mB3 904, the exact location of WTRU 901 may be determined. The data fed back to mB1 902 may be of any form such as, for example, GPS co-ordinates, gyroscope/accelerometer measurements or other mB's measurements namely, power, time taken, distance, and the like and may be provided in accordance with any of the methods described herein.

According to yet another embodiment, mB1 902, mB2 903, and mB3 904 may belong to a group, which for example may be called Group mBs. Coordinated beam tracking between multiple mBs, mB1 902, mB2 903, and mB3 904 may also enable mBs as a group to identify an optimal beam to communicate with WTRU 901 or to identify an alternative beam when a current link fails. This method may also include a logical controller, which can either be co-located or not with one of the mBs in the group.

The Group mBs may share the location of WTRU 901 and orientation information of WTRU 901 with a controller. In the case of simultaneous association of WTRU 901 with multiple mBs, each mB reports the location of WTRU 901 and orientation information of WTRU 901 to the controller. The controller then determines the best beam to communicate with mB1 902, mB2 903, or mB3 904. If the controller determines that the best beam belongs to an mB that is different than the current serving mB, then it informs the serving mB to command the WTRU to switch to another Group mB once the current message exchange is complete. The reported data to the neighbor mB may include any of the location or orientation related information listed herein.

FIG. 10A shows an example of a WTRU providing data feedback from multiple mBs to the serving mB for multiple mB-aided tracking in accordance with yet another embodiment **1000**. In this example, WTRU **1001** may get attached to serving mB**1 1002** by performing a beam acquisition procedure and determining the strongest possible mmW link. The serving mB**1 1002** may request WTRU **1001** perform signal strength measurements on signals originating in other networks. These networks may be operating either in the same frequency channel as serving mB **1002** or another channel. In either case a measurement gap may be configured by serving mB **1002** allow WTRU **1001** to perform measurement procedures that may occur when WTRU **1001** switches channels or receives beam direction for signal measurements. By setting up a measurement gap, serving mB **1002** may ensure that no data transmissions are scheduled for WTRU **1001** during the measuring interval.

In-band measurements may also be used. WTRU **1001** may be directed by serving mB **1002** to report directional signal strength measurements for signals received from the neighboring mBs such as mB**2 1003** and mB**3 1004**. In case of an IEEE 802.11ad system, WTRU **1001** may be directed to report RSSI of directional beacons from the neighboring mB**2 1003** and mB**3 1004**. In some embodiments, WTRU **1001** may measure the beacon strength of neighboring mB**2 1003** and mB**3 1004** with an omni or quasi-omni antenna pattern. Alternatively, WTRU **1001** may measure the beacon strength using a beam directed towards neighboring mB**2 1003** and mB**3 1004**. This may require successful completion of a beam training procedure at WTRU **1001**, via Responder-Receive Sector Sweep (R-RXSS) procedure, to identify optimum receive antenna pattern. If the report of WTRU **1001** also includes the antenna pattern used for signal measurements, then serving mB **1002** may estimate the absolute range of WTRU **1001** from neighboring mB**2 1003** and mB**3 1004**. If the receive antenna configuration information is not included in the report of WTRU **1001**, then serving mB **1002** may estimate relative WTRU **1001** displacement by comparing successive signal strength reports.

Out-of-band measurements may also be used. Serving mB **1002** may request WTRU **1001** make signal strength measurements in a different frequency channel, either within the same band or different. Additionally, serving mB **1002** may provide other information such as mB identifiers in other channels and their coordinates. Serving mB **1002** may also establish a measurement gap for WTRU **1001** making signal strength measurements on a different frequency channel.

Alternatively or additionally, WTRU **1001** may report the beam identifiers of neighboring mB**2 1003** and mB**3 1004** corresponding to strongest beacon reception. In general, neighboring mB**2 1003** and mB**3 1004** may include the transmit beam identifier in the transmitted beacon, and this may be reported by WTRU **1001** to the serving mB **1002** if the packet is successfully decoded.

During the measurement gap, WTRU **1001** may listen to the neighboring mBs such as mB**2 1003** and mB**3 1004** and receive information from mB**2 1003** and mB**3 1004**. WTRU **1001** may then perform calculations and measurements. The WTRU may then feed all of these details back to serving mB**1 1002**, which may then analyze the received information, perform calculations, and determine the exact position of WTRU **1001**.

Reference signaling with respect to multiple mB-aided WTRU tracking may also be used. A reference signal may be defined as one that is sent between two entities exclusively in order to measure or estimate the mmW link quality. A triangulation method or any of the other methods described herein may be applied. This reference signal may be include but is not limited to the following:

1) A known sequence—this signal may be solely sent for the purpose of calculating the power of the signal at arrival;

2) A time-stamp—this signal may have a timestamp attached to it to calculate the time taken by either RTT, ToA or TDoA to determine position; or

3) Beam+mB identifier—this signal may have details about which beam was sent from which mB so that a ranking system may be established as to which one was the strongest.

FIG. **10**B shows an example of mB to mB communication signaling in accordance with another embodiment. This method involves the direct communication of data from the neighboring mB**2 1013** to the connected mB **1012**. In this process, WTRU **1011** initially may get attached to serving mB**1 1012** by performing a beam acquisition procedure and determining the strongest possible mmW link. Serving mB**1 1012** may configure a measurement gap and allow WTRU **1011** to perform measurement procedures. During the measurement gap, WTRU **1011** may listen to the neighboring mBs such as mB**2 1013** and mB**3 1014** and receive information from mB**2 1013** and mB**3 1014**. WTRU **1011** may then perform calculations and measurements. The WTRU may then feed all of these details back to mB**2 1013**. mB**2 1013** may either reports these details back to mB**1 1012** in raw form or may analyze the received information, perform calculations and send processed information to allow mB**1 1012** to determine the position of WTRU **1011**.

WTRU **1011** may also provide feedback to neighbor mB **1013**. Under some conditions WTRU **1011** may want to convey its changed location or orientation information to its serving mB**1 1012** earlier than its next service period (SP), and when no contention-based access period (CBAP) is available before its next SP. Then WTRU **1011** may send its location or orientation information to neighbor mB**2 1013**, with which it is simultaneously associated. Simultaneous association as used herein may refer to any kind of multiple association, such as temporary association, association for control signaling only, and the like. In this case, data transmissions may still occur through serving mB**1 1012**, but WTRU **1011** communicates with neighbor mB**2 1013** for measurement reports and other control messaging. Neighbor mB**2 1013** may forward the received information to the serving mB**1 1012** of WTRU **1011** either through the distribution system (DS) or via a direct link between mB**1 1012** and mB**2 1013**, if one is available. This may allow the serving mB**1 1012** of WTRU **1011** to proactively adjust its beam towards the WTRU for the next transmission. This allows the serving mB**1 1012** to react to rapid movement by WTRU **1011** between two successive measurement report transmissions, which may result in loss of the serving mB**1 1012**-WTRU **1011** link when the neighbor mB **1013**-WTRU **1011** link may still be operational. This may also enable WTRU **1011** to make better handover decisions to neighbor mB**2 1013** and mB**3 1014**. The reported quantities to neighbor mB**2 1013** may include any of the location or orientation related information described herein.

Initial beam training optimization is also described herein in accordance with yet another embodiment. The current IEEE 802.11ad beam training procedure specifies quasi-omni reception at the responder/STA for device discovery, followed by beamforming training involving signal strength measurements on multiple candidate beams to arrive at the optimum pair of transmit and receive beams at the initiator/

AP and responder/STA. The beamforming training procedure may be simplified with location and orientation information as described herein.

FIG. **11**A shows an example of the current IEEE 802.11ad Sector Level Sweep (SLS) procedure **1100**. At the end of the SLS procedure, the initiator **1111** and the responder **1112** normally identify their best transmit sectors by exchanging sector sweep frames. The procedure begins with the initiator **1111** (personal basic service set (PBSS) control point/access point (PCP/AP)) transmitting sector sweep frames **1120** or beacons in multiple directions with a sectorized antenna pattern, while the responder **1112** (STA) receives with a quasi-omni antenna pattern **1122**. Each of these messages **1121***a*, **1121***b*, and **1121***c* contains a unique countdown field and a sector identifier. This phase is called Initiator Sector Sweep (ISS) **1123**. This is followed by the Responder Sector Sweep (RSS) **1124***a* that normally consists of the Receive Sector Sweep (RXSS), called Responder-Receive Sector Sweep (R-RXSS). In this phase, the responder transmits multiple sector sweep **1124***b* frames in different directions using sectorized antenna patterns, while the initiator receives with a quasi-omni antenna pattern **1129**. Each sector sweep frame **1125***a*, **1125***b*, and **1125***c* transmitted by the responder contains unique countdown and sector identifier fields, and also the initiator's best sector identifier. Therefore, at the end of the SLS procedure, the initiator and responder identify their optimal transmit sectors **1126***a* while receiving with a quasi-omni antenna pattern **1126***b* and **1127***a*.

FIG. **11**B shows an example of a revised SLS procedure in accordance with yet another embodiment. In this procedure nodes exchange their coordinates leading to discovery of optimum transmit and receive sectors at the initiator and the responder. The nodes, initiator **1111** and responder **1112**, may identify their coordinates with high accuracy using any of the procedures described herein. The accuracy of the location information naturally affects the performance and the time required to converge to the optimum sectors, but the procedure is flexible enough to accommodate different input accuracy levels. Moreover, the described procedure is backward compatible with IEEE 802.11ad SLS procedure, such that legacy devices are also accommodated.

The first phase, ISS **1133**, begins with the initiator **1111** transmitting multiple sector sweep **1130** frames or beacons in different directions. However, the initiator now may include its precise coordinates in the transmitted frames **1131***a*, **1131***b*, and **1131***c* while the responder **1112** may receive with a quasi-omni antenna pattern **1132**. Legacy devices that receive one of the transmitted frames may discard the coordinate information and proceed normally to the next phase.

The second SLS phase, RSS **1134***a*, may use the location information transmitted by the initiator **1111**. Now, any responder **1112** that is able to successfully decode one of the sector sweep or beacon frames, **1131***a*, **1131***b*, and **1131***c*, may identify the precise coordinates of the initiator **1111**. Based on the knowledge of its own location, previously acquired by any of the options described earlier, the responder **1112** may determine the optimum sector to use for sector sweep frame transmission. Depending on the accuracy of the location information, the responder may identify one optimum sector or a set of candidate sectors to try out in the second phase. It then may transmit the sector sweep **1134***b* frames **1135***a* and **1135***b* through the identified sectors while the initiator **1111** may modify the countdown field to reflect the number of transmit sectors under test. The responder **1112** may also include its own coordinates in all the transmissions. During this time the initiator **1111** may receive with a quasi-omni antenna pattern **1136**. In the case of a response received from a legacy device, the initiator **1111** may proceed to the next stage according to the standardized procedure. If however, the received response contains the coordinate field, the initiator **1111** may switch to the modified third phase as described below.

At the end of the second phase (RSS), the initiator **1111** may also learn the coordinates of the responder **1112** and may switch to transmit mode to transmit sector sweep frames **1138***a*, **1138***b*, **1138***c*, **1138***d* through a small set of transmit sectors, identified based on the coordinates of the initiator **1111** and the responder **1112**. In the first sub-phase, the initiator **1111** may transmit sector sweep frames **1138***a*, **1138***b*, **1138***c*, **1138***d* through some sectors while the responder **1112** may receive through its receive sectors **1139***a*, **1139***b*, **1139***c*, and **1139***d* that were identified earlier, at the end of ISS. At the end of this sub-phase, the responder **1112** may also be able to uniquely identify the optimum sector. Then the responder **1112** may transmit sector sweep frames **1140***b* and **1140***d* through the optimum sector while the initiator **1111** may receive through its identified sectors **1140***a* and **1140***c*. At the end of this sub-phase, the initiator **1111** also may identify the optimum sector. Therefore, both nodes may be able to identify optimum sectors, aided by location information. By having an mB include location information, a WTRU may get additional location and directional information of the mB. Furthermore, because the WTRU may include its location information in the procedure described herein, the mB may estimate the location of the WTRU more accurately. These sectors may be used as starting points for fine beam training in the Beam Refinement Protocol (BRP) procedure. If the initiator **1111** determines that it may not finish the modified SLS procedure in the current Association-Beam Forming Training (A-BFT) period, then the procedure may be split into multiple A-BFT periods or the remaining steps completed in a SP or CBAP.

FIG. **12** shows an example of improved method for geo-location precision **1200**. mB **1201** may improve geo-location precision by using beam tagging. A WTRU's location may be estimated using GPS or related technologies as described using any of the methods described herein. However, there may be error in some of these calculations due to factors including but not limited to environmental conditions, such as the terrain in dense urban areas. To mitigate any estimation errors, mB **1201** may create a narrow beam that illuminates a small area with radio waves using a highly directional antenna. The area covered by a directional beam **1202** may be smaller than the uncertainty region **1203** of a localization technique such as GPS or any of the other methods described herein, especially when the WTRU is close to mB **1201**. This method may be used to correct localization errors and refine such estimates.

In this method, mB **1201** may continuously collect the reported coordinates of associated WTRUs over a period of time. The WTRU then may filter the reported coordinates according to the associated beams. By time-averaging the reported coordinates of WTRUs served by a particular beam, mB **1201** may estimate the precise coordinates of the centroid of the area illuminated by the beam **1202** on the ground. Therefore, by collecting the coordinates of WTRUs associated with different beams, mB **1201** may precisely estimate the coordinates associated with each beam, i.e., mB **1201** may tag each beam with a GPS coordinate. The coordinates associated with a beam may be transmitted to a WTRU using that beam to improve its location estimate. This may improve the handover performance of the WTRU, due to an improved location estimate. Additionally, mB **1201** may supply location information to WTRUs that lack secondary localization capabilities such as GPS. Such low-capability devices may take advantage of location estimates supplied by serving mB **1201** for improved beam-tracking and better handover performance.

Beam tracking methods for indirect links may be performed in accordance with yet another embodiment. Beam tracking via in-band signaling is one technique described herein. FIG. **13** shows an example of direct and indirect mB-WTRU links **1300**. WTRU **1301** has a direct communication link with mB **1302** and also indirect links to mB **1302** via Relay WTRUs, R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a*. R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* may perform beam tracking on the WTRU **1301**-R-WTRU**1** **1303***b* link and WTRU **1301**-R-WTRU**2** **1303***a* link. R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* may perform beam tracking for the relay link without direct communication with the WTRU.

In one method in accordance with this embodiment, WTRU **1301** may report its location information to serving mB **1302**. These reports may be sent periodically, may be trigger-based, or may be sent in response to mB **1302** requests. Location information of WTRU **1301** may be used by mB **1302** to update the associated beam. Additionally, location information of WTRU **1301** may be sent to R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* that may be registered with mB **1302** as relays for WTRU **1301**. Based on location information of WTRU **1301** received from mB **1302**, R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* may update their respective beams to point towards WTRU **1301**. Additionally, location information supplied by R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* may be forwarded by mB **1302** to WTRU **1301**, so that WTRU **1301** may maintain appropriate beams for relay links. In accordance with any of the location-related feedback methods described herein, the beam orientation relative to a global reference may also be transmitted by WTRU **1301**, R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a*, or mB **1302** to enable tracking in the other link. For example, beam orientation for the direct link, (such as orientation with respect to geographic North), may be transmitted by WTRU **1301** to mB **1302** and this may be forwarded to R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* to assist it in tracking WTRU **1301**. Similar feedback from R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* to assist WTRU **1301** may also possible.

Alternatively or additionally, mB **1302** may send test signals using different transmit beams and request WTRU **1301** to report signal strength measurements on the test signals. This may allow mB **1302** to identify the best beam to associate with a particular WTRU. mB **1302** may use a logical numbering scheme for its beams linked to geographical orientation, or some other commonly known basis. Upon receiving the feedback from WTRU **1301** about the best beam, mB **1302** may forward the optimum beam identifier to the active relays, R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* associated with WTRU **1301**. From the reported mB **1302** beam identifier, R-WTRU**1** **1303***b* and R-WTRU**2** **1303***a* may estimate the relative position of WTRU **1301** and may accordingly adjust their beams associated with the relay link.

FIG. **14**A shows an example of beam tracking on the R-WTRU-WTRU link triggered by WTRU movement **1400**. When WTRU **1402** moves **1404**, R-WTRU **1403** adjusts its beam pointing direction from the initial beam pointing direction to its final beam pointing direction **1405**. Similarly, WTRU **1402** adjusts its beam pointing direction from the initial beam pointing direction **1407** to its final beam pointing direction **1406** with mB **1401**. As shown in FIG. **14**A, beam tracking on the WTRU **1402** to R-WTRU **1403** link is triggered by the WTRU **1402** motion.

FIG. **14**B shows an example of how an mB may provide relay beam tracking information to a relay WTRU and may schedule a SP for WTRU-R-WTRU beam tracking. Following beacon **1421**, data **1422***b* and **1422***d* and training (TRN) fields **1422***c* and **1422***e* may be sent between the mB and WTRU in SP **1422***a*. The mB may then provide relay and beam tracking information to the R-WTRU in **1423***b* followed by an ACK **1423***c* during SP **1423***a*.

The mB may then schedule an SP for WTRU-R-WTRU beam tracking **1424**. Following beam refinement protocol (BRP) fields **1425***b* and **1425***c* and TRN fields **1425***d* and **1425***e* during SP **1425***a*, the WTRU and mB may transmit data **1426***b*, **1426***c*, and **1426***d* with a following ACK **1426***e* during SP **1426***a*. Similarly, during SP **1427***a*, the mB and R-WTRU may transmit data **1427***b* and a following ACK **1427***c* to provide beam tracking and correction information.

FIG. **14**C shows an example of a relay beam-tracking field that may be provided by the mB to the R-WTRU. A relay beam-tracking field **1430** may include but is not limited to the following information: an azimuth correction **1431**, elevation correction **1432**, R-WTRU L-Tx **1433**, and WTRU L-Tx **1434**.

FIG. **15** shows an example of beam tracking via omni-directional band (OBand) signaling **1500**. For example, in addition to communicating in the mmW band in accordance with any of the methods described herein, WTRU **1504**, R-WTRU**1** **1505**, R-WTRU**2** **1506**, and mB **1503** may also simultaneously be connected in the mB's OBand coverage **1501** and the WTRU's OBand coverage **1502**. Several methods for WTRU-RWTRU link beam tracking via OBand signaling are described herein as examples.

In a first method, WTRU **1504** may report its location information to serving mB **1503**, via OBand signaling. These reports may be sent periodically, be trigger-based or sent in response to mB **1503** requests. WTRU **1504** location information may be used by mB **1503** to update the associated beam. Additionally, R-WTRU**1** **1505** and R-WTRU**2** **1506** within the OBand transmission range of WTRU **1504** may also obtain the location information, and adjust their associated beams to point towards WTRU **1504**. Conversely, R-WTRU**1** **1505** and R-WTRU**2** **1506** may report their location information to serving mB **1503** using OBand signaling, and this may be simultaneously heard by WTRU **1504**. Based on the received R-WTRU**1** **1505** and R-WTRU**2** **1506** location information, WTRU **1503** may modify its beam associated with R-WTRU**1** **1505** and R-WTRU**2** **1506**.

Alternatively or additionally, mB **1503** may send test signals using different transmit beams and request WTRU **1504** to report signal strength measurements on the test signals via OBand signaling. This may allow mB **1503** to identify the best beam to associate with a WTRU **1504**. mB **1503** may use a logical numbering scheme for its beams linked to geographical orientation, or some other commonly known basis. Upon receiving the feedback from WTRU **1504** about the best beam, mB **1503** may use that particular beam for the next communication with WTRU **1504**. Simultaneously, when R-WTRU**1** **1505** and R-WTRU**2** **1506** are within transmission range of WTRU **1504**, R-WTRU**1** **1505** and R-WTRU**2** **1506** may also receive optimum mB **1503** beam feedback. From the reported mB **1503** beam identifier, R-WTRU**1** **1505** and R-WTRU**2** **1506** may estimate the relative position of WTRU **1504** and may accordingly adjust their beams associated with the relay link. Alternately or additionally, mB **1503** may echo the beam choice of WTRU **1504** via OBand signaling, so that any R-WTRUs that are outside the OBand transmission range of WTRU **1504**, but within range of mB **1503** transmissions, may still obtain WTRU **1504** position information.

OBand signaling may also be used for beam tracking of WTRUs with less traffic or non-periodic/bursty traffic. For these inactive WTRUs there may be long periods of time between successive packet transmission and reception. This may lead to larger beam misalignment with their peer nodes than what may be corrected by beam-tracking procedures. So, some tracking related signaling may need to be exchanged to track user mobility between packet transmissions.

In IEEE 802.11ad, beam tracking packets may be appended to regular data packets exchanged between a WTRU and an mB. However, in the absence of regular data packet transmissions, the mB may set up a schedule for regular exchange of location information between the mB and the WTRU. Alternatively, OBand signaling may be used for beam tracking for inactive WTRUs. Then WTRU or mB may signal on the OBand when the data packet arrives in its buffer, addressed to the other node. Then, location information or beam tracking packets may be exchanged to correct any beam misalignment since last transmission, before regular packet exchange is attempted.

Due to user mobility, beamwidth adaptation may be necessary. FIG. **16** shows an example of the use of variable beamwidths **1600**. Beam tracking according to IEEE 802.11ad procedures involves some control message overhead. This involves transmission of training fields for transmitter or receiver beam evaluation. These training fields are transmitted using different transmit beams for transmitter training, and received using different receive beams for receiver training. If user mobility is high, then more frequent exchange of the training fields may be used. For high user mobility, wider beamwidths may be used, which may require less frequent updates. Each node (mB/WTRU) may maintain a mapping of beams of varying beamwidths that are related to each other as shown in FIG. **16**. WTRU **1601** may maintain a mapping of narrow beams **1603** and wide beams **1602**. Similarly, mB **1604** may maintain a mapping of narrow beams **1607**, intermediate beams **1606**, and wide beams **1605**. For example, mB **1604** and WTRU **1601** may know that a set of narrow beams and a wider beam all point in the same direction, and that the wider beam may be used if contact is lost or performance is degrading while using one of the narrow beams belonging to the set. Alternatively, the node (mB/WTRU) may decide to switch to the wider beam to reduce the beam tracking overhead. The decision to switch to the wider beam may be communicated from mB **1604** to WTRU **1601** or from WTRU **1601** to mB **1604** so that SP allocation and Modulation and Coding Scheme (MCS) selection may be changed.

FIG. **17** illustrates a receiver beam adaptation procedure **1700**. The WTRU and mB start communicating and transmitting data **1701** in the SP using the beams identified earlier in accordance with any of the methods described herein. However, due to relative motion, the beams may no longer be aligned correctly. Therefore, timing synchronization fails at the receiver (mB), and upon detecting the failure the receiver may switch to a wider beam pointing in the same direction to detect the end of packet transmission **1702**. Packet transmission may be detected via energy detection. Then, the mB may send a re-transmission request **1704** to the WTRU after a SIFS **1703** duration following end of packet transmission. The re-transmission request may also contain a request for a new MCS due to a changed receive antenna configuration, or may contain information related to the new antenna configuration itself, such as beamwidth or gain. The WTRU may attempt packet retransmission **1705** using the MCS level requested by the mB or by selecting the appropriate MCS based on a new receive antenna configuration reported by the mB, which then may send an ACK **1706**.

Although features and elements are described above in particular combinations, one of ordinary skill in the art will appreciate that each feature or element can be used alone or in any combination with the other features and elements. In addition, the methods described herein may be implemented in a computer program, software, or firmware incorporated in a computer-readable medium for execution by a computer or processor. Examples of computer-readable media include electronic signals (transmitted over wired or wireless connections) and computer-readable storage media. Examples of computer-readable storage media include, but are not limited to, a read only memory (ROM), a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs). A processor in association with software may be used to implement a radio frequency transceiver for use in a WTRU, UE, terminal, base station, RNC, or any host computer.

What is claimed:

1. A wireless transmit/receive unit (WTRU) comprising:

a receiver configured to receive a request, from a base station (BS), to perform directional signal strength measurements for one or more received signals;

the receiver further configured to receive a request, from the BS, to provide location data associated with the WTRU;

a transmitter configured to transmit directional signal strength measurements, based on the request and the location data associated with the WTRU, to facilitate generation of a directional radio environment map (DREM); and

the receiver further configured to receive a request to switch to a new transmission and reception beam pair based on the DREM.

2. The WTRU of claim **1**, further comprising:

the receiver further configured to receive a request from the BS to provide orientation data associated with the WTRU; and

the transmitter further configured to transmit the orientation data.

3. The WTRU of claim **1**, further comprising:

the transmitter further configured to transmit historical data on beams used by the WTRU.

4. The WTRU of claim **1**, wherein the directional signal strength measurements are performed on inter-cell signals.

5. The WTRU of claim **1**, further comprising:

the receiver further configured to receive location information associated with the BS.

6. The WTRU of claim **1**, further comprising:

a processor configured to filter the directional signal strength measurements based on time and GPS coordinates.

7. A method performed by a wireless transmit/receive unit (WTRU), the method comprising:

receiving a request, from a base station, to perform directional signal strength measurements for one or more received signals;

receiving a request from the BS to provide location data associated with the WTRU;

transmitting directional signal strength measurements based on the request and the location data associated with the WTRU to facilitate generation of a directional radio environment map (DREM); and

receiving a request to switch to a new transmission and reception beam pair based on the DREM.

8. The method of claim 7, further comprising:

receiving a request, from the BS, to provide orientation data associated with the WTRU; and

transmitting the orientation data.

9. The method of claim 7, further comprising:

transmitting historical data on beams used by the WTRU.

10. The method of claim 7, wherein the directional signal strength measurements are performed on inter-cell signals.

11. The method of claim 7, further comprising:

receiving location information associated with the BS.

12. The method of claim 7, further comprising:

filtering the performed directional signal strength measurements based on time and GPS coordinates.

13. A base station (BS) comprising:

a transmitter configured to transmit a request, to a wireless transmit/receive unit (WTRU), to perform a directional signal strength measurement on a signal received by the WTRU and to provide location data associated with the WTRU;

a receiver configured to receive, from the WTRU, the performed directional signal strength measurement and the location data associated with the WTRU;

a processor configured to generate a directional radio environment map (DREM) based on the performed directional signal strength measurement and the location data associated with the WTRU; and

the processor configured to perform a handover of a communication link from a primary beam to a secondary beam, on a condition that the primary beam is disrupted, wherein the secondary beam is selected based on the generated DREM.

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