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(54) **SYSTEM AND METHOD FOR SELECTIVE REGISTRATION IN A MULTI-BEAM SYSTEM**

(71) Applicant: **Magnolia Broadband Inc.**, Englewood, NJ (US)

(72) Inventors: **Kenneth Kludt**, San Jose, CA (US); **Haim Harel**, New York, NY (US)

(73) Assignee: **Magnolia Broadband Inc.**, Englewood, NJ (US)

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CPC ***H04W 48/20*** (2013.01); ***H04W 60/00*** (2013.01); ***H04W 16/28*** (2013.01); ***H04W 72/046*** (2013.01)
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(58) **Field of Classification Search**
CPC H04W 16/28; H04W 60/00; H04W 72/046
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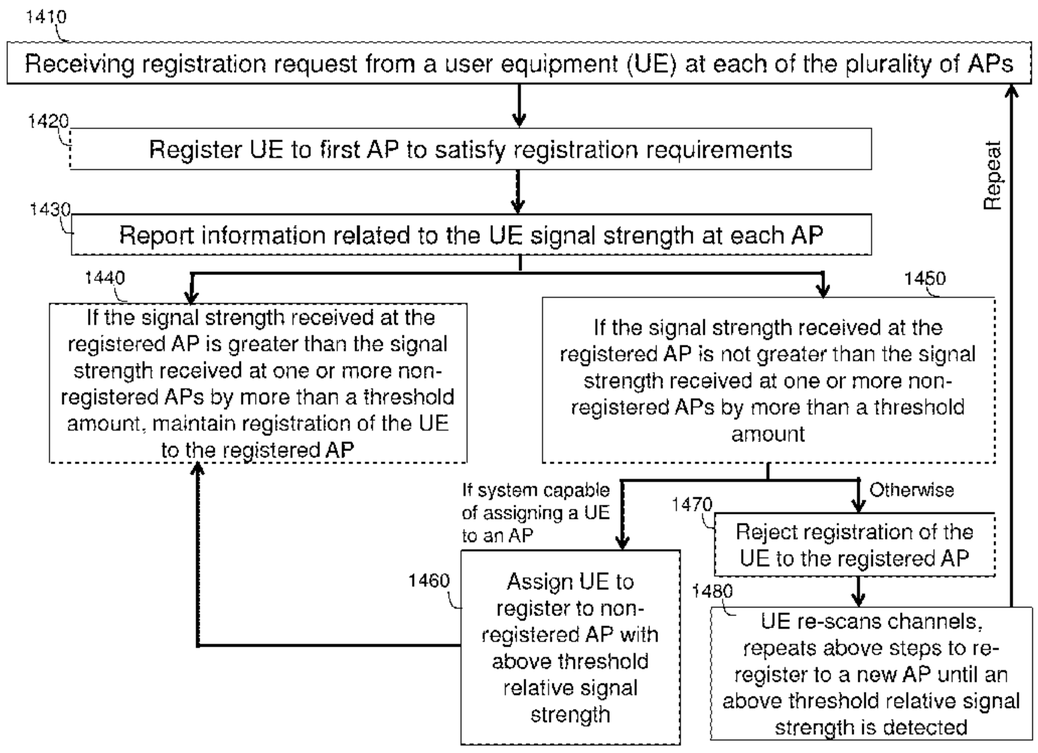
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Primary Examiner — John Pezzlo
(74) *Attorney, Agent, or Firm* — Pearl Cohen Zedek Latzer Baratz LLP

(57) **ABSTRACT**

A system and method for selective registration of a user equipment (UE) to one of a plurality of access points (APs). An indication may be received that each of a plurality of APs have received a signal from a UE. The UE may be registered to the first one of the plurality of APs to satisfy registration requirements associated with the UE. Information may be reported to a controller related to the signal strength of communication received at each AP from the UE. If the signal strength received at the registered AP is less than the signal strength received at one or more of the non-registered APs by more than a threshold amount, the registration of the UE to the registered AP may be rejected.

14 Claims, 15 Drawing Sheets



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* cited by examiner

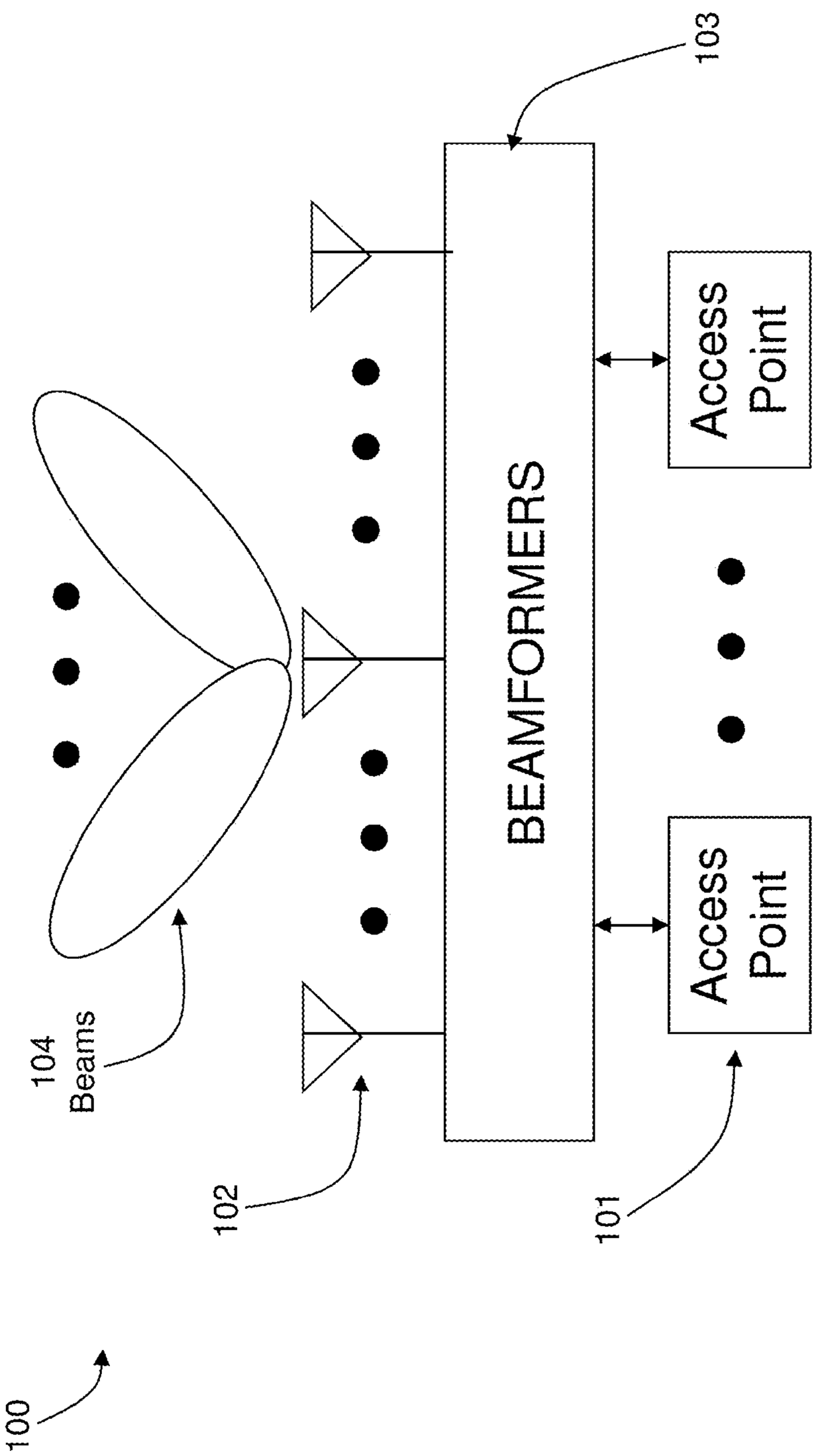

103
104
Beams
BEAMFORMERS
Access Point
Access Point
102
101
100

Fig. 1

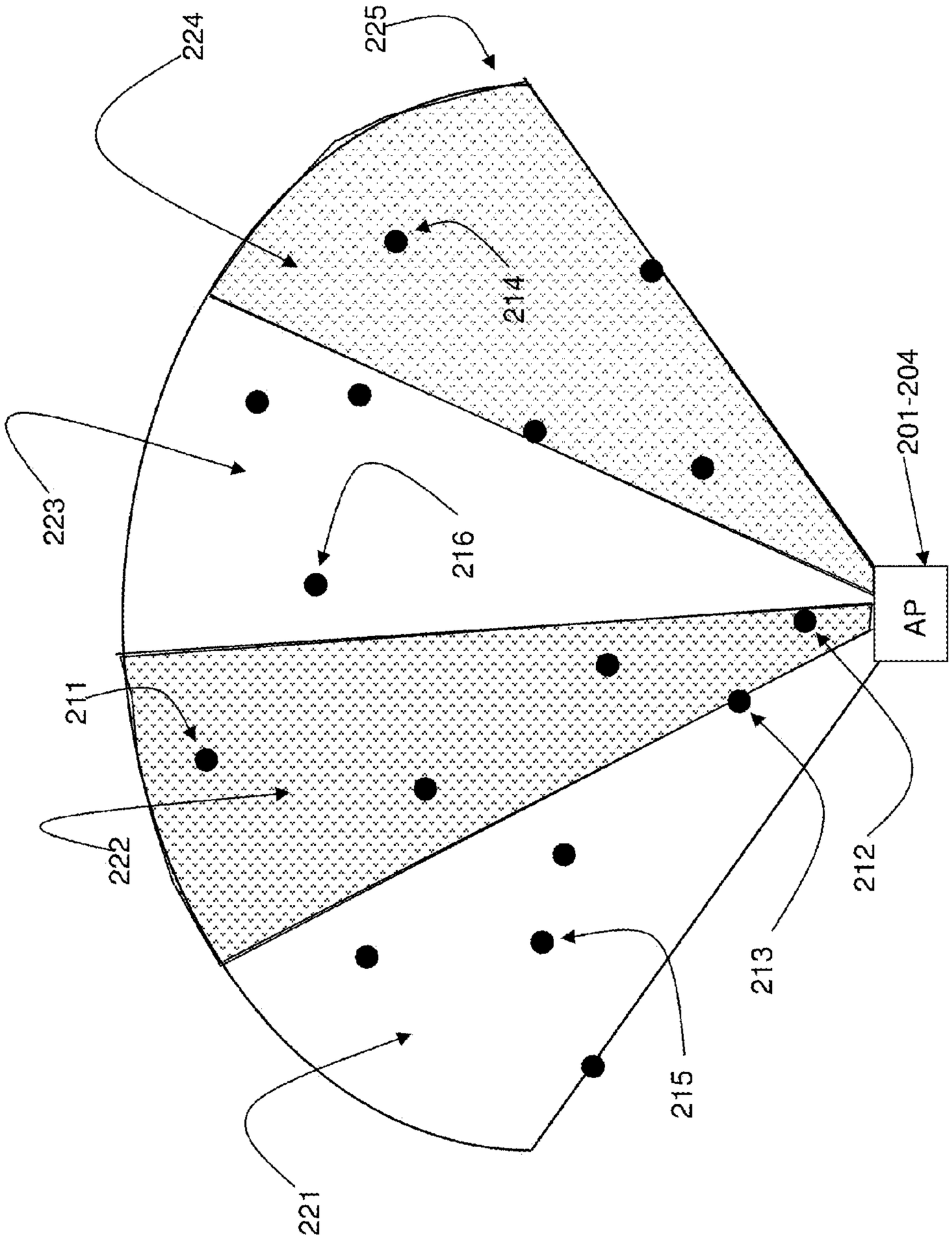


Fig. 2

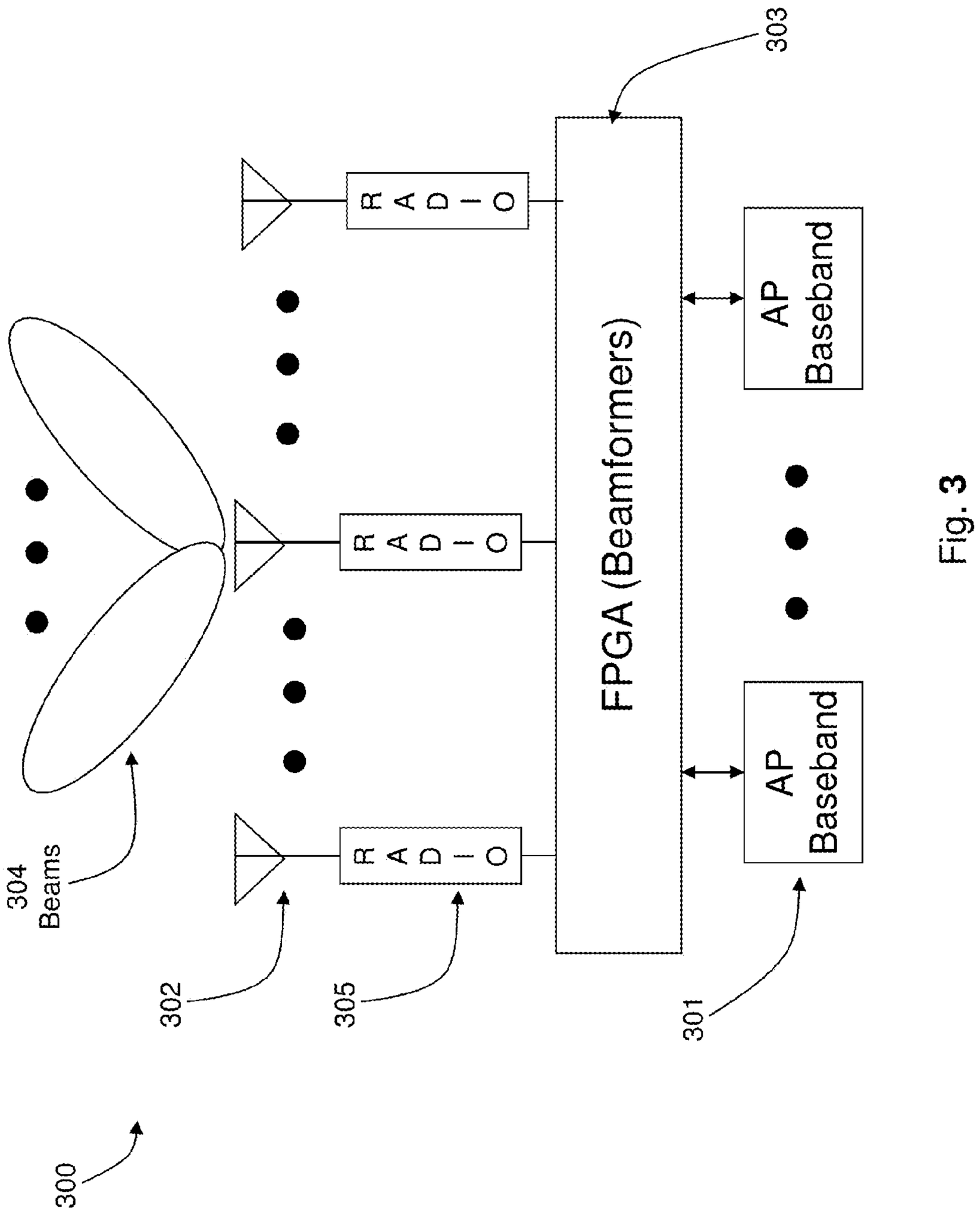

303
RADIO
RADIO
RADIO
FPGA (Beamformers)
AP Baseband
AP Baseband
304 Beams
302
305
301
300

Fig. 3

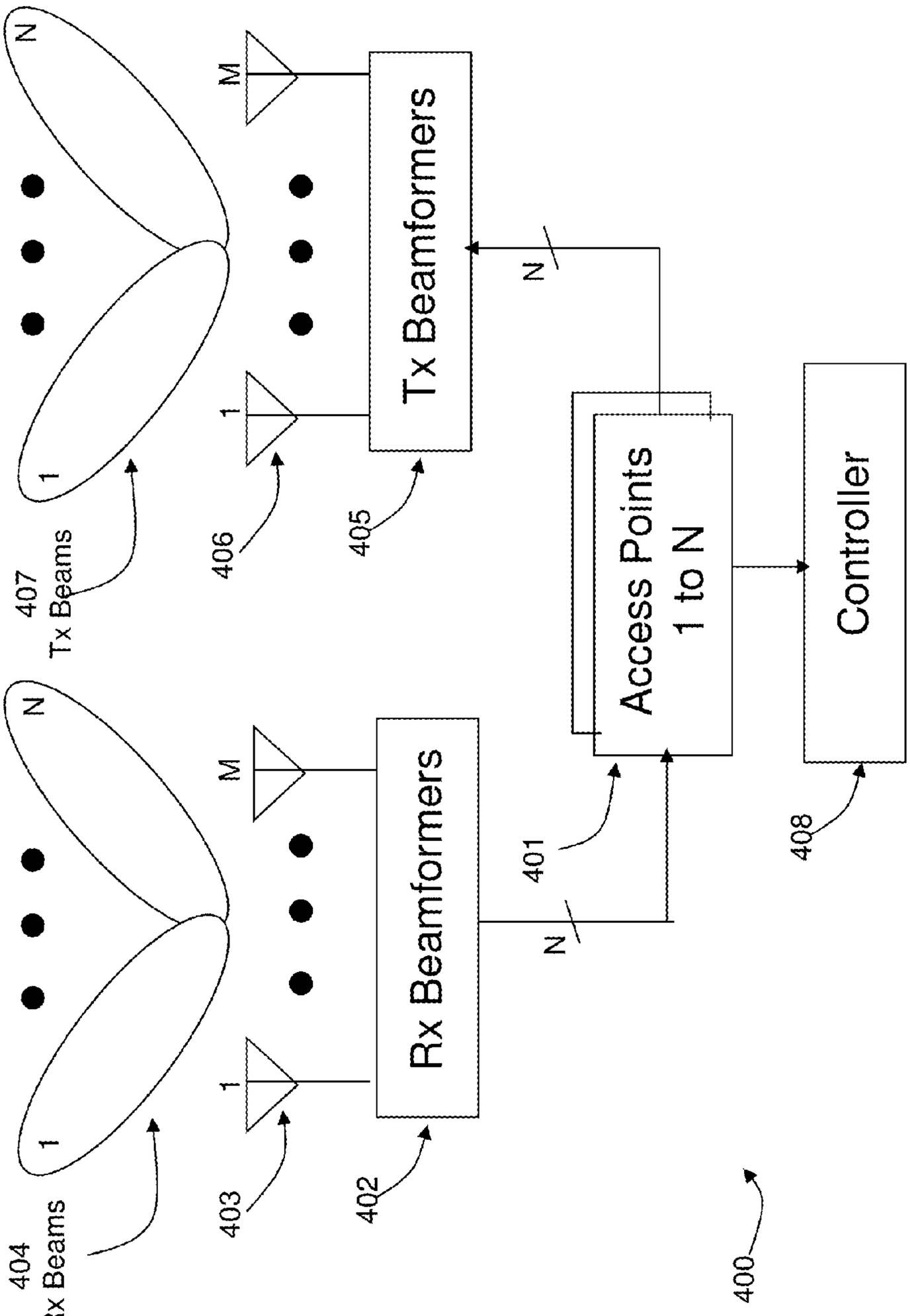

N
M
1
407
Tx Beams
406
405
Tx Beamformers
N
Access Points
1 to N
Controller
401
408
N
M
1
404
Rx Beams
403
402
Rx Beamformers
400

Fig. 4

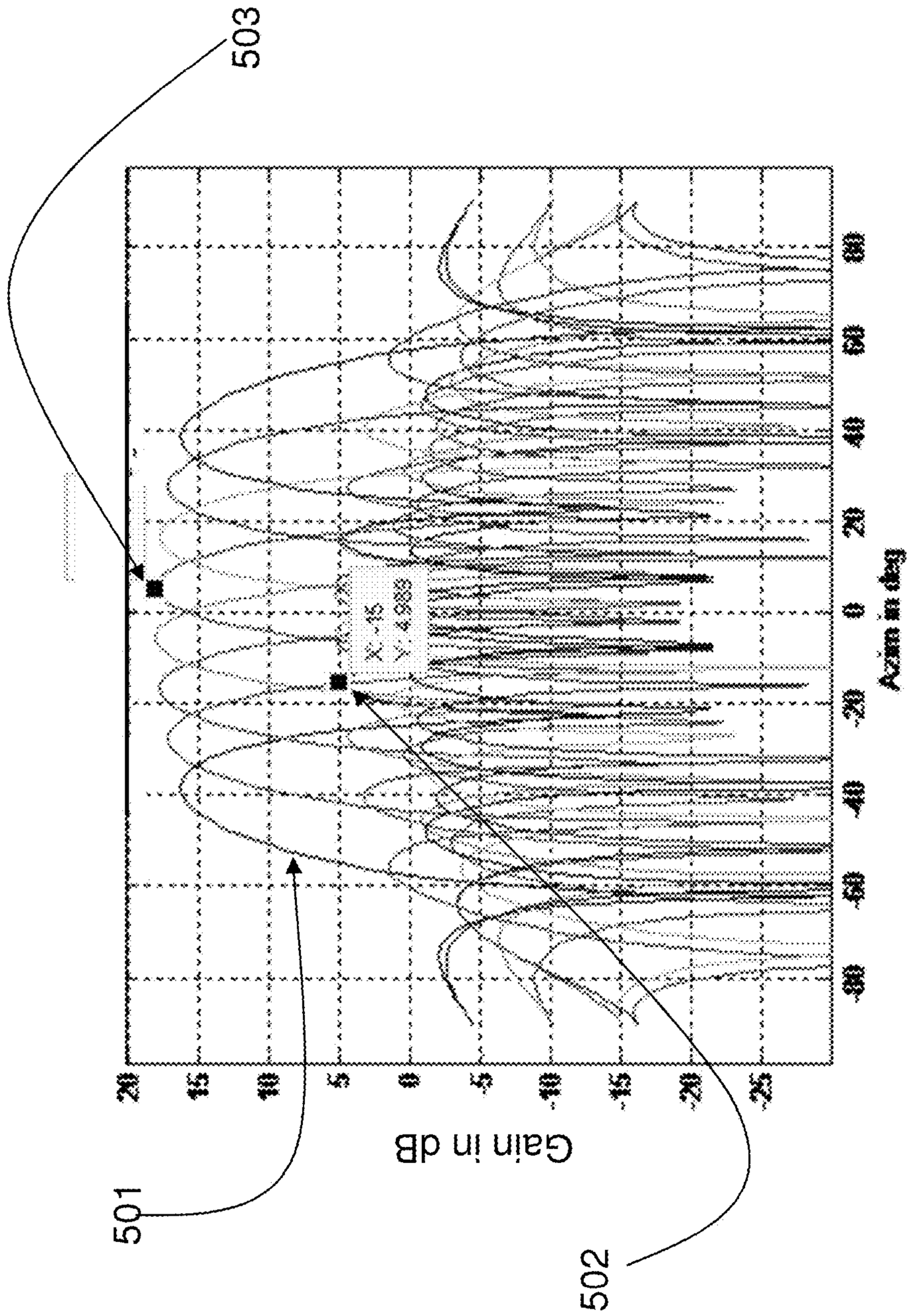

503
501
502
Gain in dB
Azim in deg
-180
-150
-120
-90
-60
-30
0
30
60
90
120
150
180
-25
-20
-15
-10
-5
0
5
10
15
20
25
X: 15
Y: 4.939

Fig. 5

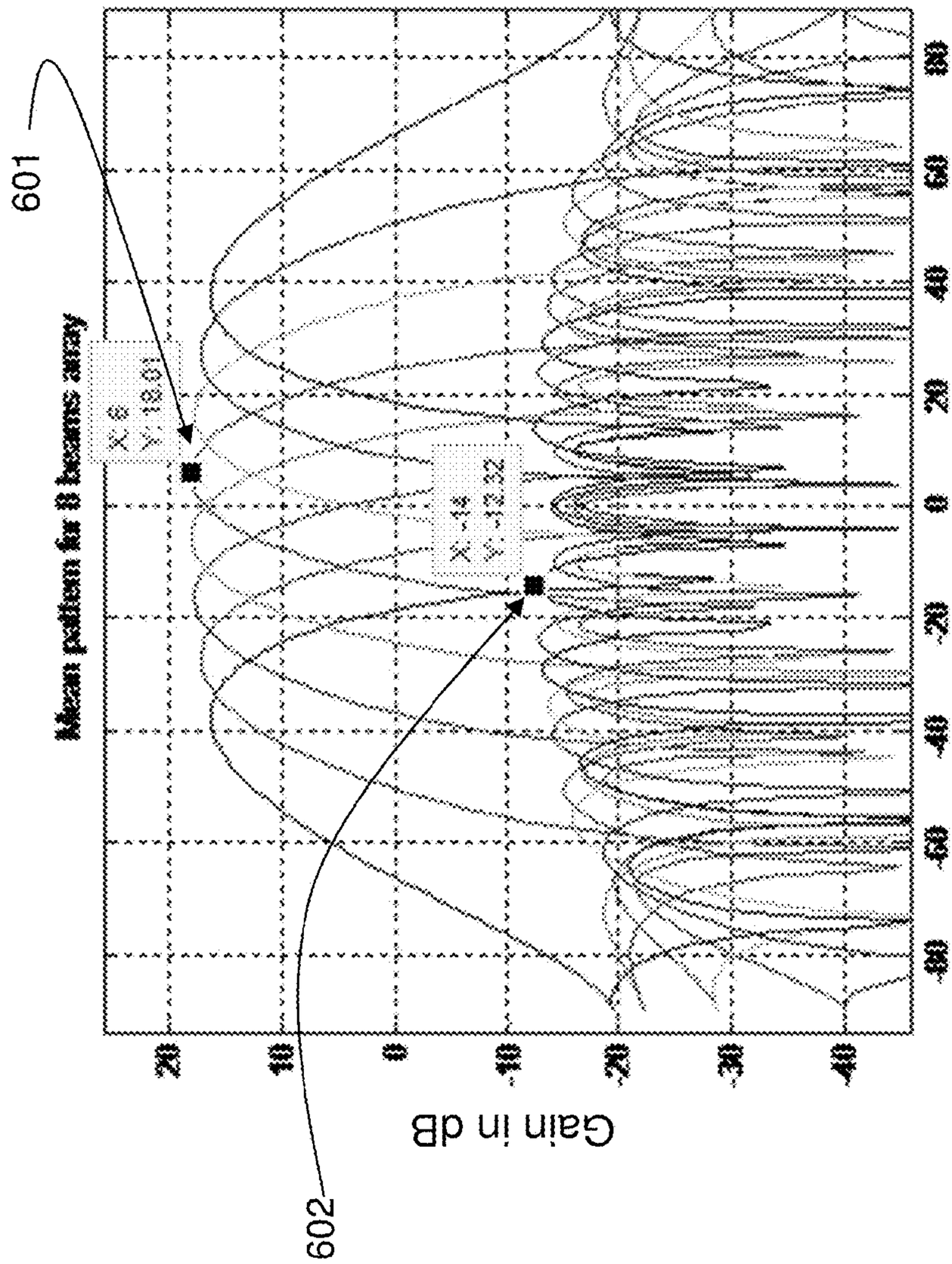

601
Mean pattern for 8 beams array
X: 0
Y: 18.01
X: -14
Y: -12.32
Azim in deg
Gain in dB
602

Fig. 6

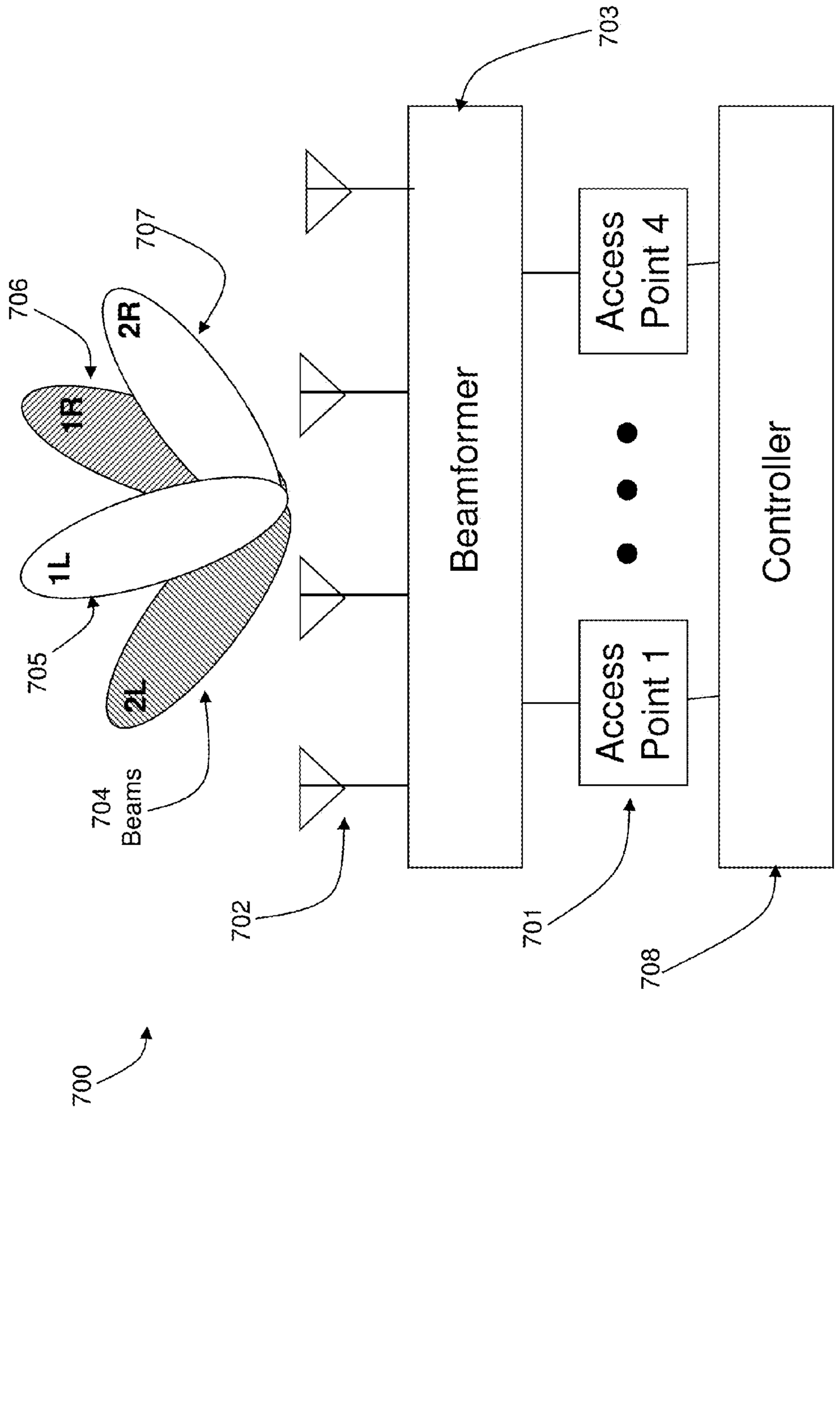

703
707
706
2R
1R
1L
705
2L
704
Beams
Beamformer
Access Point 4
Access Point 1
Controller
702
701
708
700

Fig. 7

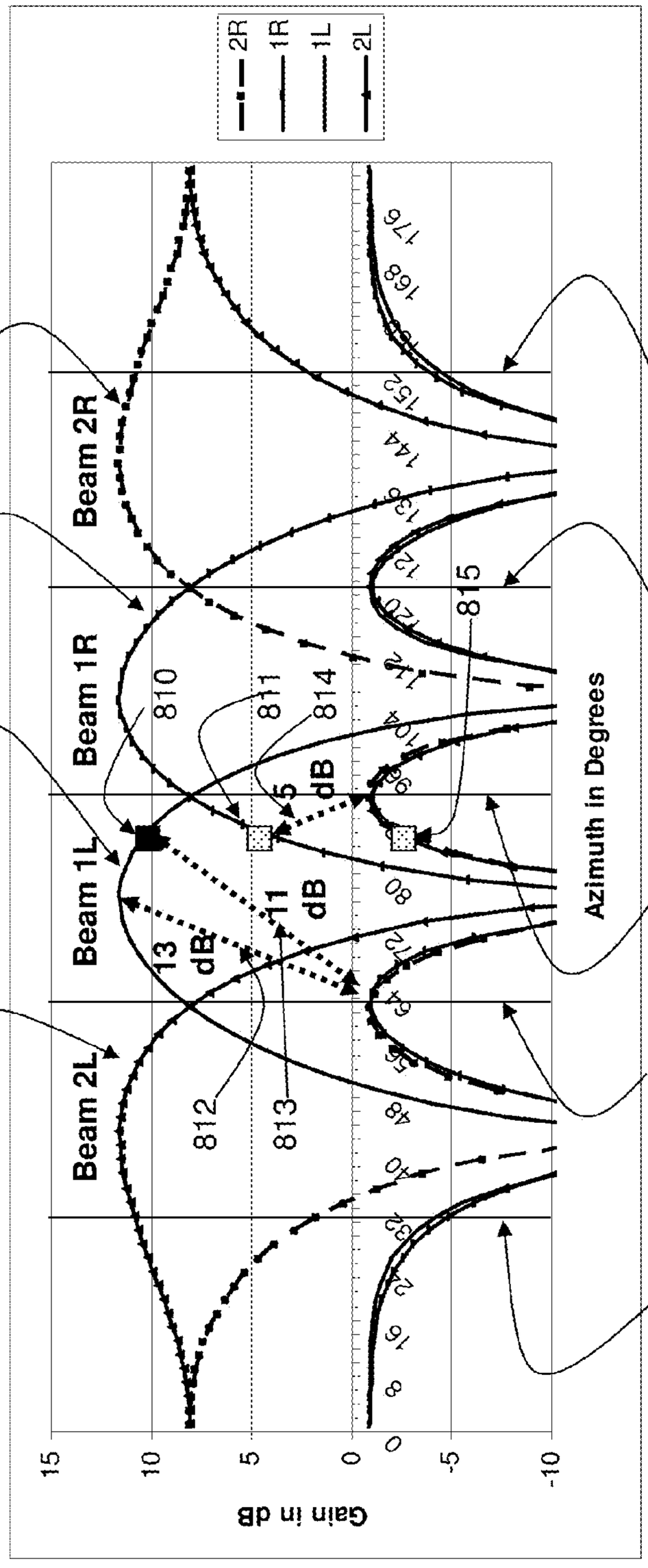


Figure 8. Exemplary radiation pattern of 4 beam antenna using 4 antennas and Butler matrix beamformer [800]

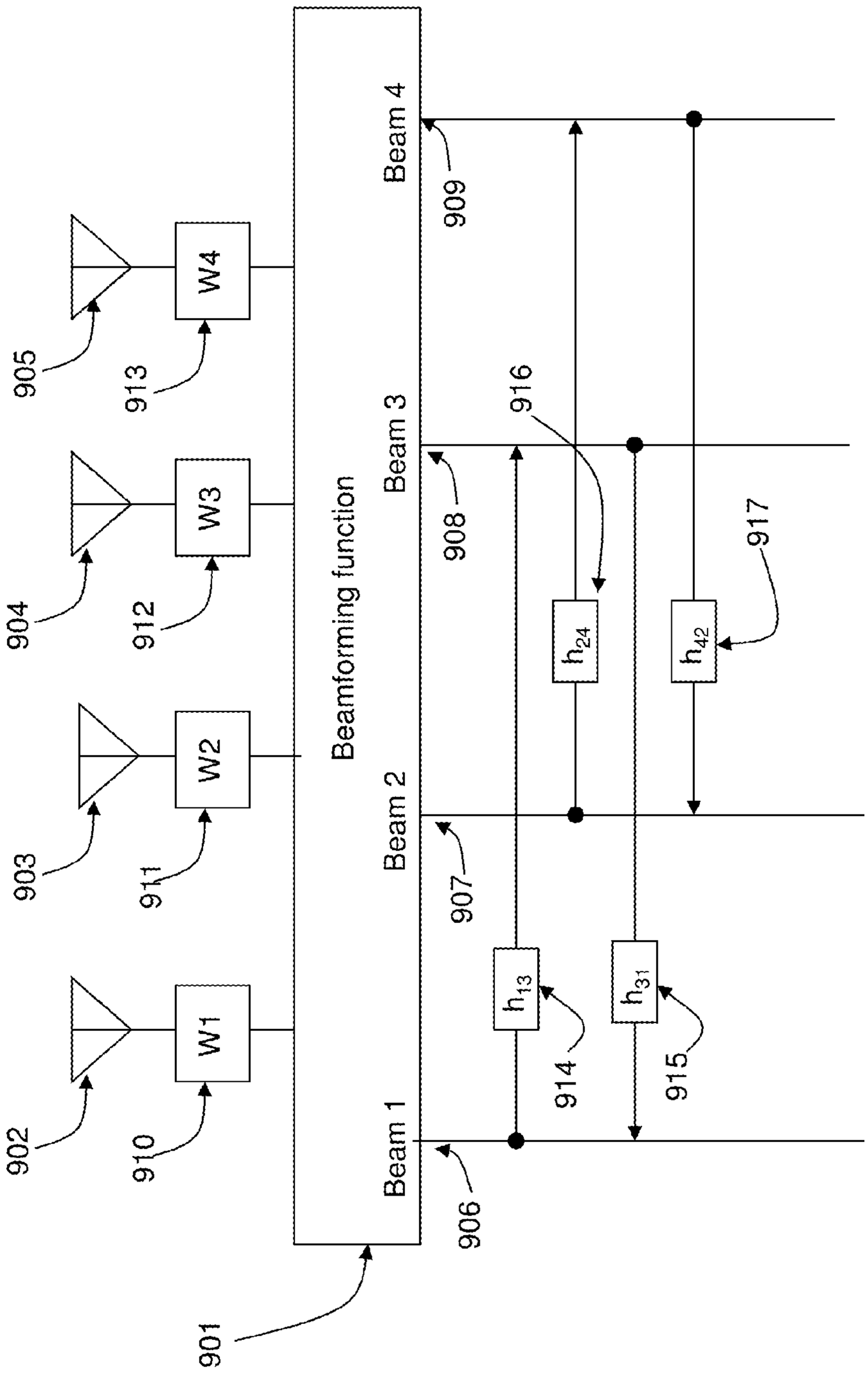


Figure 9. Functional diagram for tapering and sidelobe cancelling (Analog or Digital) [900]

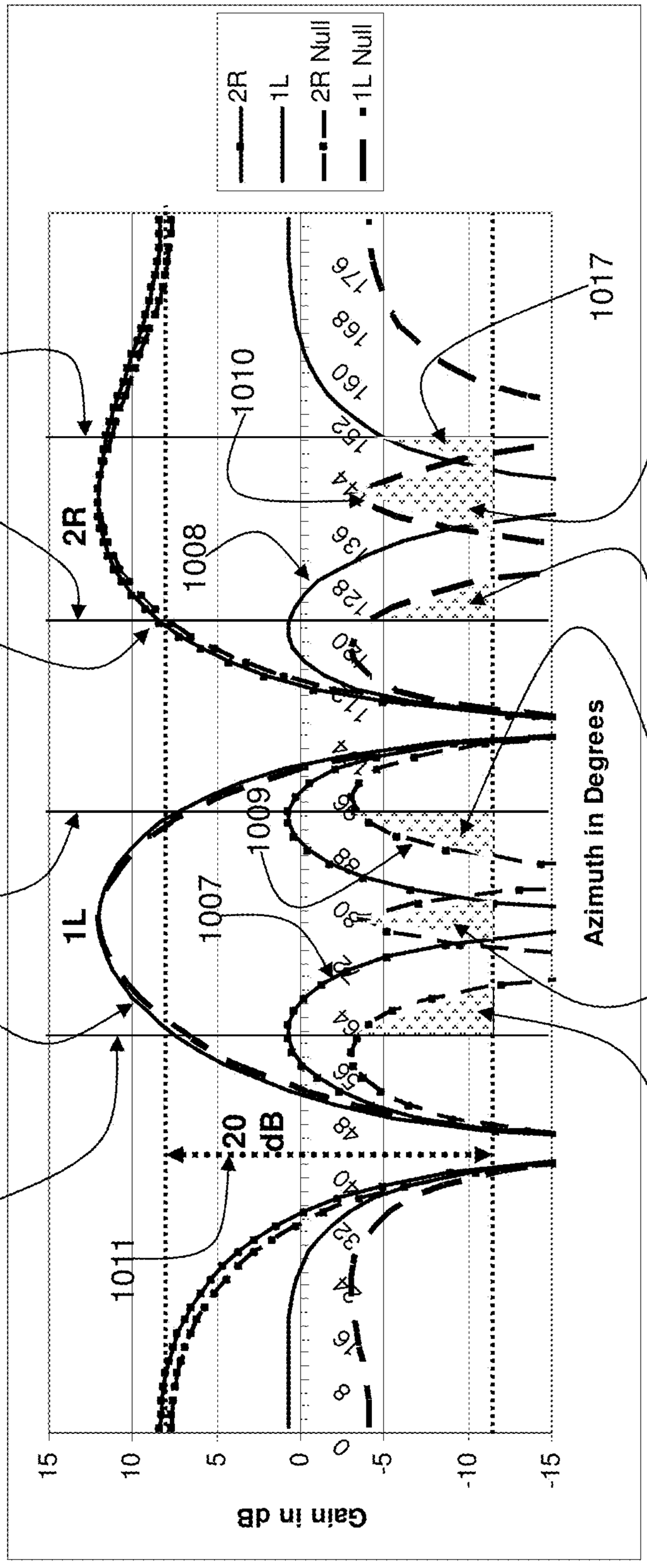

2R
1L
2R Null
1L Null
Gain in dB
Azimuth in Degrees
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
2R
1L
20 dB

Fig. 10

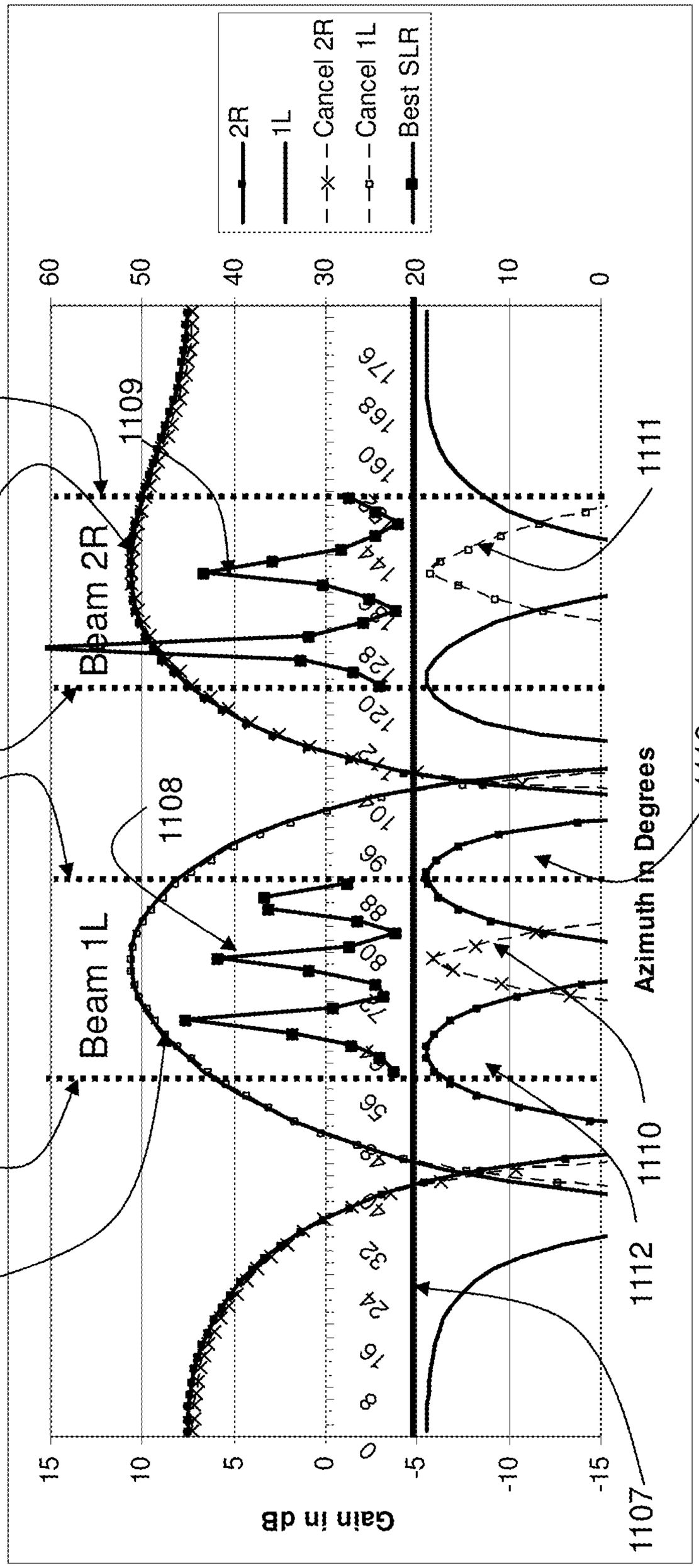

2R
1L
Cancel 2R
Cancel 1L
Best SLR
Beam 2R
Beam 1L
Azimuth in Degrees
Gain in dB
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113

Fig. 11

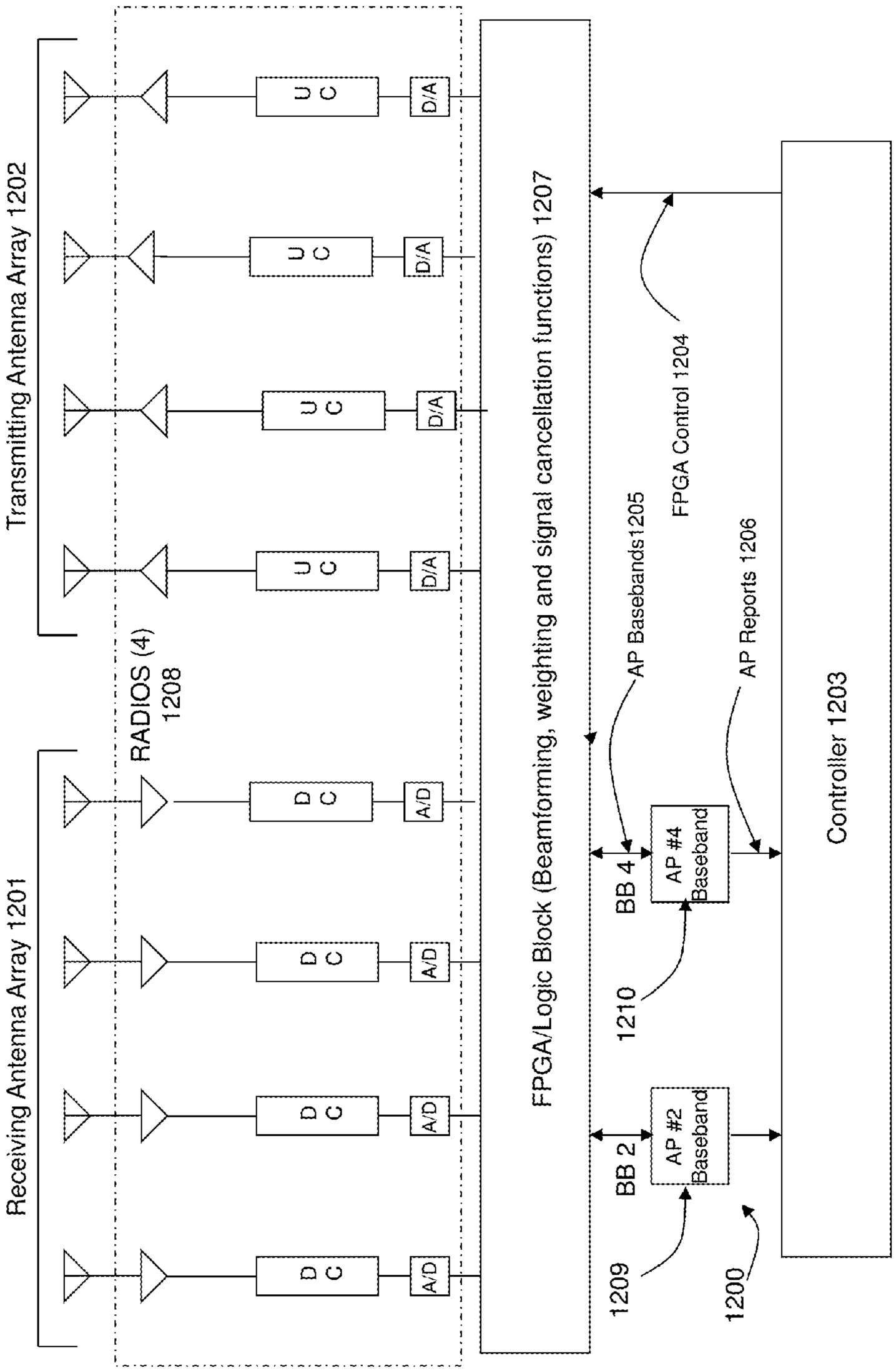

Transmitting Antenna Array 1202
Receiving Antenna Array 1201
RADIOS (4) 1208
D C
A/D
U C
D/A
FPGA/Logic Block (Beamforming, weighting and signal cancellation functions) 1207
FPGA Control 1204
AP Basebands1205
AP Reports 1206
BB 4
BB 2
AP #4 Baseband
AP #2 Baseband
Controller 1203
1210
1209
1200

Fig. 12

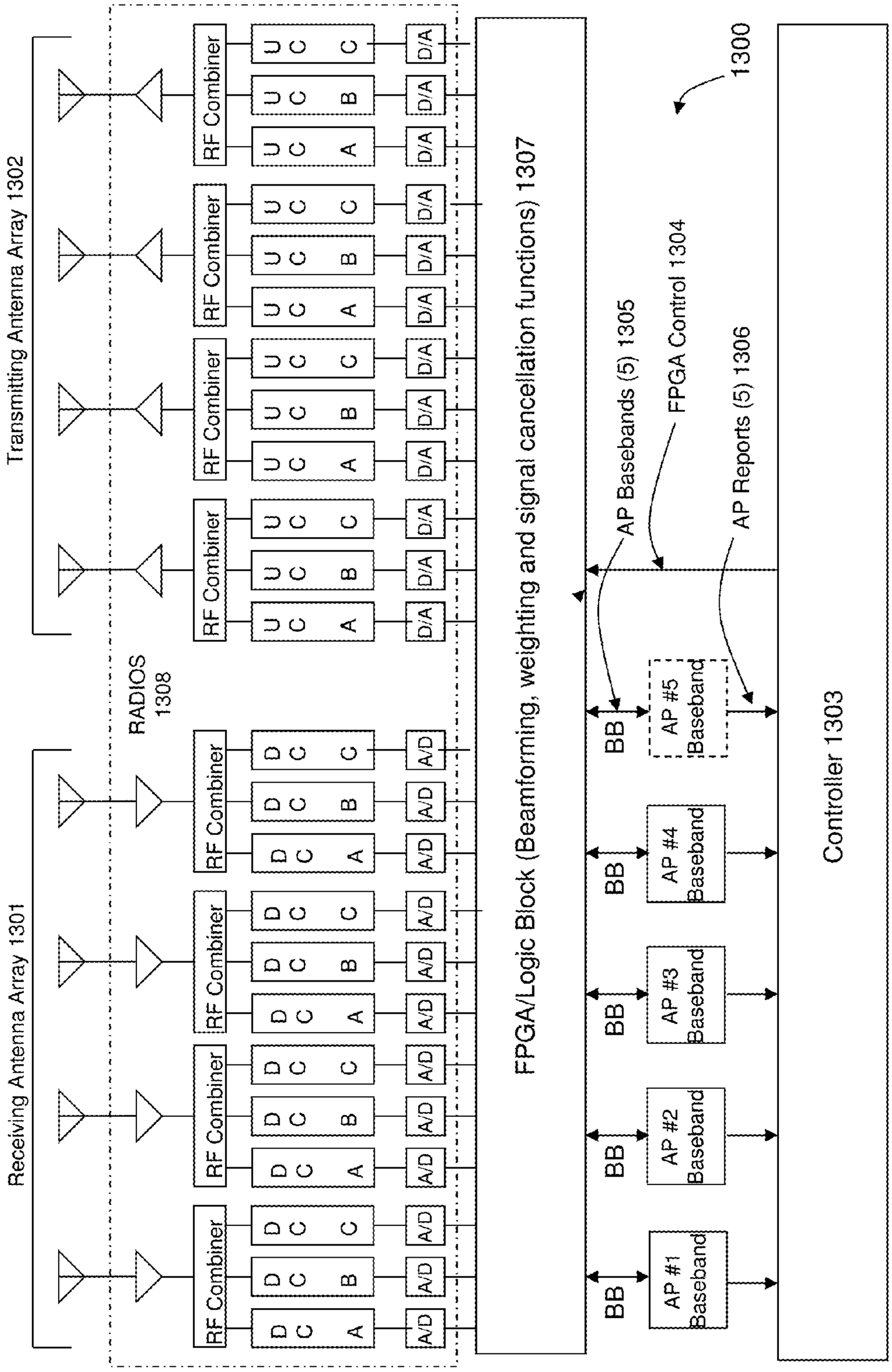

1300
Receiving Antenna Array 1301
Transmitting Antenna Array 1302
RADIOS 1308
RF Combiner
A/D
D/A
FPGA/Logic Block (Beamforming, weighting and signal cancellation functions) 1307
1305
FPGA Control 1304
AP Basebands (5) 1305
AP Reports (5) 1306
BB
AP #1 Baseband
AP #2 Baseband
AP #3 Baseband
AP #4 Baseband
AP #5 Baseband
Controller 1303

Fig. 13

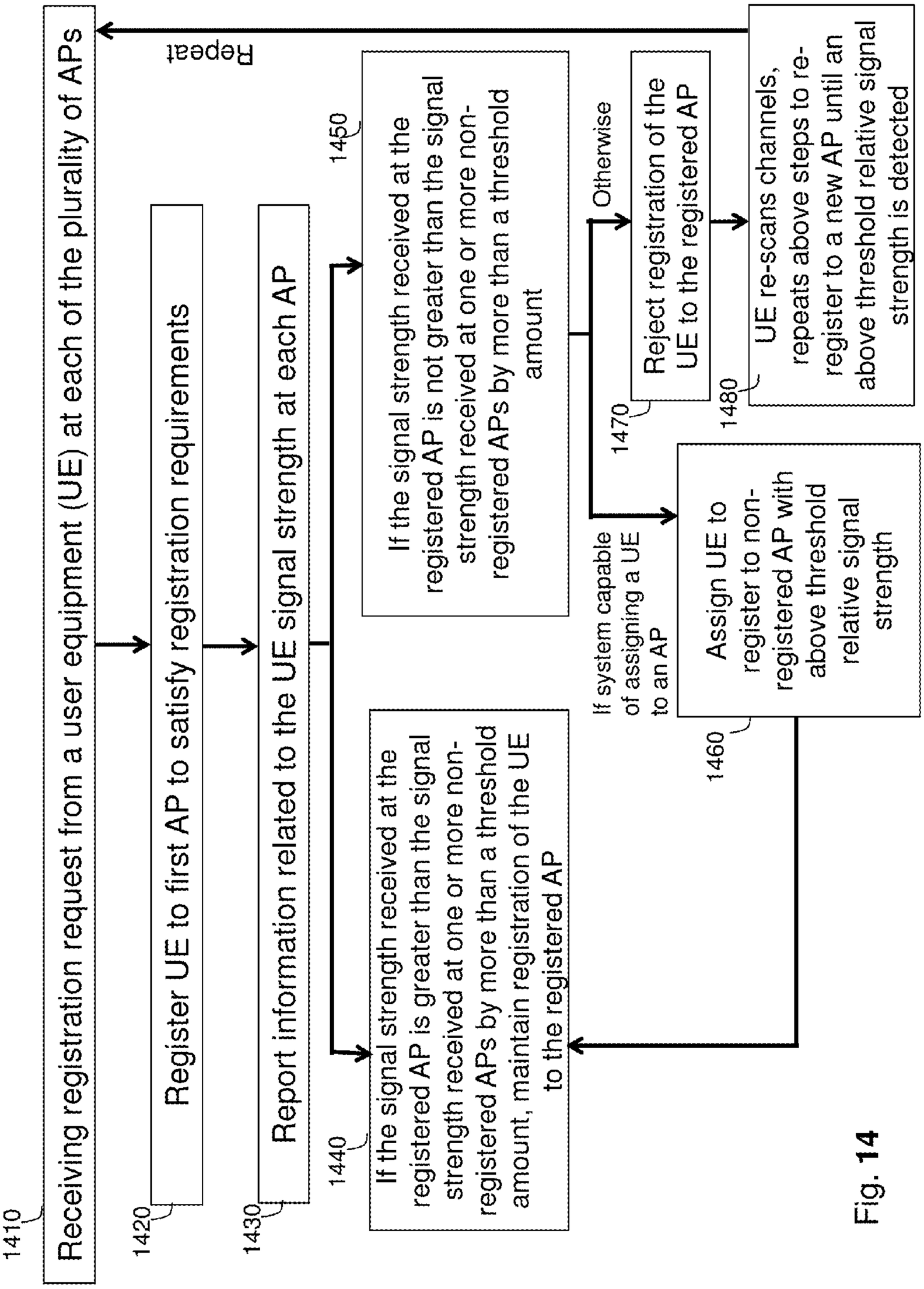

1410
Receiving registration request from a user equipment (UE) at each of the plurality of APs
1420
Register UE to first AP to satisfy registration requirements
1430
Report information related to the UE signal strength at each AP
1440
If the signal strength received at the registered AP is greater than the signal strength received at one or more non-registered APs by more than a threshold amount, maintain registration of the UE to the registered AP
If the signal strength received at the registered AP is not greater than the signal strength received at one or more non-registered APs by more than a threshold amount
If system capable of assigning a UE to an AP
Otherwise
1460
Assign UE to register to non-registered AP with above threshold relative signal strength
1470
Reject registration of the UE to the registered AP
1480
UE re-scans channels, repeats above steps to re-register to a new AP until an above threshold relative signal strength is detected
Repeat

Fig. 14

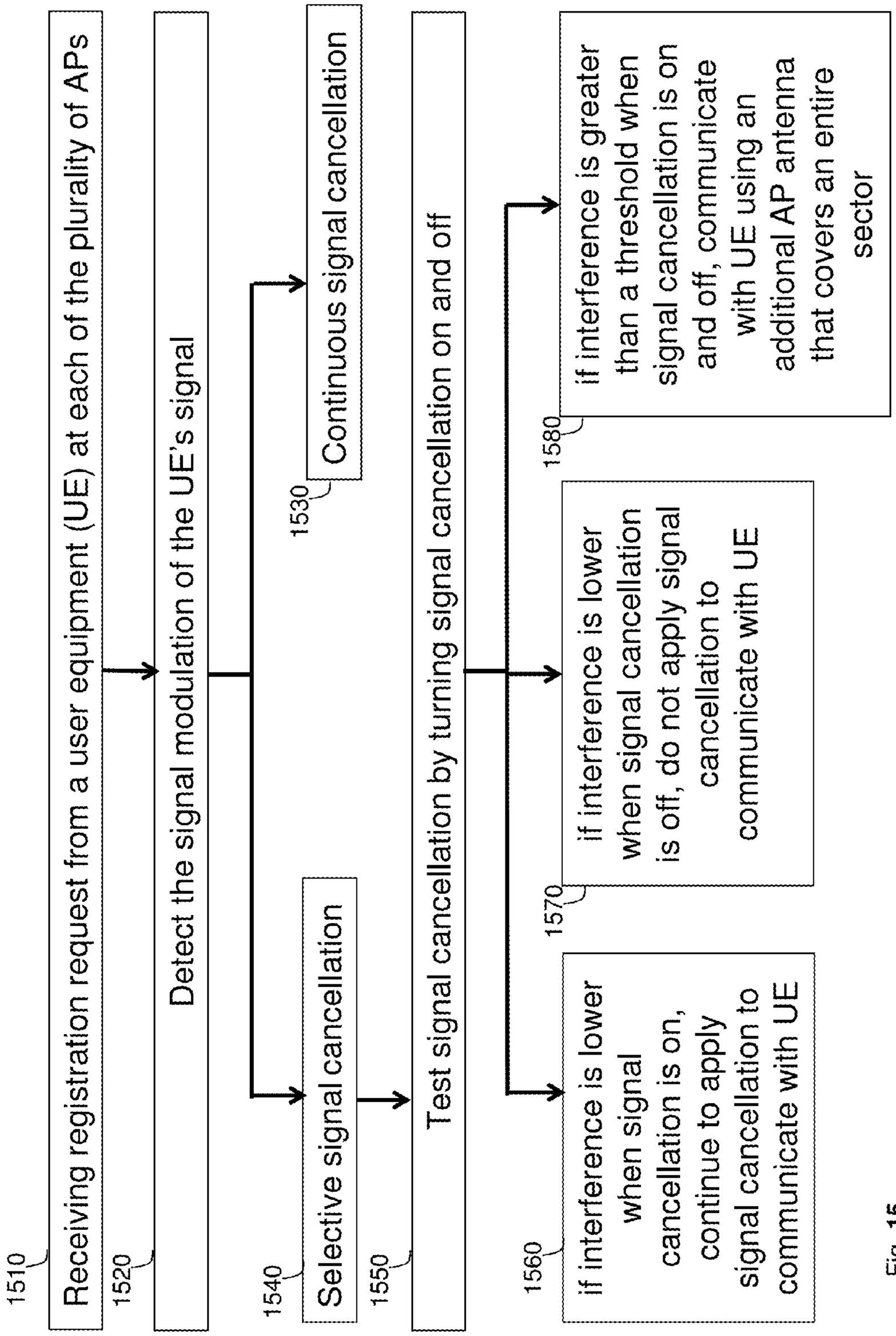

1510
Receiving registration request from a user equipment (UE) at each of the plurality of APs
1520
Detect the signal modulation of the UE's signal
1530
Continuous signal cancellation
1540
Selective signal cancellation
1550
Test signal cancellation by turning signal cancellation on and off
1560
if interference is lower when signal cancellation is on, continue to apply signal cancellation to communicate with UE
1570
if interference is lower when signal cancellation is off, do not apply signal cancellation to communicate with UE
1580
if interference is greater than a threshold when signal cancellation is on and off, communicate with UE using an additional AP antenna that covers an entire sector

Fig. 15

SYSTEM AND METHOD FOR SELECTIVE REGISTRATION IN A MULTI-BEAM SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to the field of radio frequency (RF) multiple-input-multiple-output (MIMO) systems and in particular to systems and methods for enhanced performance of RF MIMO systems using RF beamforming and/or digital signal processing (DSP). Embodiments of the present invention relate to the following fields and technologies: WiFi, Institute of Electrical and Electronics Engineers (IEEE) 802.11a, b, g, n, ac standards, antenna arrays, side lobe reduction, receivers, transmitters, beamforming, DSP, digital filtering, analog and digital signal cancellation and interference mitigation.

BACKGROUND OF THE INVENTION

Prior to setting forth a short discussion of the related art, it may be helpful to set forth definitions of certain terms that will be used hereinafter.

The term "MIMO" as used herein, is defined as the use of multiple antennas at both the transmitter and receiver to improve communication performance. MIMO offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. It achieves this goal by spreading the transmit power over the antennas to achieve spatial multiplexing that improves the spectral efficiency (more bits per second per Hz of bandwidth) or to achieve a diversity gain that improves the link reliability (reduced fading), or increased antenna directivity.

The term "beamforming" sometimes referred to as "spatial filtering" as used herein, is a signal processing technique used in antenna arrays for directional signal transmission or reception. This is achieved by combining elements in the array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beamforming can be used at both the transmitting and receiving ends in order to achieve spatial selectivity.

The term "beamformer" as used herein refers to RF and/or digital circuitry that implements beamforming and includes combiners and phase shifters or delays and in some cases amplifiers and/or attenuators to adjust the weights of signals to or from each antenna in an antenna array. Digital beamformers may be implemented in digital circuitry such as a digital signal processor (DSP), field-programmable gate array (FPGA), microprocessor or the CPU of a computer to set the weights (phases and amplitudes) of the above signals. Various techniques are used to implement beamforming such as using a Butler matrix, Blass Matrix, Rotman Lens and/or phased array of antennas. In general, most approaches to beamforming attempt to provide simultaneous coverage within a sector using multiple beams.

WiFi has been implemented with a limited amount of frequency resources that use techniques of collision avoidance to allow multiple user equipment (UEs) to share the same channel. As the numbers of UEs proliferate, the impact of such a scheme restricts the ability of a base station Access Point (AP) to support many users without impacting the performance to and from each. This invention discloses an apparatus and methods to allow the reuse of resources by implementing AP clusters using multi-beam antennas breaking down a sector area of coverage into smaller subsectors. In order to accomplish this, several limitations of multi-beam antennas must be addressed. First, since WiFi is a time division multiplex system (TDD), the transmitting and receiving

functions use the same channel. Unsynchronized operation between APs means a transmitting AP's signal may interfere with the reception of another AP that uses the same channel unless sufficient isolation (e.g., 125 dB) is provided between the transmitting and receiving functions. Prior art cited above addresses the problem by using physically separated antenna arrays for transmit and receive and by providing cancellation of each transmitted signal within the receiver processing functions. Another limitation is that multi-beam antennas do not offer infinite separation of the coverage of one beam to the others. The following discusses the impacts of this performance limitation and presents approaches to mitigate its effect.

SUMMARY OF EMBODIMENTS OF THE INVENTION

Beamforming networks include multi-beam antenna arrays to provide multiple beams pointed at different directions to independently communicate with multiple respective APs. In order to provide continuous coverage to UEs throughout a sector, the coverage of adjacent beams of a multi-beam antenna overlap. This presents a potential for interference when adjacent beams illuminate the same area on the same frequencies or channel. In order to reduce such interference from one beam to another, adjacent beams may provide communication over different channels.

To register to an AP, UEs typically scan channels for an available AP and stop searching upon finding a first AP that satisfies their registration requirements. However, when a communication link is sufficiently strong, APs and/or frequencies outside of the UE's optimal range may provide sufficiently strong signals to satisfy the UE's registration requirements, causing the UE to register to a sub-optimal AP. Further, as a UE moves from one beam to the next, commonly referred to as "roaming," an AP and/or frequency that is optimal in one location becomes sub-optimal as the UE travels to another location. The problem of roaming may be compounded for UEs that are close to APs since they travel across beams more quickly and, because of their proximity to the antennas, experience relatively good communication causing registration to the "wrong" AP to be more likely.

According to an embodiment of the invention, a system and method is provided for detecting registration to sub-optimal APs and/or frequencies and providing means to re-register the UE to an optimal AP and/or frequency.

According to an embodiment of the invention, a system and method is provided for selective registration of a user equipment (UE) to one of a plurality of access points (APs) in a multi-beam system. An indication may be received that each of a plurality of APs have received a signal from a single UE. The UE may communicate with each AP over an associated beam that includes a primary lobe providing a relatively higher signal strength surrounded by one or more sidelobes providing a relatively lower signal strength. The UE may register to a first one of the plurality of APs that satisfies registration requirements associated with the UE. The registration of the UE to the registered AP may be maintained if the UE communicates with the registered AP over a primary lobe providing a greater than threshold relative signal strength relative to the other (non-registered) APs, whereas the registration of the UE to the registered AP may be rejected when the UE communicates with the registered AP over a sidelobe or over a primary lobe providing a less than threshold relative signal strength relative to the other APs.

According to an embodiment of the invention, a system and method is provided for selective registration of a UE to one of

a plurality of access points (APs). An indication may be received that each of a plurality of APs have received a signal from a user equipment (UE). The UE may be registered to the first one of the plurality of APs to satisfy registration requirements associated with the UE. Information may be reported to a controller related to the signal strength of communication received at each AP from the UE. If the signal strength received at the registered AP is less than the signal strength received at one or more of the non-registered APs by more than a threshold amount, the registration of the UE to the registered AP may be rejected.

Another problem in multi-beam systems is sidelobe interference caused by non-ideal directivity of the beams. A beam may include a primary lobe (PL) pointed along a main axis or direction of the beam and which typically provides relatively high signal gain, amplitude or power. The primary lobe may be surrounded by a sidelobe (SL), which may be an echo of the primary lobe, and which typically provides relatively lower signal gain, amplitude or power. Sidelobes (SL) radiate in directions askew from the main direction or axis of the beam and thus, are typically a source of interference when transmitting in those other sidelobe directions. Sidelobes may simultaneously receive energy, not only from UEs along the beam path, but also from UEs that are not located within the beam path.

Various techniques may be used to reduce, suppress or cancel sidelobe signals. One sidelobe suppression technique is referred to as "tapering" or "Taylor weighting," in which the gain or amplitude of each antenna element may be weighted differently depending on its position in the antenna array. Typically the gain or amplitude of an antennae element is weighted lower the farther the antenna is positioned from the center of the antenna array. However, to achieve acceptable performance, tapering typically requires antenna arrays with a substantially large number of antenna elements (e.g. greater than eight).

According to an embodiment of the invention, a system and method is provided for sidelobe suppression with any number (e.g. four) antenna elements.

According to an embodiment of the invention, a system and method is provided for selective suppression of sidelobe signals using controlled signal cancellation. An indication may be received that a signal from a single user equipment (UE) is received at each of two or more access points (APs) over the same channel. The relatively stronger power signal may be received over a primary lobe of a communication beam of one of the APs and the relatively weaker power signal may be received over a side lobe of a communication beam of another one of the APs. The efficacy of signal cancellation may be tested by turning signal cancellation on and off to measure the UE signals received at one of the APs. If interference is lower when signal cancellation is turned on, said signal cancellation may be applied for continued communication with said UE to cancel side lobe signals and if interference is lower when signal cancellation is turned off, said UE may be communicated with without applying said signal cancellation.

According to an embodiment of the invention, a system and method is provided for selective suppression of sidelobe signals using controlled signal cancellation. Signals may be transmitted/received to/from a plurality of access points (APs) along the direction of a plurality of (N) different respective beams, wherein each of the plurality of (N) beams includes a primary lobe providing relatively high signal power surrounded by two or more side lobes providing relatively low signal power, wherein a primary lobe of one beam is substantially separated from a primary lobe of an adjacent beam communicating over the same channel but at least partially overlapping one or more side lobes of the adjacent beam. It may be determined if user equipment (UE) detected by two or more APs is communicating using a side lobe signal or a primary lobe signal. Signal cancellation may be applied to suppress the sidelobe signals if the UE is determined to communicate using a sidelobe signal but not applied if the UE is determined to communicate using a primary lobe signal.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention and in order to show how it may be implemented, references are made, purely by way of example, to the accompanying drawings in which like numerals designate corresponding elements or sections. In the accompanying drawings:

FIG. **1** is a schematic illustration of a multi-beam system including a plurality of access points driving one or more beamformers and an antenna array to create a plurality of beams in accordance with an embodiment of the invention;

FIG. **2** is a schematic illustration of a sector coverage area subdivided into subsector zones covered by multiple beams in accordance with an embodiment of the invention;

FIG. **3** is a schematic illustration of a multi-beam system using digital beamformers in accordance with an embodiment of the invention;

FIG. **4** is a schematic illustration of a multi-beam system with separated transmit and receive circuitry in accordance with an embodiment of the invention;

FIG. **5** is a schematic illustration of a radiation pattern of a multi-beam system in accordance with an embodiment of the invention;

FIG. **6** is a schematic illustration of a radiation pattern of a multi-beam system as shown in FIG. **5** that is tapered in accordance with an embodiment of the invention;

FIG. **7** is a schematic illustration of a multi-beam system for optimally registering UEs to APs in accordance with an embodiment of the invention;

FIG. **8** is a schematic illustration of a radiation pattern for the antenna array of FIG. **7** in accordance with an embodiment of the invention;

FIG. **9** is a schematic illustration of a multi-beam system for tapering and signal cancellation in accordance with an embodiment of the invention;

FIG. **10** is a schematic illustration of a radiation pattern transmitted by the antenna array of FIG. **9** with and without signal cancellation in accordance with an embodiment of the invention;

FIG. **11** is a schematic illustration of a radiation pattern transmitted by the antenna array of FIG. **9** with tapering and selective signal cancellation in accordance with an embodiment of the invention;

FIG. **12** is a schematic illustration of a multi-beam system for selective signal cancellation using digital beamforming in accordance with an embodiment of the invention;

FIG. **13** is a schematic illustration of a multi-beam system for selective signal cancellation using digital beamforming in accordance with an embodiment of the invention; and

FIGS. **14-15** are flowcharts of methods in accordance with embodiments of the invention.

The drawings together with the following detailed description make the embodiments of the invention apparent to those skilled in the art.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

It is stressed that the particulars shown are for the purpose of example and solely for discussing the preferred embodi-

ments of the present invention, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention. The description taken with the drawings makes apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

Before explaining the embodiments of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following descriptions or illustrated in the drawings. The invention is applicable to other embodiments and may be practiced or carried out in various ways. For example, although the following figures describe four or eight beam systems, any number of a plurality of beams may be used greater than or equal to two. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Reference is made to FIG. **1**, which schematically illustrates a multi-beam system **100** including a plurality of access points **101** driving one or more beamformers **103** and an antenna array **102** to create a plurality of beams **104** in accordance with an embodiment of the invention. Each of the plurality of beams **104** may be pointed toward different directions to spatially divide communication into multiple transmission zones using phased array technology. The zones may be divided in one-dimension (along the azimuth direction only) or in two-dimensions (along the azimuth and zenith/elevation directions). Each access point **101** may independently control a single corresponding beam **104** to simultaneously communicate independently with the user equipment in each zone using the same radio channel. Each zone may be occupied by zero, one or multiple mobile devices serviced by a single beam or data stream.

Reference is made to FIG. **2**, which schematically illustrates a sector coverage area **225** subdivided into subsector zones covered by multiple beams **221-224** in accordance with an embodiment of the invention. UEs **211-216** located in the subsector zones may communicate with access points **201-204** over beams **221-224**. User devices may scan the channels for the first available access point that satisfies its registration requirements. User device **215** in the zone covered by beam **221** may register to access point **201**, user devices **212** and **211** in the zone covered by beam **222** may register to access point **202**, user device **216** in the zone covered by beam **223** may register to access point **203**, and user device **214** in the zone covered by beam **224** may register to access point **204**. A user device **213** near zone boundaries may register to either access point **201** or **202**. Although FIG. **2** shows an idealized partition of area **225** into subsector zones with adjacent beams having perfectly coinciding and non-overlapping boundaries, adjacent beams may overlap causing interference (e.g. see FIGS. **5** and **6**).

Reference is made to FIG. **3**, which schematically illustrates a multi-beam system **300** using digital beamformers **303** in accordance with an embodiment of the invention. To transmit signals over multiple beams **304**, a plurality of AP baseband stations **301** may provide baseband signals to digital beamformers contained in logical block elements of beamformers **303**. Beamformers **303** may output digitized intermediate frequency (IF) signals that are converted to analog signals in radios **305**, upconverted, and then radiated by antennas **302** to create radiated beams **304**. To receive signals over multiple beams **304**, the process is reversed. Signals received over beams **304** by antennas **302** are amplified, downconverted and digitized in radios **305**. The digitized IF signals may then be processed by the beamformer logical block elements of beamformers **303** to isolate the individual received beam signals and route those signals to the appropriate AP baseband station **301**.

In WiFi systems, an AP typically transmits and receives signals over the same frequency at alternating times using a time division duplex (TDD) protocol. Ideally, each individual AP should not create interference between transmitted and received signals because the AP will not be transmitting and receiving at the same time. However, in multi-beam systems (e.g. system **100** of FIG. **1**) using multiple APs (e.g. APs **101** of FIG. **1**), one AP may be transmitting at the same time as another AP is receiving. Accordingly, transmitted signals from the one AP may be coupled to the receiving circuits of the other AP and create interference at that AP. Such coupling may be due to insufficient isolation between transmit and receive circuits. One way to mitigate the problem of coupling is to physically separate the transmit and receive antenna arrays as shown in FIG. **4**.

Reference is made to FIG. **4**, which schematically illustrates a multi-beam system **400** with separated transmit and receive circuitry in accordance with an embodiment of the invention. The transmit circuitry may include a plurality of (N) APs **401** that generate transmit signals to a plurality of (N) transmit beamformers **405** which drive transmit antenna array **406** including a plurality of (M) antennas to create a plurality of (N) transmit beams **407**. The receive circuitry operates in reverse and includes a receive antenna array **403** including a plurality of (M) antennas to receive a plurality of (N) of receive beams **404** and to be used in conjunction with a plurality of (N) receive beamformers **402** to create received signals for each individual AP **401**. APs **401** may report received signal parameters to a controller **408**. Embodiments of the invention may either be performed with analog beamformers or digital beamformers. In general, the number of beams (N) and APs (N) in each of the transmit or receive circuitry of system **400** is less than or equal to the number of antennas (M) in each of the transmit or receive antenna arrays **403** or **406** ($N \leq M$).

Reference is made to FIG. **5**, which schematically illustrates a radiation pattern of a multi-beam system including a plurality of (e.g., N=8) beams **501** transmitted by an antenna array including a plurality of (e.g., N=8) antenna elements in accordance with an embodiment of the invention. The antenna array may be coupled to a beamformer to generate the signals using beamforming (e.g., Butler matrix) techniques. Each of the (N) beams **501** may include a primary lobe **503** having a relatively higher gain or amplitude and sidelobes **502** having a relatively lower gain or amplitude. Primary lobe **503** of each beam **501** may be oriented in a different direction along a main axis of symmetry of the beam **501** (e.g. away from the emission plane of the antenna array) and sidelobes **502** of each beam **501** may be oriented in directions askew or surrounding the main axis of symmetry of the beam **501**. To minimize interference, the ratio of the gain/amplitude of primary lobes **503** to the gain/amplitude of sidelobes **502** is preferably more than a threshold, for example, approximately 20 dB. In the example shown in FIG. **5**, the ratio is approximately 13 dB, which may be below the threshold. Accordingly, a sidelobe suppression technique, such as, tapering or Taylor weighting, may be used to reduce the sidelobe interference of antenna arrays as shown in FIG. **6**.

Reference is made to FIG. **6**, which schematically illustrates a radiation pattern of a multi-beam system as shown in FIG. **5** that is tapered, for example, using Taylor weighting, in

accordance with an embodiment of the invention. The antenna array generates a plurality of (e.g., N=8) beams, each beam including a primary lobe **601** and sidelobe **602**. In the example shown in FIG. **6**, the ratio of primary lobe **601** to sidelobe **602** may be increased to approximately 30 dB. Although Taylor weighting may reduce sidelobe interference, effective tapering typically requires a substantially large antenna array. For example, an eight element linear antenna array is typically about 1.5 feet across for 2.4 GHz WiFi band coverage. This size may increase when using separate transmit/receive circuits as shown in FIG. **4**. For example, an array with 3 feet of spacing between two 1.5 feet transmit/receive antenna arrays may result in a 6 foot antenna structure. Devices may become even more cumbersome when using digital beamformers e.g. as shown in FIG. **3**. For example, a (N=8) beam system may use 16 radios, which may add complexity to calibrate those radios. Further, large tapered arrays may result in highly overlapped coverage of adjacent beams.

Reference is made to FIG. **7**, which schematically illustrates a multi-beam system **700** for optimally registering UEs to APs in accordance with an embodiment of the invention. Multi-beam system **700** may include a plurality of access points **701** driving one or more beamformers **703** and an antenna array **702** to create a plurality of beams **704-707** controlled by controller **708**. Beamformer **703** may be analog or digital. Although FIG. **7** shows four access points **701**, four antennas **702**, and four beams **704-707**, any number of such components greater than four (or greater than two) may be used. When using separate transmit/receive circuits as shown in FIG. **4**, the circuitry configuration shown in FIG. **7** may be used for each of the transmitter circuitry and the receiver circuitry.

Adjacent beams **704-707** may overlap in coverage causing one beam (e.g. beam **705**) to interfere with communications on adjacent beams (e.g. beams **704** and **706**). To minimize interference near beam boundaries, adjacent beams may communicate over different frequency channels. In FIG. **7**, beams **704** and **706** may be operated on one channel (indicated in the figure by shading) and beams **705** and **707** may be operated on a different channel (indicated in the figure by no shading) to provide frequency isolation between coverage areas. Although alternating channels across adjacent beams reduces interference, other sources of interference, in particular, sidelobe interference among the co-channel beams remains, as shown in FIG. **8**.

Reference is made to FIG. **8**, which schematically illustrates a radiation pattern for the antenna array of FIG. **7** in accordance with an embodiment of the invention. FIG. **8** shows the radiation gain/amplitude versus the azimuth of a signal transmitted by the antenna array of FIG. **7**. In the example of FIG. **8**, the radiation pattern is generated using a Butler beamformer with four isotropic radiators, although any other beamformer and/or radiator may be used. A four antenna four beam system is shown in the example of FIG. **8**, although the figure and accompanying description may be generalized to a multi-beam system having any number of antenna elements and beams.

In FIG. **8**, beams **801**, **802**, **803** and **804** are respectively identified as beams 2L, 1L, 1R and 2R to designate their positions to the left and right relative to the direction normal to the emission plane of the antenna array. The subsector coverage areas of beams **801-804** (e.g. each defining a range of azimuth values relative to the antenna radiation plane) are identified by lines **805-809** (e.g. each defining a single azimuth value) that represent the subsectors boundaries. Dashed line **812** shows that the gain/amplitude of each primary lobe is approximately 13 dB greater than the gains/amplitudes of sidelobes from other beams. The gain of each beam's primary lobe at its boundary with adjacent primary lobes is approximately 4 dB lower than the beam's maximum gain trace. Accordingly, the worst case of interference caused by a sidelobe may provide a gain ratio of approximately 9 dB in the example of FIG. **8**. Since a UE typically scans multiple channels and registers with the first AP that accepts it, UEs located near overlapping beam boundaries may register with a sub-optimal AP in spite of the fact that the APs are operating on different channels.

A UE located along a single azimuth direction (e.g. 88° in FIG. **8**) may register according to one of three possible outcomes by communicating with APs at one of three possible beam locations **810**, **811** or **812**. In the first outcome, the UE registers with an optimal AP associated with beam 1L **802** at beam location **810**. In the second outcome, the UE registers with a sub-optimal AP associated with beam 1R **803** at beam location **811**. In the third outcome, the UE registers with one of two sub-optimal APs associated with a sidelobe **807** of beam 2L **801** or beam 2R **804** at beam location **815**. To identify the actual outcome, all APs may report to a controller (e.g., controller **408** of FIG. **4**) the signal level from each UE communicating therewith, for example, together with a UE identifier such as a basic service set identifier (BSSID) (e.g. the media access control (MAC) address of the wireless access point (WAP) for each UE). If the UE has registered to a sub-optimal AP on an overlapping beam (e.g. at location **811**) or on a sidelobe (e.g. at location **815**), another optimal AP will report a stronger received signal (e.g. at location **810**) than the level reported by the registered AP. The sub-optimal APs associated with overlapping beam **803** or with sidelobe **807** may reject the registration of the UE at beam location **811** or **815**. In one embodiment, the rejected UE may subsequently be instructed to register with the optimal AP associated with beam **802** at beam location **810** (e.g. in accordance with IEEE 802.11k) or may be allowed to continue scanning the channels and register again, iteratively repeating the registration process, until it finds and registers with the optimal AP associated with beam 1L **802**. The latter embodiment may be examined by comparing beam locations **810** and **811**. Since beam location **810** shows a situation in which a UE registers to an AP over the primary lobe of beam 1L **802** providing a greater than threshold relative signal strength relative to the signal strength received over other beams 2R **804** of other APs on the same channel, the registration of the UE to the AP beam 1L **802** may be maintained. For example, when the UE is registered at beam location **810** of beam 1L **802**, the AP associated with beam 1L **802** experiences a relatively higher gain/amplitude (and therefore a higher received signal level) of approximately 11 dB than the received signal by the sidelobe of co-channel beam 2R **804** as indicated by dashed line **813**. However, beam location **811** shows a less desirable situation in which a UE registers to an AP over the primary lobe of adjacent beam 1R **803** providing a less than threshold relative signal strength relative to signals received over beam 2L **801** of the other co-channel AP. For example, when the UE is registered at beam location **811** of beam 1R **803**, the AP associated with beam 1R **803** experiences approximately 6 dB lower gain or SNR indicated by dashed line **814** when its co-channel AP is operating on beam 2L **801**. Accordingly, the registration of the UE to the AP associated with adjacent beam 1R **803** may be rejected.

In one embodiment, rejecting the registration of the UE to a sub-optimal AP may improve signal quality for the UE. In this example the UE may be roaming or located close to a boundary between beams. In conventional systems, as the UE moves closer and closer to the boundary and the signal wors-

ens and worsens, the AP connection is maintained until the connection is so bad that it no longer meets the UE's registration standards. In contrast, according to embodiments of the invention, the AP may end or reject the registration when another non-registered AP provides a relatively higher signal strength than the currently registered AP, for example, before the signal quality degrades to levels below registration standards. Accordingly, the signal strength of the communication between the UE and the registered AP may be reassigned to a better AP in spite of being above the minimum signal strength allowed by the UE's registration standards for being rejected, thereby improving system communication.

According to an embodiment of the invention, a system and method of communicating in a wireless multi-beam network is provided for optimizing signal reception quality in a communication channel between an AP and a UE. Embodiments of the invention may enable the UE to selectively register with an AP when the ratio of the power level of said channel beam to the power level of another (suboptimal) channel or beam, such as a sidelobe of a co-channel beam, satisfies a predefined threshold. A plurality of APs may receive, measure and report to a controller, their respective power levels received from the same UE. The controller may determine if the UE ratio of received signal power levels is within a predefined threshold range. The controller may select an optimal communication channel for the UE based on said threshold determination. The controller may use the predefined threshold of the signal power ratios to select between the signal presented in a desired channel over that of an undesirable channel, as may be present in a sidelobe channel. The controller may determine if the predefined threshold is further defined to be approximately, for example, 6 dB. Other measurements of signal strength ratios may be used.

According to embodiments of the invention, when a UE registers to a system and is detected by only one AP, no re-registration takes place. If the UE is detected by two or more APs (e.g. two in the case of a 4-beam system), the controller may determine if the UE is registered to an optimal or suboptimal beam/channel/AP based on the relative ratio of signal strengths recorded by each AP. If the UE is registered with an AP on a stronger signal, for example, where the ratio of signal strength of the stronger signal to a weaker signal with another AP is greater than a predetermined threshold (e.g., >6 dB), the controller may determine that the UE is registered with the optimal beam/channel/AP and no re-registration takes place. If the UE is registered with an AP on another signal, for example, where the ratio of signal strength of the stronger signal to a weaker signal with another AP is less than a predetermined threshold (e.g., <6 dB), the controller may determine that the UE is registered with a suboptimal beam/channel/AP and may assign the UE to re-register with the AP associated with the stronger signal or another AP. Further, if the UE is registered but the ratio of received signal levels is less than the threshold, the controller may determine that neither beam/AP is ideal, and that another beam/AP may be ideal, which cannot be detected because the UE is registered on a different channel (frequency) than the ideal beam/AP. Accordingly, the AP may reject the sub-threshold registration and re-register either by requiring the UE to re-scan channels to repeat the above steps or may be directly assigned to a new AP (e.g., when using the IEEE 802.11k protocol) and verify the assignment is to the optimal AP/beam by repeating the above steps.

According to some embodiments, in order to support the maximum capability offered by WiFi, 64-quadrature amplitude modulation (QAM) may be used. Systems using 64-QAM typically require at least a −20 dB signal to interference (sidelobe) ratio in order to achieve acceptable performance. As described above, antenna element tapering (e.g., Taylor weighting) may reduce sidelobe interference when the antenna arrays are large (e.g., eight antenna elements or more). A disadvantage of tapering however is it reduces antenna array efficiency thereby lowering the achievable gain. For this reason, systems typically use tapering, which may be insufficient to effectively suppress sidelobe interferences to desired levels. Accordingly, embodiments of the invention may provide a combination of tapering and a signal cancellation technique to reduce sidelobe interference.

Reference is made to FIG. **9**, which schematically illustrates a multi-beam system **900** for tapering and signal cancellation in accordance with an embodiment of the invention. FIG. **9** may include one or more beamforming functions **901** to taper signals to/from a plurality of antennas **902-905** with weights w_1, w_2, w_3 and w_4 **910-913** to transmit/receive a plurality of tapered beams **906-909**, respectively. In addition, beamforming function **901** may use coupling coefficients h_{13}, h_{31}, h_{24} and h_{42}, **914-917** (e.g. complex weighting functions having real and/or imaginary parts) to couple beams **908**, **906**, **909**, and **907**, respectively, for signal cancellation. For example, one beam may be coupled to another beam on the same channel, e.g. h_{13} is used to couple beam **906** with beam **908** and h_{24} is used to coupling beam **907** with beam **909**, for example, to cancel, suppress or reduce the level or strength of the undesired signal being received or transmitted in the sidelobe direction.

Reference is made to FIG. **10**, which schematically illustrates a radiation pattern transmitted by the antenna array of FIG. **9** with and without signal cancellation in accordance with an embodiment of the invention. FIG. **10** shows the radiation gain versus the azimuth of the signal without signal suppression (solid lines) and with tapering and signal cancellation (dashed lines). For clarity, only two co-channel beams are shown, for example, beam 1L **1001** and beam 2R **1002**, although a similar radiation pattern exists for the beams 1R and 2L on the other channel. Lines **1003-1006** identify the subsector boundaries for the two beams **1001** and **1002**.

FIG. **10** shows the level of the sidelobes from one beam in the direction of the other. Trace **1007** identifies the level of beam 2R **1002** in the direction of beam 1L **1001** and trace **1008** identifies the level of the sidelobes of beam 1L **1001** in the direction of beam 2R **1002**, all without signal cancellation. Similarly, trace **1009** identifies the level of beam 2R **1002** in the direction of beam 1L **1001** and trace **1010** identifies the level of the sidelobes of beam 1L **1001** in the direction of beam 2R **1002**, all with signal cancellation. Line **1011** shows the threshold level required for a worst case of sidelobe interference of e.g. −20 dB from the lowest beam gain within the subsector. Shaded areas **1012-1017** define directions that do not meet that criterion.

Reference is made to FIG. **11**, which schematically illustrates a radiation pattern transmitted by the antenna array of FIG. **9** with tapering and selective signal cancellation in accordance with an embodiment of the invention. The radiation plots of FIG. **11** show the gains or amplitudes of the same co-channel beams 1L **1101** and 2R **1102** after tapering of the elements has been applied. In the example shown in FIG. **11**, tapering weights W1-W4 (e.g. **910-913** of FIG. **9**) are 0.7, 1.0, 1.0 and 0.7, respectively. A comparison of the radiation patterns FIG. **10** (without tapering) and FIG. **11** (with tapering) shows that after tapering the primary lobe beam to sidelobe ratio is approximately 16 dB in FIG. **11** compared to the non-tapered ratio of approximately 13 dB in FIG. **10**, which has little or no tapering, and at the subsector boundaries, after tapering the ratio is approximately 13 dB in FIG. **11** com-

pared to the non-tapered ratio of approximately 9 dB in FIG. **10**. Traces **1110** and **1111** correspond to the signal cancellation achieved by a beamformer applying coupling coefficients h_{24} and h_{42} (e.g. **916** and **917** of FIG. **9**) to beams 2R and IL (e.g. **909** and **907** of FIG. **9**), respectively. Traces **1110** and **1111** show that, although the combination of tapering and signal cancellation may increase the primary lobe to sidelobe ratio, the ratio is still less than the 20 dB threshold used to support 64-QAM. Accordingly, additional measures may be used to achieve the 20 dB threshold ratio. One such measure is selective signal cancellation.

FIG. **10** shows that in the direction of beam 1L **1001**, signal cancellation or coupling may reduce the strength of sidelobe signals of co-channel beam 2R from 1007 to 1009 near the boundaries **1003** and **1004** of the 1L subsector. However, near the center of the subsector (e.g. an azimuth range of approximately)75-85°, signal cancellation or coupling adds an interference artifact **1013** for beam 1L **1001** and **1016** for beam 2R **1002** in FIGS. **10** and **1110** and **1111** in FIG. **11**. Thus, signal cancellation may improve the primary lobe to sidelobe ratio near subsector boundaries (in the sidelobe directions), but may worsen the ratio near the subsector center (in the primary lobe direction) where there are typically no significant sidelobes. The benefit of signal cancellation may therefore depend on the location of a UE in the subsector. Accordingly, embodiments of the invention may selectively activate signal cancellation based on the UE location. When the UE is near the subsector boundaries and sidelobe interference is above a threshold ratio, beamformer may apply signal cancellation. However, when the UE is near the subsector center and sidelobe interference is below a threshold ratio, beamformer may not apply signal cancellation. To determine the level of sidelobe interference and thus the location of the UE, embodiments of the invention may conduct a signal cancellation test, turning signal cancellation on and then off, to determine whether or not interference is reduced or increased by the signal cancellation. If interference is reduced, signal cancellation may be turned on for continued communication with the UE, while if interference is increased, signal cancellation may be turned off.

Reference is made to FIG. **12**, which schematically illustrates a multi-beam system **1200** for selective signal cancellation using digital beamforming in accordance with an embodiment of the invention. A UE signal may be received by two or more APs, for example, over beam 1L **1101** and beam 2R **1102** of FIG. **11**, where one is received on a sidelobe. In one example configuration, the signal received over beam 1L **1101** is stronger than that received over beam 2R **1102**, although a corresponding technique applies if the beam 2R **1102** signal is stronger than that the beam 1L **1101** signal. System **1200** may provide a test to determine if signal cancellation is effective or not. In one step, signal cancellation may be turned off and the beamformer may not activate a coupling coefficient h_{24} **916** of FIG. **9**. When signal cancellation is off, a radiation pattern may reveal the sidelobe patterns **1112** and **1113** of beam 2R **1102** shown in FIG. **11** in which a UE is not in the direction of the center of the beam 1L **1101** (e.g. an azimuth range of)75-85° but in a location either to the right of the beam center at **1113** (e.g. an azimuth range of)60-75° or to the left of the beam center at sidelobe **1112** (e.g. an azimuth range of)85-90° because the sidelobe level in the direction of the center of beam 1L **1101** is nearly null (zero). In another step, coupling may be turned on and the beamformer may activate the coupling coefficient h_{24} **916** of FIG. **9**. When signal cancellation is on, a radiation pattern may reveal a UE located in the direction of the center of beam 1L **1101** because the signal cancellation pattern of trace **1110** of FIG. **11** shows that the sidelobe level of beam 2R **1102** is high in the direction of the center of beam 1L **1101** and not off center.

According to one embodiment of the invention, each AP may use the two on/off signal cancellation modes to test whether or not to activate signal cancellation by measuring and recording the better performing mode (e.g. whether interference was lower with coupling coefficient h_{24} **916** on or off). Each AP may identify which signals are from each UE by the signal's UE identification code (e.g., MAC address). Subsequently after an AP (e.g. AP #2 **1209** assigned to beam 1L of FIG. **12**) receives signals from a UE in both on and off modes and identifies the preferred mode, the AP informs the controller (e.g. controller **1203** of FIG. **12**) of the preferred mode (e.g. turn coupling coefficient h_{24} **916** of FIG. **9** on or off) that produces the best performance when receiving UE signals (e.g. with beam 2R **1102** of FIG. **11**). If neither mode with coupling coefficient h_{24} **916** on or off reduces the UE signal received by two beams/APs, the UE may be too close to the antenna array(s). In such cases, the UE may be assigned to communicate with an alternate AP/channel using an antenna that covers the whole sector.

In another embodiment, once the aforementioned UE has been identified, the controller **1203** may command the logical block element **1207** to perform real time cancellation or suppression of the specific UE signal component received in beam 2R **1102** from that UE based on filtering and cancelling using finite impulse response (FIR) and correlation techniques, and the stronger signal received in beam 1L **1101**.

Embodiments of the invention may reduce interference from the sidelobes of beam 2R **1102** for UEs located in the direction of beam 1L **1101**, which may reduce the UE signal strength received at the AP #4 **1210** assigned to beam 2R **1102**. Such embodiments may similarly apply to the alternate beam by substituting h_{42} **917** for h_{24} **916**, beam 2R **1102** for 1L **1101** and beam 1L **1101** for beam 2R **1102** to reduce interference from the sidelobes of beam 1L **1101** for UEs located in the direction of beam 2R **1102**, which may reduce the UE signal strength received at the AP #2 **1209** assigned to beam 1L **1101**.

According to an embodiment of the invention, a system and method is provided for using a controller to select an optimal channel and/or beam in a wireless network. Entry of a UE may be detected in a sector that contains a plurality of beams for communicating with a plurality of access points. A suboptimal UE registration may be determined within an AP's beam subsector. A more optimal reception channel may be selected using a predefined algorithm directed to the slope of a selected beam. An optimal communication channel may be selected by comparing the offered signal quality available to a UE by using said controller to assess the effect of selectively applying signal cancellation methods to/at the access points. An optimal communication channel may be selected when in the presence of both a desired beam and a sidelobe beam. The impact of applying signal cancellation methods may be determined by selectively activating and deactivating beam to beam signal coupling or signal cancellation using coupling coefficients, for example, h_{13}, h_{31}, h_{24} and h_{42}.

Traces **1110** and **1111** of FIG. **11** show that when applying signal cancellation according to embodiments of the invention, the sidelobe ratio is rarely worse than −20 dB and has a worse case of −17 dB for only a small percentage of directions. According to an alternative embodiment of the invention, signal cancellation may be applied continuously to sufficiently reduce the sidelobe ratio to below threshold (e.g. −20 dB) in most cases, leaving a small percentage of cases in which the sidelobe ratio is above threshold. However, this −20

dB threshold may be required for only some types of modulation (e.g. 64-QAM). Accordingly, in one embodiment, some UEs located in below threshold directions may communicate with less efficient modulation. In another embodiment, APs may detect and record the modulation used by each UE, and may apply selective signal cancellation for modulations requiring a relatively higher range of the sidelobe rejection ratios (e.g. 64-QAM requiring greater than a 20 dB ratio) and apply continuous signal cancellation for modulations requiring a lower range of the sidelobe ratios (e.g. 16-QAM requiring greater than approximately a 14 dB ratio).

According to an embodiment of the invention, a system and method is provided for operating a controller in a wireless network. Embodiments of the invention may include detecting the entry of a UE in a sector containing a plurality of beam spaces offered by a plurality of access points. Signal cancellation may be continuously, indiscriminately or non-selectively applied to all signals, for example, upon detecting a received signal cancellation indicator from said controller identifying the presence of a sidelobe channel. Embodiments of the invention may include allocating any UE with a less that optimal signal power to an alternate access point. Embodiments of the invention may include detecting the modulation of each UE and may apply selective signal cancellation only to UEs operating in 64 QAM mode and continuous signal cancellation to UEs operating in all other modulations, for example, allowing higher sidelobe interference.

The signal strength information gathered and recorded from each UE during reception periods by an AP may be used to reduce interference during transmission periods. Referring to FIGS. **11** and **12**, when AP #4 **1210** associated with beam 2R **1102** transmits signals, the signal radiation from sidelobes **1112** and **1113** may cause interference with transmissions by AP #2 **1209** to UEs in the subsector covered by beam 1L **1101**. When an AP is transmitting on beam 2R with AP #4, and AP #2 is attempting to communicate to a UE in its subsector using beam 1L, the system may use the information previously measured and recorded that estimated the advantage or disadvantage of coupling for the UE to instruct the logical block element whether or not to apply signal suppression or cancelling. For example, if during a reception period, an AP determines that when receiving signals from the UE on beam 1L signal cancellation using coupling coefficients h_{24} **916** substantially suppressed reception on that beam by AP #4, the coupling signal h_{42} **917** may be used for the transmission to prevent transmissions of beam 2R from interfering with transmissions to that UE on beam 1L. As the system prepares to send data to a specific UE, the controller checks its stored profile on that specific UE, determining various parameters for that UE including the negotiated data rate. As part of that decision logic, the system controller may determine if applying signal cancellation is appropriate and, if so, instructs the logical block element of the upcoming transmission and duration of the transmission, for example, as indicated in a network allocation vector (NAV) counter. The system controller may then create a datagram or other communication unit to send to the UE as soon as other conditions such as clear channel assessment (CCA) are satisfied. The system controller may create signal cancellation information in advance of actually transmitting the datagram. The optimal time for the logical block element to implement signal cancellation, or not, may be coincident with or simultaneous to the transmission of the signal. This optimum time may be achieved by the AP generating a timing strobe coincident with the data transmission. The logical block element may initiate signal cancellation, or not, coincident with this timing strobe, for example, for the duration of the NAV value. A near optimal timing by the logical block element may occur if the logical block element cancels or does not cancel the signal within several microseconds (μ sec) of the actual transmission by the UE. There is typically no significant degradation of the signal if the signal cancellation is early. If the signal cancellation is late, a signal preamble may experience a reduced signal-to-interference-plus-noise ratio (SINR). However, since the preamble is typically sent at a much lower modulation rate, the impact may be negligible. Further, data frames transmitted/received in the signals may include forward error correction (FEC) bits, which may be used to correct any errors caused by delayed signal cancellation to prevent retransmission.

According to an embodiment of the invention, a system and method is provided for optimizing reception quality in a wireless network between an access point and a user equipment apparatus. Embodiments of the invention may include detecting entry of a user equipment in a sector covered by a plurality of beams provided by a plurality of access points, measuring and determining the effect of applying signal cancellation methods for said user equipment, reporting to the controller the specific identifiers of said user equipment prior to transmission, allowing the controller to select an optimal signal cancellation function or coupling coefficients hij to apply during receive intervals as a function of the received signal over each beam i to the received signal over each beam j, and applying signal cancellation during transmit intervals as an inverse or transpose of coupling coefficients hji when transmitting over both beams i and j. The coupling coefficients h_{ji} for signal cancellation may be applied coincident with the transmission over beams and j. Embodiments of the invention may include continually applying said method to all user equipment. Embodiments of the invention may include allocating any user equipment with less that optimal signal power to an alternate access points. Embodiments of the invention may include detecting a user equipment operating in 64 QAM mode, applying selective signal cancellation methods only to those user equipment operating in 64 QAM mode.

Reference is made to FIG. **13**, which schematically illustrates a multi-beam system **1300** for selective signal cancellation using digital beamforming in accordance with an embodiment of the invention. System **1300** may include separate receive and transmit antenna arrays **1301** and **1302** as described in reference to FIG. **4**. System **1300** may include a plurality of radios **1308** to process RF signals at antenna arrays **1301** and **1302**. Radios **1308** may include a plurality of upconverters (UC) A, B and C and downconverters (DC) A, B and C to support a plurality of (e.g. N=3) channels. "UC A" and "DC A" may provide communication over one channel A assigned to two or more access points (e.g., AP #1 and AP #3). "UC B" and "DC B" may provide communication over another channel B assigned to two or more other access points (e.g., AP #2 and AP #4). The plurality of APs (e.g. AP #1-AP #4) may generate a multi-beam system subdividing an area of coverage (e.g. area **225** of FIG. **2**) into a plurality of subsector zones or beams over which the APs may independently communicate with UEs. Adjacent beams may operate over alternating channels A and B to minimize interference at zones boundaries, as described in reference to FIG. **7**. According to an embodiment of the invention, an additional access point (e.g., AP #5) may provide a sector beam spanning across the entire area (or at least across multiple subsector zones). The additional access point may operate on an independent channel C different from channels A and B, for example, to avoid interference with overlapping beams associated with other APs 1-4. In the example shown in FIG. **13**, a logical block

element such as the FPGA **1307** may connect the signals from all antenna elements in arrays **1301** and **1302** with UC C and DC C to form the sector beam. In another embodiment, only one of the antenna elements (e.g. an outer-most element) may be used to form the sector beam, which may be operated at reduced power case because of tapering for the other channels A and B.

Reference is made to FIG. **14**, which is a flowchart of a method in accordance with an embodiment of the invention. Operations described in reference to FIG. **14** may be executed using one or more processor(s) disposed in devices shown in FIGS. **7**, **9**, **12** and/or **13**, such as, controllers **408**, **708**, **1203** and/or **1303** and/or APs **401**, **701**, **1209**/**1210** and/or AP#1-5 of FIG. **13**.

In operation **1410**, a processor may receive an indication that each of a plurality of APs have each received a signal or transmission from the same user equipment (UE) over the same channel. The UE reception is with each AP over an associated beam. The UE may communicate with an optimal AP over a primary lobe providing relatively higher signal strength or suboptimal APs over one or more surrounding sidelobes providing relatively lower signal strength. The AP may identify a signal from the UE by receiving an associated UE identifier such as a BSSID in the signal.

In operation **1420**, a processor may determine that the first one of the plurality of APs to satisfy registration requirements associated with the UE may register the UE. The first registered AP may be an optimal or suboptimal AP.

In operation **1430**, each AP may report to the processor information related to the signal strength of communication received at the AP from the UE. Depending on the relative signal strengths received at each AP, a process or processor may proceed to operation **1440** or **1450**.

In operation **1440**, if the controller determines that the signal strength received at the registered AP is greater than the signal strength received at one or more of the non-registered APs by more than a threshold amount, the processor may maintain the registration between the UE and AP in operation **1420**. The registered AP may receive such an above threshold relative signal strength when the UE communicates with the registered AP over a primary lobe.

In operation **1450**, if the controller determines that the signal strength received at the registered AP is not greater than (e.g. less than or equal to) the signal strength received at one or more of the non-registered APs by a threshold amount, the processor may reject the registration between the UE and AP in operation **1420**. The non-registered AP may receive such a signal strength when the UE communicates with the non-registered AP over a primary lobe and the registered AP over a sidelobe.

A process or processor may proceed to operation **1460** if the UE is capable of being directed to a specific AP, for example, operating according to the IEEE 802.11k protocol. For such a UE, a processor may direct the UE to re-register or associate with a non-registered AP that receives signals from the UE having a signal strength that is greater than the signal strength received at the registered APs by more than a threshold amount. Accordingly, the condition of operation **1440** is satisfied and the process or processor ends. Otherwise, process or processor may proceed to operation **1470**.

In operation **1470**, a processor may direct the AP to reject registration of the UE to the registered AP by either denying the UE ability to register (e.g. authenticate) or by sending the UE a de-authentication message.

In operation **1480**, the UE may re-scan the channels, repeating the above operations **1410**-**1430** to iteratively re-register with a new AP until the UE re-registers with an AP receiving an above threshold relative signal strength at operation **1440** and the process or processor ends.

Reference is made to FIG. **15**, which is a flowchart of a method in accordance with an embodiment of the invention. Operations described in reference to FIG. **15** may be executed using one or more processor(s) disposed in devices shown in FIGS. **7**, **9**, **12** and/or **13**, such as, controllers **408**, **708**, **1203** and/or **1303** and/or APs **401**, **701**, **1209**/**1210** and/or AP#1-5 of FIG. **13**.

In operation **1510**, a processor may receive an indication that a signal is received from a single user equipment (UE) at each of two or more APs over the same channel. A relatively stronger power signal may be received over a primary lobe of a communication beam of one of the APs and a relatively weaker power signal may be received over a sidelobe of a communication beam of another one of the APs.

In some embodiments, a processor may detect the signal modulation of the UE's signal. In operation **1520**, the processor may apply continuous signal cancellation if the modulation allows a below threshold interference level (e.g. 16-QAM requires greater than approximately a 14 dB SNR, but less than a threshold of 20 dB SNR). In operation **1530**, the processor may apply the selective signal cancellation of operations **1550**-**1560** or **1570** if the modulation requires an above threshold maximum interference level (e.g. 64-QAM requires greater than the threshold of 20 dB SNR). Operations in **1520**-**1540** may be optional. In other embodiments, selective signal cancellation is automatically used and no modulation is detected.

In operation **1550**, a processor may test the efficacy of signal cancellation by turning signal cancellation on and off to measure the UE signals at the registered AP or other APs.

In operation **1560**, if interference at the AP is lower when signal cancellation is turned on, a processor may apply said signal cancellation for continued communication with said UE. The processor may apply signal cancellation to suppress sidelobe signals if the UE is determined to communicate over a sidelobe, but not applying signal cancellation if the UE is determined to communicate over a primary lobe. The processor may apply said signal cancellation by modulating the signals by coupling coefficients h_{ij} of each beam i signal to each beam j signal.

In operation **1570**, if interference is lower when signal cancellation is turned off, a processor may communicate with said UE without applying said signal cancellation.

In some embodiments, in optional operation **1580**, if a greater than threshold amount of interference is experienced when signal cancellation is both on and off, a processor may control an additional AP to provide an additional channel of coverage, for example, using an antenna that covers an entire sector serviced by the two or more APs.

Other operations or orders of operations may be used.

According to an embodiment of the invention, a system and method is provided for operating a wireless network. Embodiments of the invention may provide additional sector coverage by allocating an additional access point upon detecting conditions indicating a use for additional coverage.

As will be appreciated by one skilled in the art, signal or sidelobe suppression, cancellation or reduction may refer to reducing interference e.g. due to sidelobe or other noise, to a below threshold amount or ratio such as SINR or a ratio of sidelobe gain to primary lobe gain. The threshold may be specified according to a communication standard, modulation standard, or other device or network requirement, and may allow some interference e.g. below a threshold level. For

example, signal cancellation of a signal may only reduce, suppress, or partially cancel interference, noise or sidelobe artifacts.

As will be appreciated by one skilled in the art "selective signal cancellation" may refer to activating or deactivating signal cancellation based on a condition related to the efficacy of the signal cancellation, e.g., if signal cancellation reduces signal interference or reduces said interference by an amount greater than when no signal cancellation is used. In contrast, "continuous signal cancellation" may refer to activating signal cancellation without testing or predicting the efficacy of the signal cancellation. Continuous signal cancellation may be activated, for example, based on a condition unrelated to interference, such as, the signal modulation or device, network or communication standards.

As will be appreciated by one skilled in the art, aspects of the present invention may be embodied as a system, method or an apparatus. As such, any limitations commonly associated with the term "FPGA" should not be construed to be implementation technology specific; rather it may be embodied in any logical apparatus. Accordingly, aspects of the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system."

In some embodiments, access points (e.g., APs **401**, **701**, **1209**/**1210** and/or AP#1-5 of FIG. **13**) may passively transfer signal information from UE to a controller (e.g. controller **408**, **708**, **1203** and/or **1303**), which compares relative signal strengths between APs to thresholds, makes decisions regarding relative signal strength, determines whether to maintain or reject registration between UEs and APs for selective registration, and determines whether to apply signal cancellation. In another embodiment, such operations may be executed by another device in FIGS. **7**, **9**, **12** and/or **13**, for example, access points (e.g., APs **401**, **701**, **1209**/**1210** and/or AP#1-5 of FIG. **13**). In various embodiments, the processor(s) executing the operations of FIGS. **14** and **15** may be located, in part or in whole, in one or more controllers such as a base station controller (BSC) or other centralized network device, or in one or more APs or base stations (BSs).

The aforementioned block diagrams illustrate the architecture, functionality, and operation of possible implementations of systems and methods according to various embodiments of the present invention. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

In the above description, an embodiment is an example or implementation of the inventions. The various appearances of "one embodiment," "an embodiment" or "some embodiments" do not necessarily all refer to the same embodiments.

Although various features of the invention may be described in the context of a single embodiment, the features may also be provided separately or in any suitable combination. Conversely, although the invention may be described herein in the context of separate embodiments for clarity, the invention may also be implemented in a single embodiment.

Reference in the specification to "some embodiments", "an embodiment", "one embodiment" or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments, of the inventions.

It is to be understood that the phraseology and terminology employed herein is not to be construed as limiting and are for descriptive purpose only.

The principles and uses of the teachings of the present invention may be better understood with reference to the accompanying description, figures and examples.

It is to be understood that the details set forth herein do not construe a limitation to an application of the invention.

Furthermore, it is to be understood that the invention can be carried out or practiced in various ways and that the invention can be implemented in embodiments other than the ones outlined in the description above.

It is to be understood that the terms "including", "comprising", "consisting" and grammatical variants thereof do not preclude the addition of one or more components, features, steps, or integers or groups thereof and that the terms are to be construed as specifying components, features, steps or integers.

If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

It is to be understood that where the claims or specification refer to "a" or "an" element, such reference is not be construed that there is only one of that element.

It is to be understood that where the specification states that a component, feature, structure, or characteristic "may", "might", "can" or "could" be included, that particular component, feature, structure, or characteristic is not required to be included.

Where applicable, although state diagrams, flow diagrams or both may be used to describe embodiments, the invention is not limited to those diagrams or to the corresponding descriptions. For example, flow need not move through each illustrated box or state, or in exactly the same order as illustrated and described.

Methods of the present invention may be implemented by performing or completing manually, automatically, or a combination thereof, selected steps or tasks.

The term "method" may refer to manners, means, techniques and procedures for accomplishing a given task including, but not limited to, those manners, means, techniques and procedures either known to, or readily developed from known manners, means, techniques and procedures by practitioners of the art to which the invention belongs.

The descriptions, examples, methods and materials presented in the claims and the specification are not to be construed as limiting but rather as illustrative only.

Meanings of technical and scientific terms used herein are to be commonly understood as by one of ordinary skill in the art to which the invention belongs, unless otherwise defined.

The present invention may be implemented in the testing or practice with methods and materials equivalent or similar to those described herein.

While the invention has been described with respect to a limited number of embodiments, these should not be con-

strued as limitations on the scope of the invention, but rather as exemplifications of some of the preferred embodiments. Other possible variations, modifications, and applications are also within the scope of the invention. Accordingly, the scope of the invention should not be limited by what has thus far been described, but by the appended claims and their legal equivalents.

The invention claimed is:

1. A method for selective registration of a user equipment (UE) to one of a plurality of access points (APs) in a multi-beam system, the method comprising:

receiving an indication that each of a plurality of APs have received a signal from a single UE, wherein the UE communicates with each AP over an associated beam that includes a primary lobe providing a relatively higher signal strength surrounded by one or more sidelobes providing a relatively lower signal strength;

registering the UE to a first one of the plurality of APs that satisfies registration requirements associated with the UE; and

maintaining the registration of the UE to the registered AP if the UE communicates with the registered AP over a primary lobe providing a greater than threshold relative signal strength relative to the other APs, or

rejecting the registration of the UE to the registered AP if the UE communicates with the registered AP over a sidelobe or over a primary lobe providing a less than threshold relative signal strength relative to the other APs.

2. The method of claim **1** comprising receiving a report from each of the plurality of APs including information related to the signal strength of communication between each AP and the UE and a UE identifier uniquely identifying the UE.

3. The method of claim **1**, wherein the relative signal strength for each AP is a ratio of the amplitude of signals communicated between the UE and the AP over the amplitude of signals communicated between the UE and another AP.

4. The method of claim **1**, wherein the relative signal strength for each AP is a signal-to-noise ratio (SNR) or a signal-to-interference-plus-noise ratio (SINR).

5. The method of claim **1** comprising, if the registration is rejected, registering the UE to the AP having the highest relative signal strength.

6. The method of claim **1** comprising, if the registration is rejected, said selective registration method of claim **1** is iteratively repeated until the UE provides a greater than threshold relative signal strength.

7. The method of claim **1**, wherein the registration is rejected before the signal quality degrades to levels below registration standards.

8. A system for selective registration of a user equipment (UE) to one of a plurality of access points (APs) in a multi-beam system, the system comprising:

a processor adapted to:

receive an indication that each of a plurality of APs have received a signal from a single UE, wherein the UE communicates with each AP over an associated beam that includes a primary lobe providing a relatively higher signal strength surrounded by one or more sidelobes providing a relatively lower signal strength,

register the UE to a first one of the plurality of APs that satisfies registration requirements associated with the UE, and

maintain the registration of the UE to the registered AP if the UE communicates with the registered AP over a primary lobe providing a greater than threshold relative signal strength relative to the other APs, or

reject the registration of the UE to the registered AP if the UE communicates with the registered AP over a sidelobe or over a primary lobe providing a less than threshold relative signal strength relative to the other APs.

9. The system of claim **8**, wherein the processor is adapted to receive a report from each of the plurality of APs including information related to the signal strength of communication between the AP and the UE and a UE identifier uniquely identifying the UE.

10. The system of claim **8**, wherein the relative signal strength for each AP is a ratio of the amplitude of signals communicated between the UE and the AP over the amplitude of signals communicated between the UE and another AP.

11. The system of claim **8**, wherein the relative signal strength for each AP is a signal-to-noise ratio (SNR) or a signal-to-interference-plus-noise ratio (SINR).

12. The system of claim **8**, wherein if the registration is rejected, the processor is adapted to register the UE to the AP having the highest relative signal strength.

13. The system of claim **8**, wherein if the registration is rejected, the UE is allowed to iteratively repeat said selective registration until the UE provides a greater than threshold relative signal strength.

14. The system of claim **8**, wherein the processor is adapted to reject the registration before the signal quality degrades to levels below registration standards.

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