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(12) **United States Patent**
Abdelmonem et al.

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(45) **Date of Patent: Feb. 23, 2016**

(54) **METHOD AND APPARATUS FOR INTERFERENCE MITIGATION UTILIZING ANTENNA PATTERN ADJUSTMENTS**

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(73) Assignee: **ISCO INTERNATIONAL, LLC**, Schaumburg, IL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 92 days.

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(51) **Int. Cl.**
H04W 28/04 (2009.01)
H04W 72/08 (2009.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04W 28/048*** (2013.01); ***H04B 1/1036*** (2013.01); ***H04B 1/709*** (2013.01); ***H04B 1/71*** (2013.01); ***H04B 1/7103*** (2013.01); ***H04B 15/00*** (2013.01); ***H04B 17/00*** (2013.01); ***H04B 17/26*** (2015.01); ***H04B 17/345*** (2015.01); ***H04L 5/0026*** (2013.01); ***H04L 5/0073*** (2013.01); ***H04W 24/08*** (2013.01); ***H04W 52/04*** (2013.01);

(Continued)

(58) **Field of Classification Search**
CPC H04W 72/082; H04W 72/0426; H04B 1/1027
USPC 455/63.1
See application file for complete search history.

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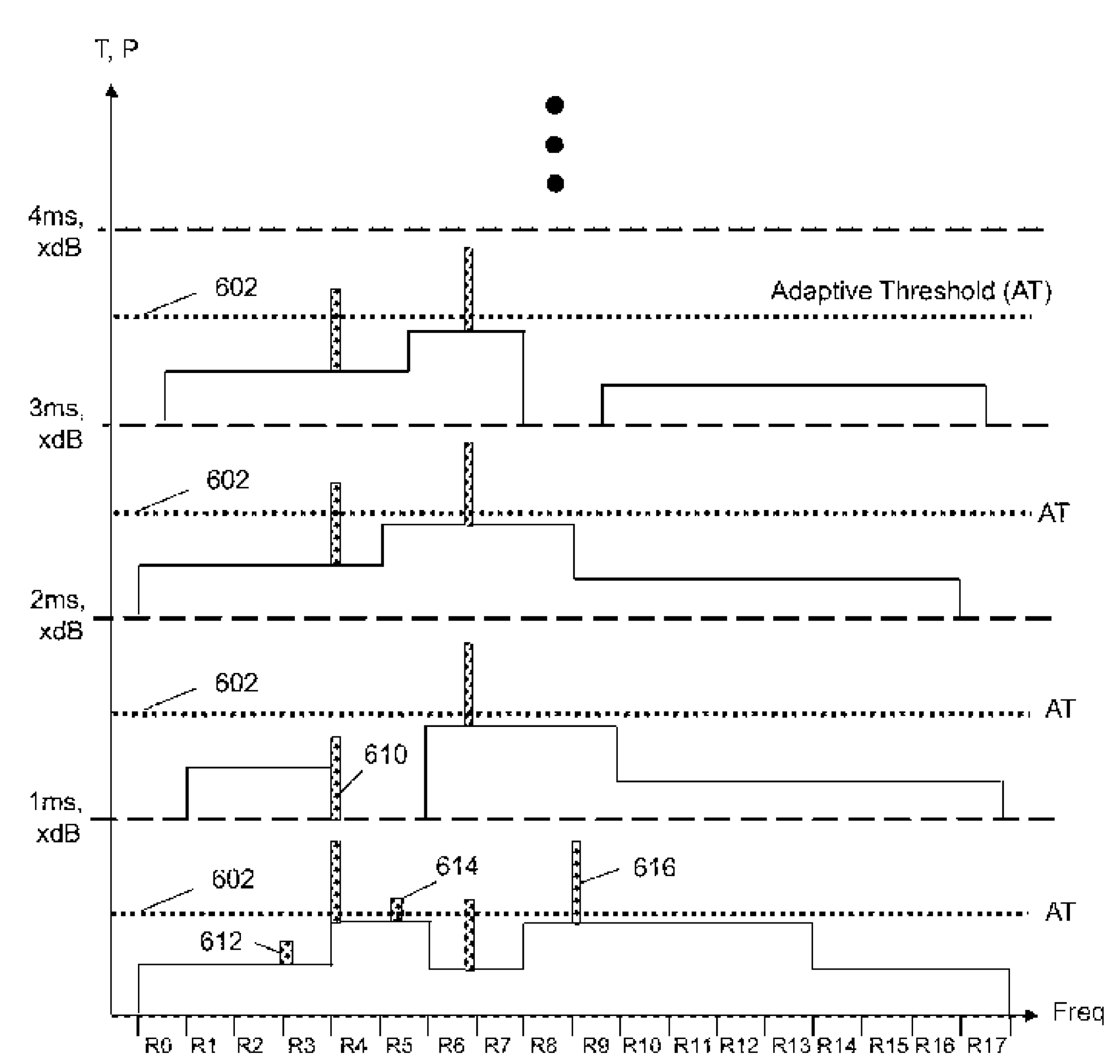
Assistant Examiner — Ernest Tacsik
(74) *Attorney, Agent, or Firm* — Guntin & Gust, PLC; Ed Guntin

(57) **ABSTRACT**

A system that incorporates the subject disclosure may perform, for example, a method for receiving interference information, identifying a plurality of interferers, approximating a location of the plurality of interferers, and adjusting an antenna pattern of an antenna. The method can include determining traffic loads and adjusting the antenna pattern according to the traffic loads. Other embodiments are disclosed.

20 Claims, 26 Drawing Sheets



(51) **Int. Cl.**

H04L 5/00	(2006.01)
H04B 1/709	(2011.01)
H04B 1/7103	(2011.01)
H04B 15/00	(2006.01)
H04W 24/08	(2009.01)
H04W 64/00	(2009.01)
H04B 17/00	(2015.01)
H04W 52/04	(2009.01)
H04B 1/10	(2006.01)
H04B 1/71	(2011.01)
H04B 17/26	(2015.01)
H04B 17/345	(2015.01)
H04W 72/04	(2009.01)

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

CPC ***H04W 64/00*** (2013.01); ***H04W 64/006*** (2013.01); ***H04W 72/0446*** (2013.01); ***H04W 72/0453*** (2013.01); ***H04W 72/082*** (2013.01); ***H04W 72/085*** (2013.01); *H04L 5/006* (2013.01)

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WO	WO2009/019074		2/2009
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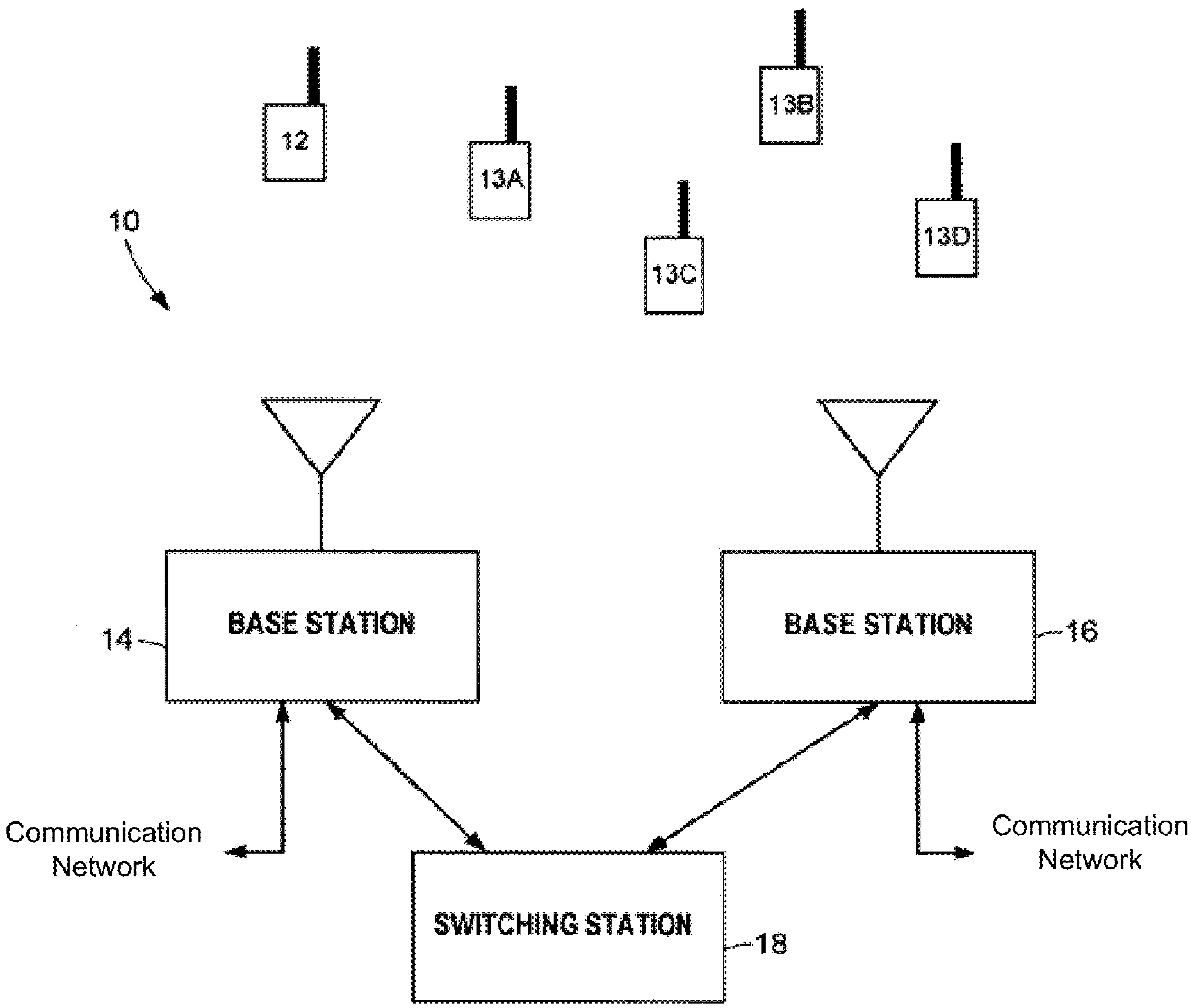

12
13A
13B
13C
13D
10
BASE STATION
14
BASE STATION
16
Communication Network
Communication Network
SWITCHING STATION
18

FIG. 1

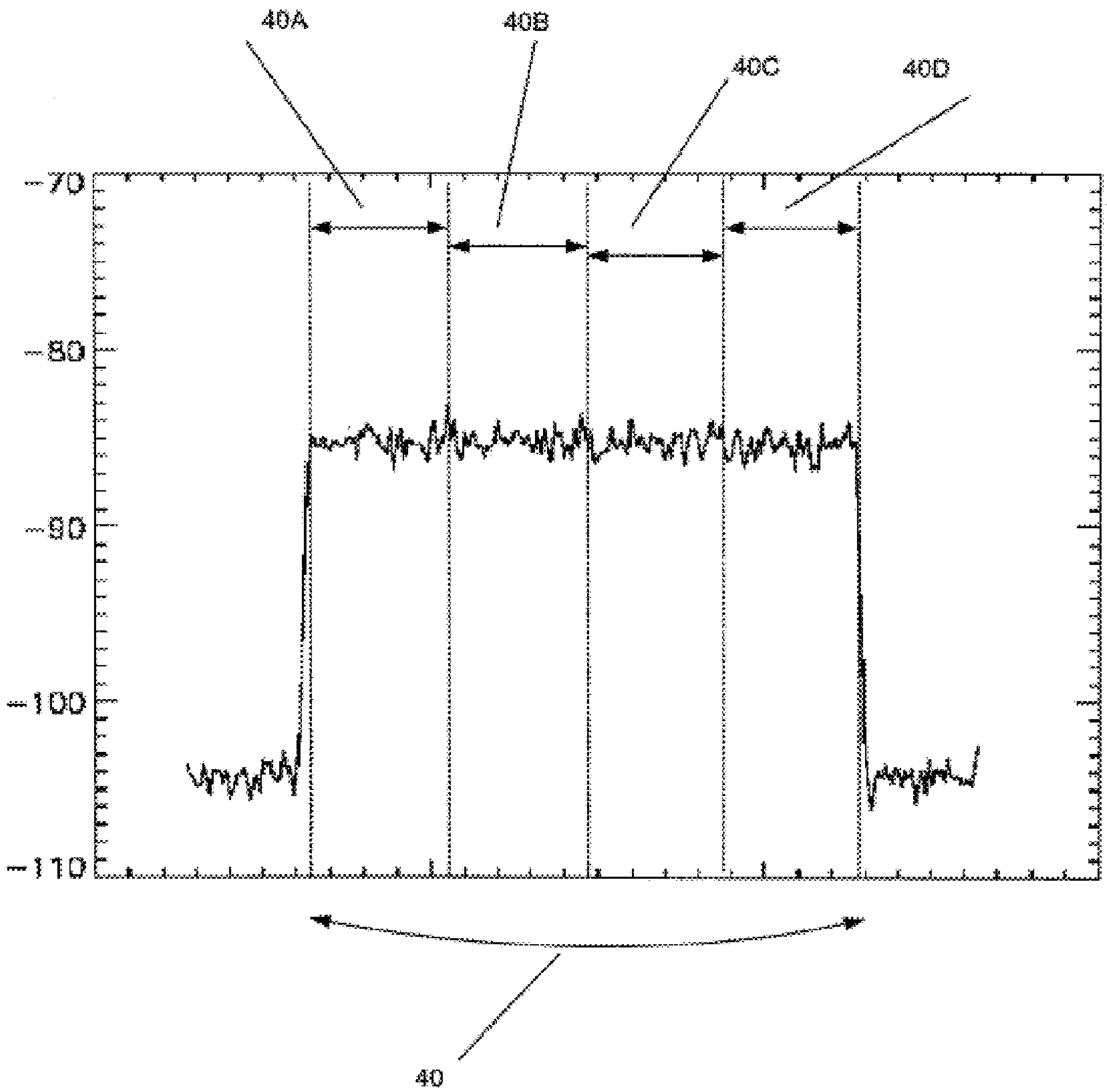


FIG. 2

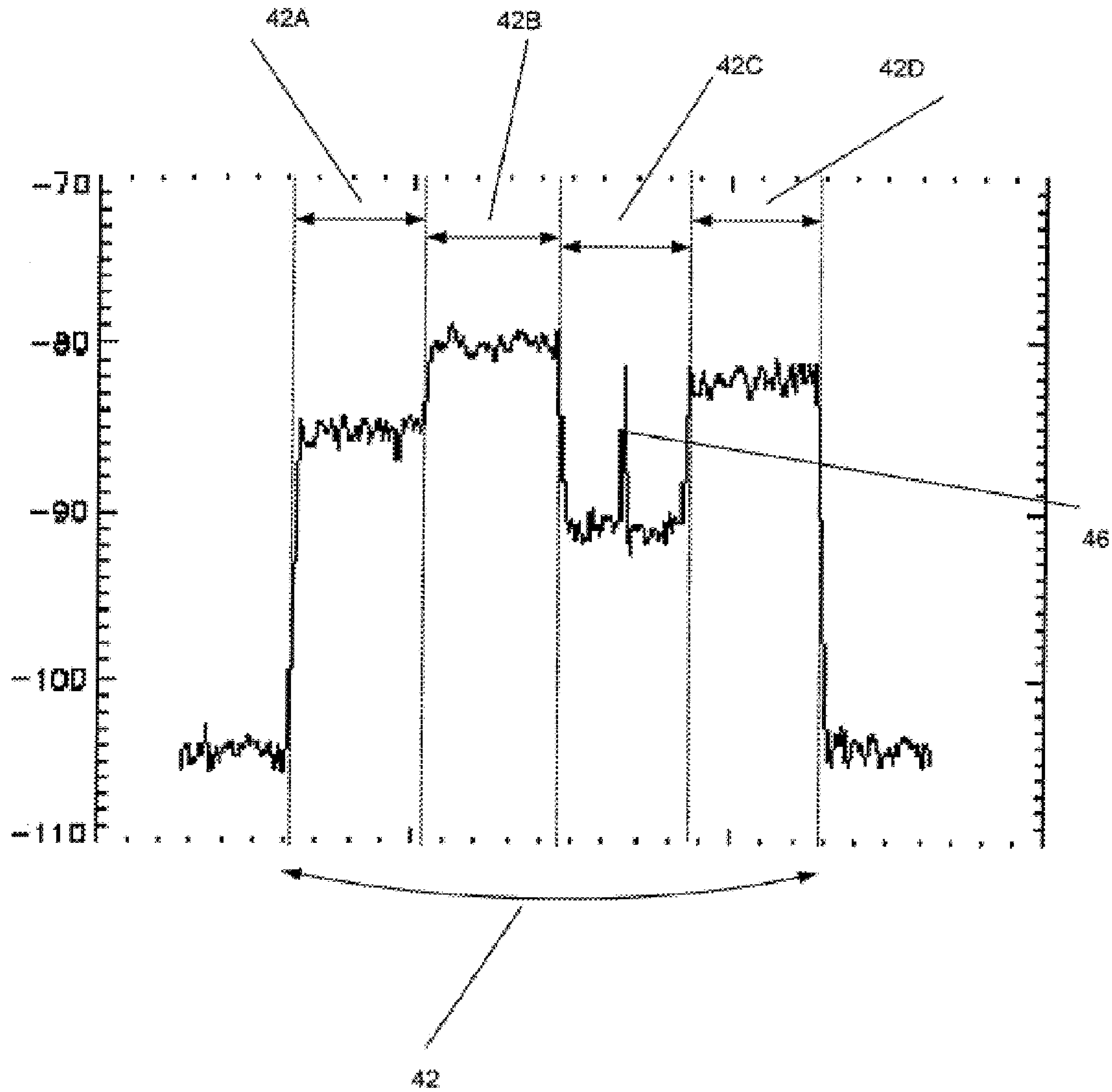


FIG. 3

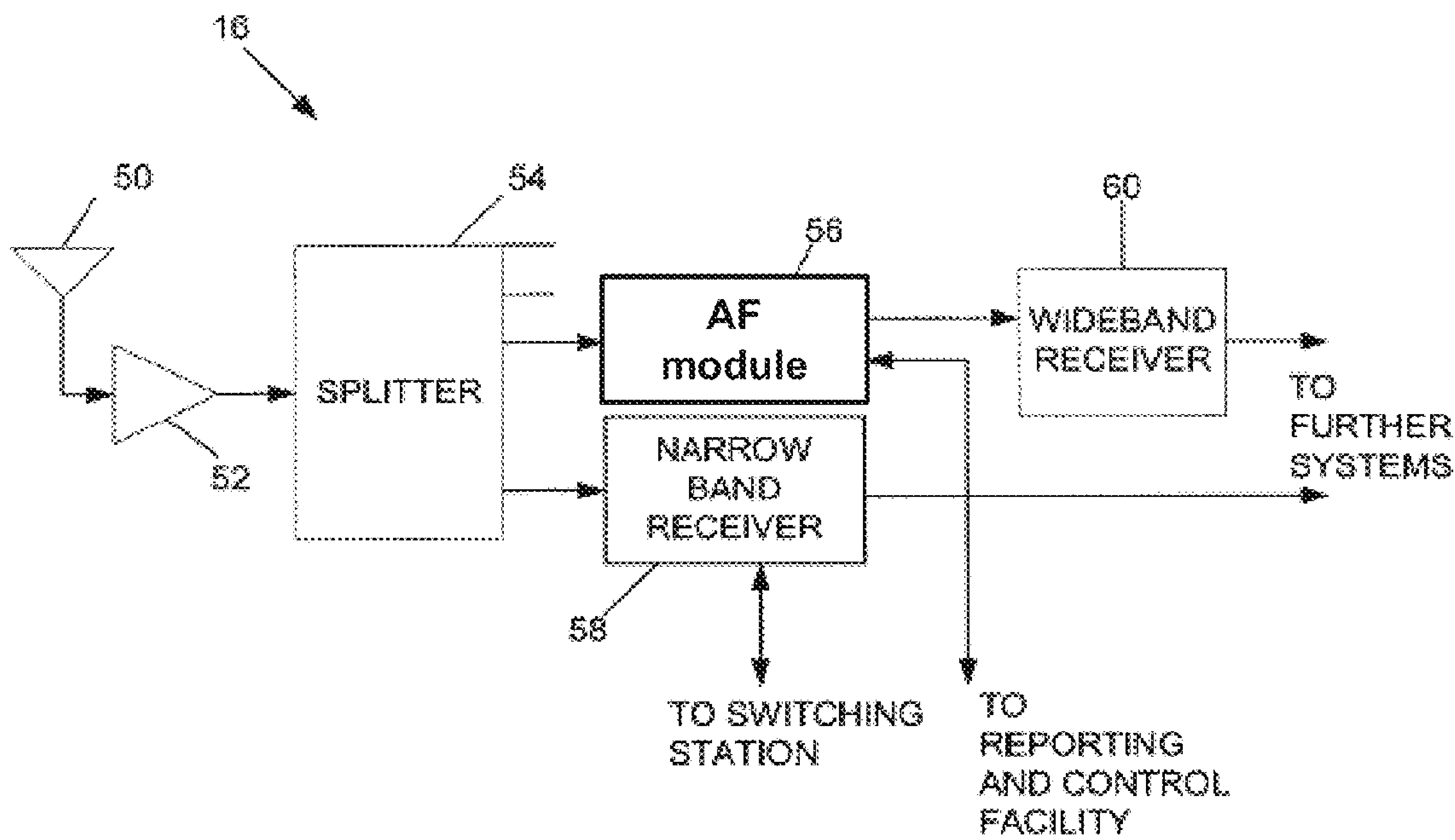

16
50
54
56
60
AF module
WIDEBAND RECEIVER
SPLITTER
52
NARROW BAND RECEIVER
TO FURTHER SYSTEMS
58
TO SWITCHING STATION
TO REPORTING AND CONTROL FACILITY

FIG. 4

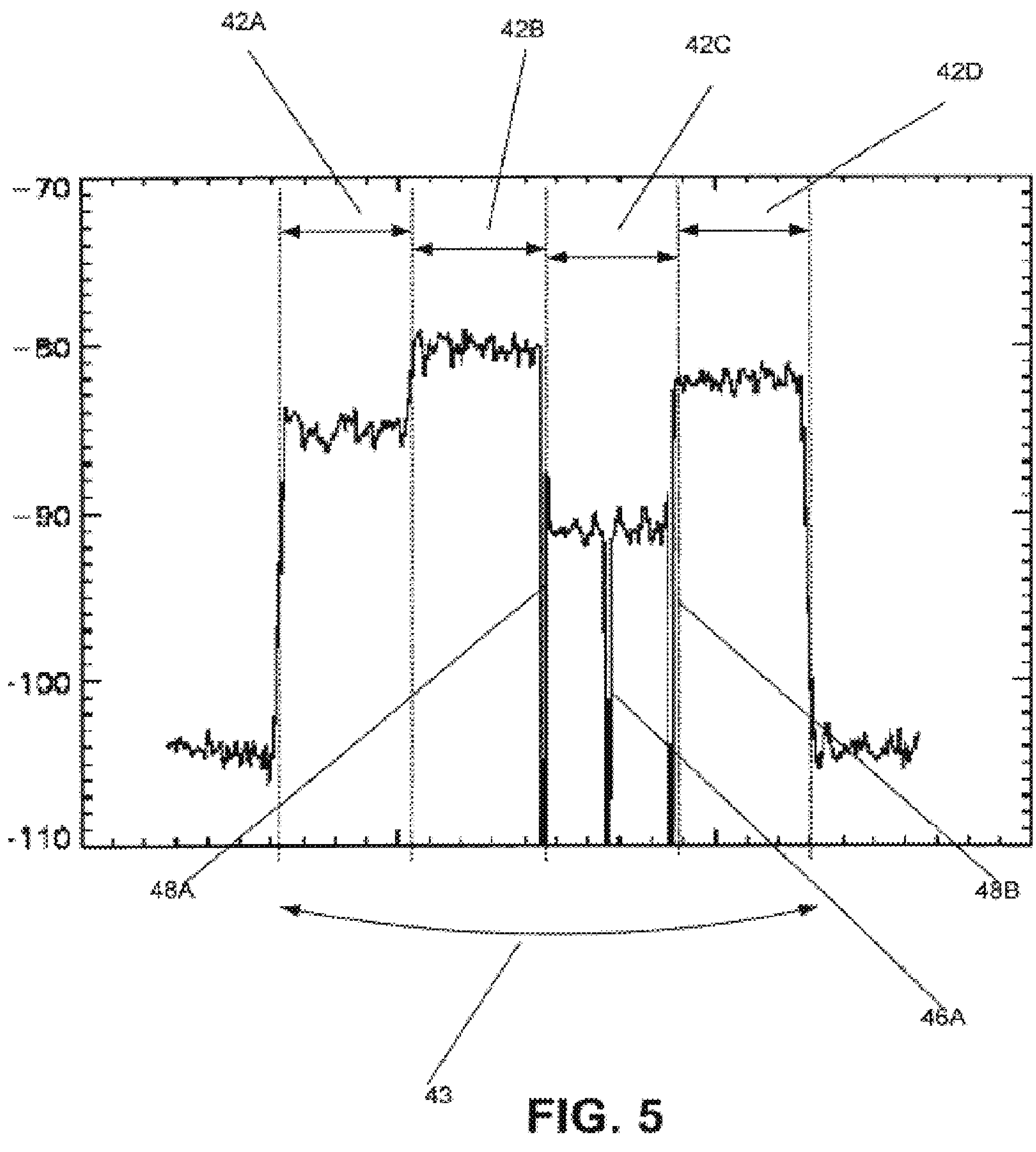


FIG. 5

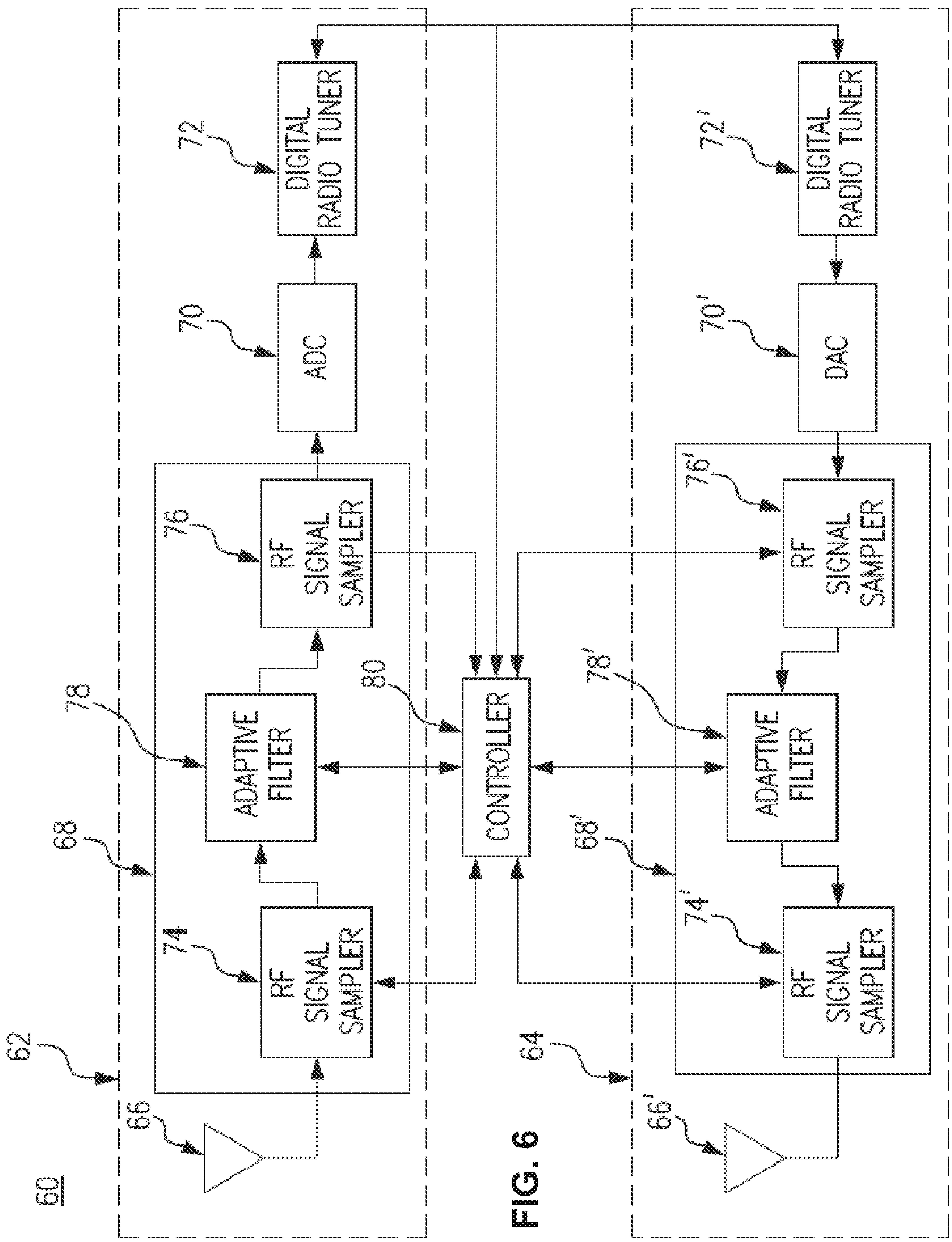

60
62
64
66
66'
68
68'
74
74'
76
76'
78
78'
70
70'
72
72'
80
RF SIGNAL SAMPLER
ADAPTIVE FILTER
ADC
DAC
DIGITAL RADIO TUNER
CONTROLLER

FIG. 6

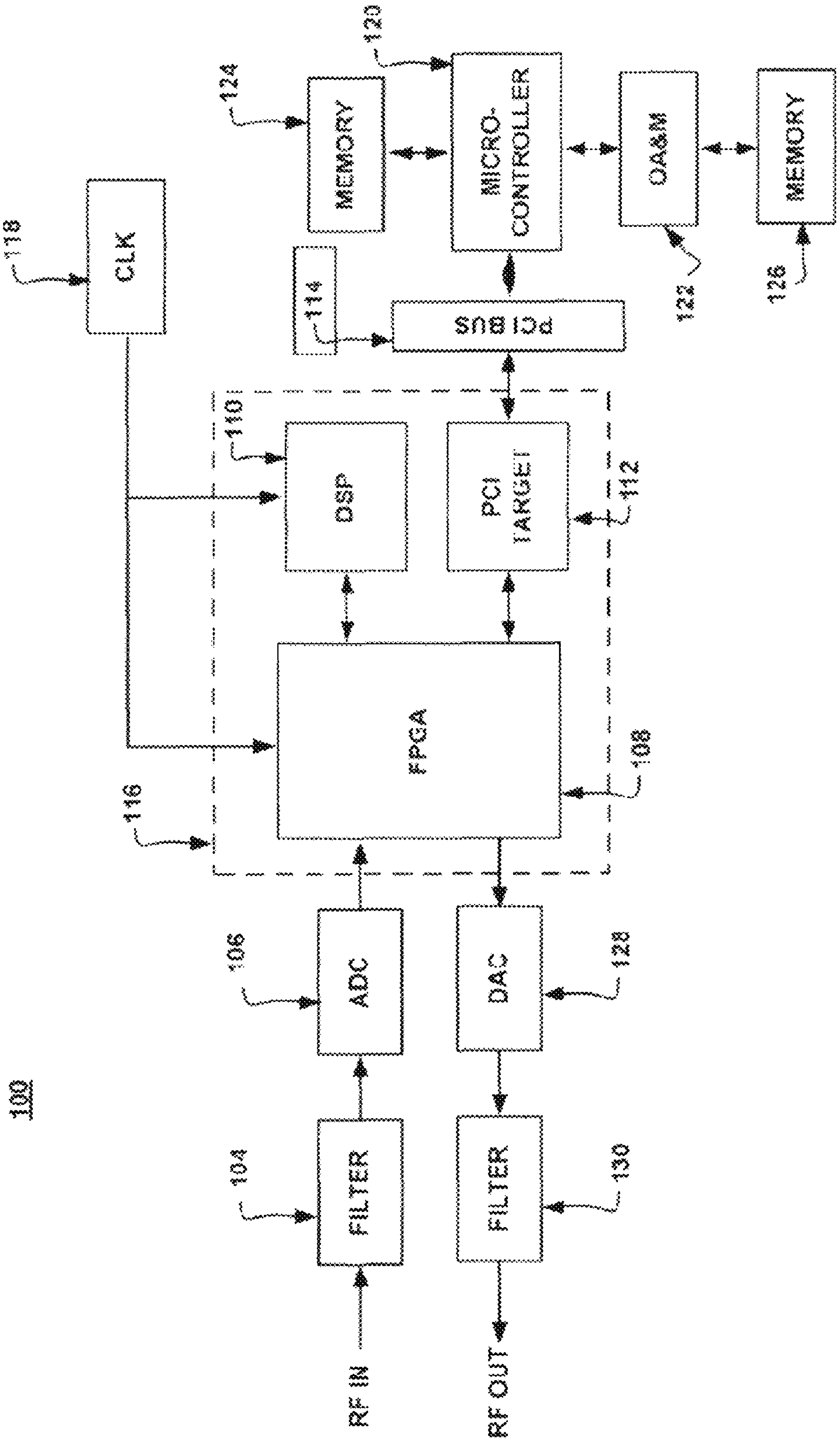
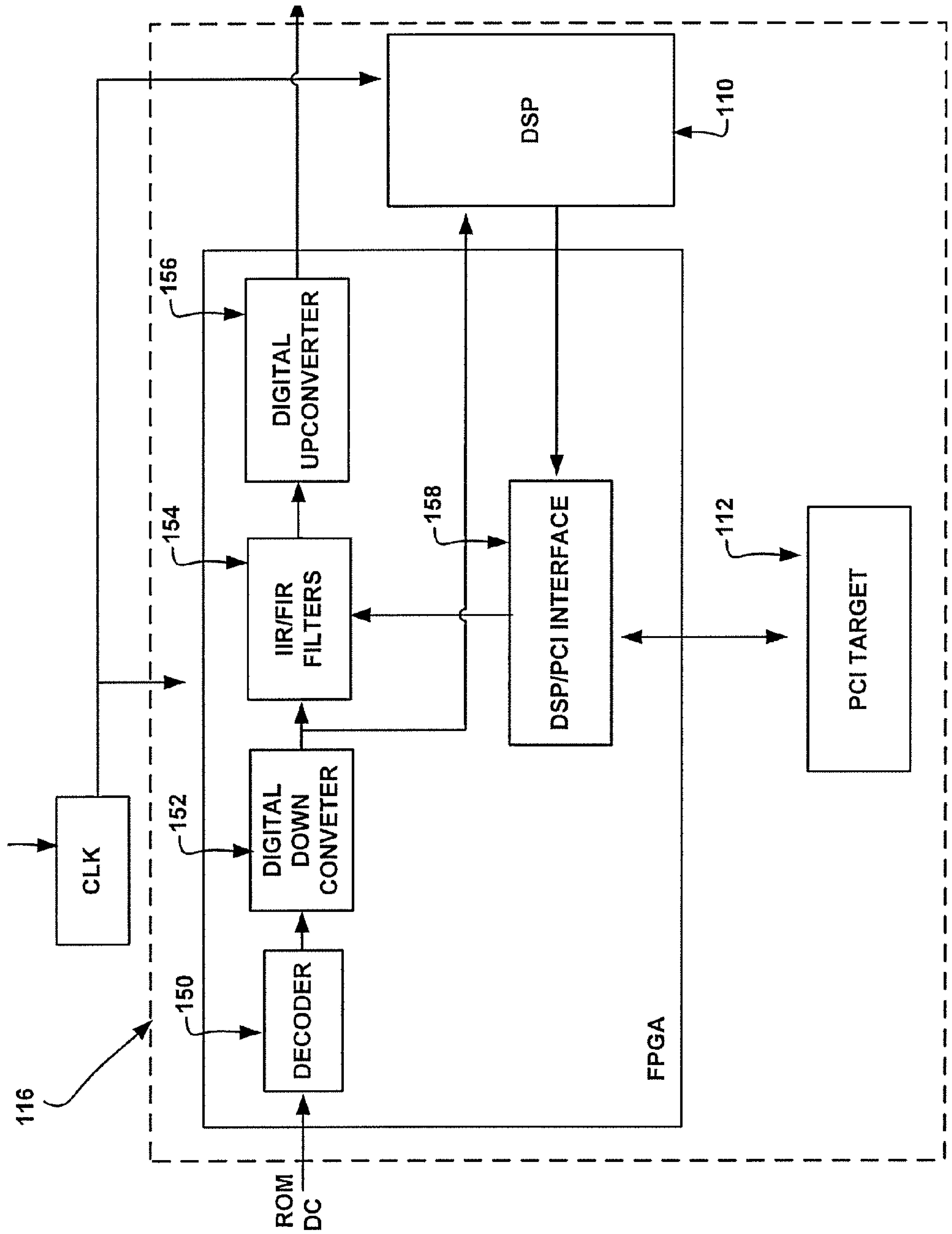

100
RF IN
FILTER
104
ADC
106
RF OUT
FILTER
130
DAC
128
FPGA
108
116
DSP
110
PCI TARGET
112
CLK
118
PCI BUS
114
MEMORY
124
MICRO-CONTROLLER
120
OA&M
122
MEMORY
126

FIG. 7



DSP
110
DIGITAL UPCONVERTER
156
IIR/FIR FILTERS
154
158
DSP/PCI INTERFACE
112
PCI TARGET
CLK
DIGITAL DOWN CONVETER
152
DECODER
150
FPGA
116
ROM DC

FIG. 8

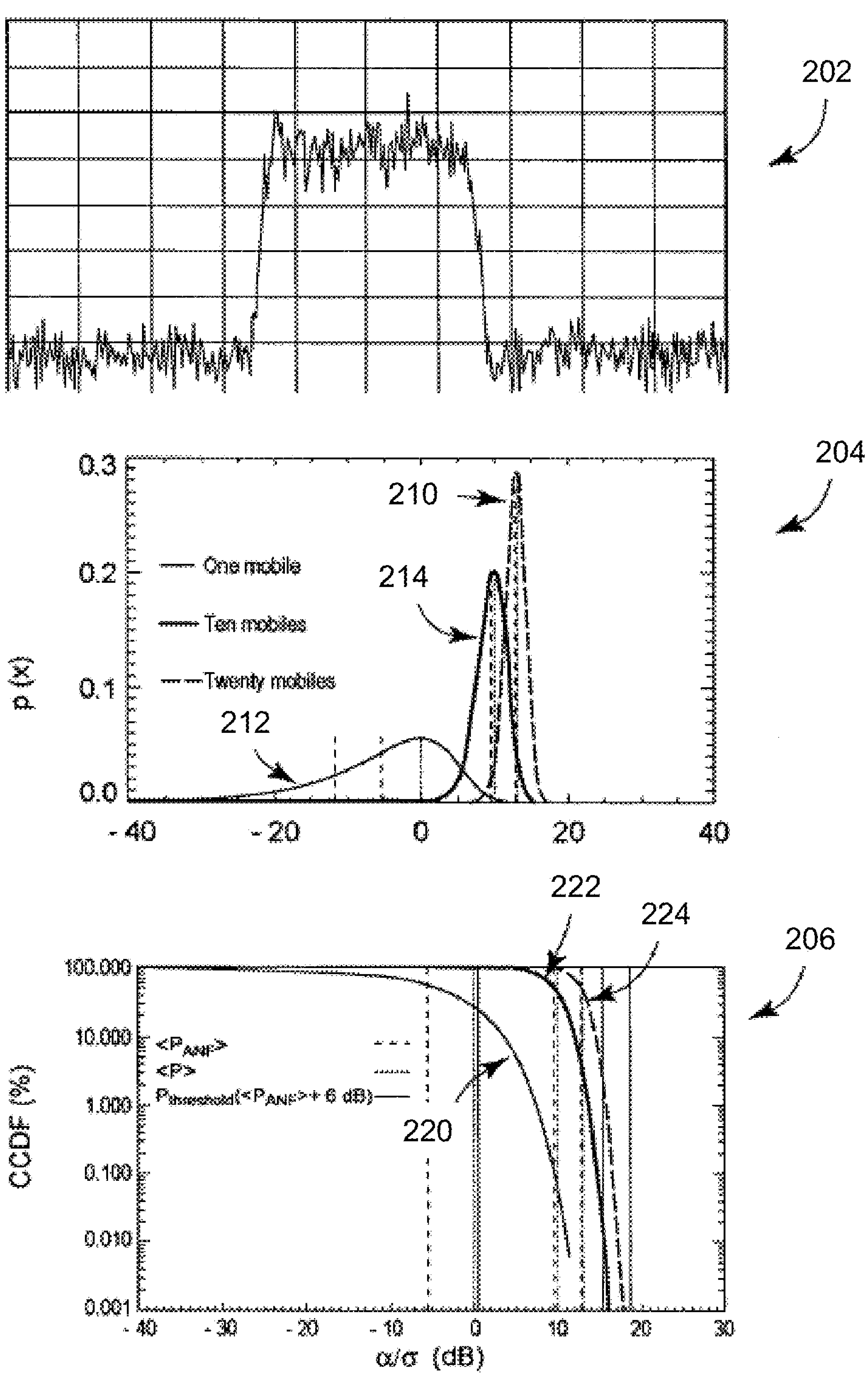

202
204
0.3
0.2
0.1
0.0
p (x)
One mobile
Ten mobiles
Twenty mobiles
210
214
212
-40
-20
0
20
40
206
222
224
220
100.000
10.000
1.000
0.100
0.010
0.001
CCDF (%)
<P_ANF>
<P>
P_threshold(<P_ANF>+6 dB)
-40
-30
-20
-10
0
10
20
30
α/σ (dB)

FIG. 9

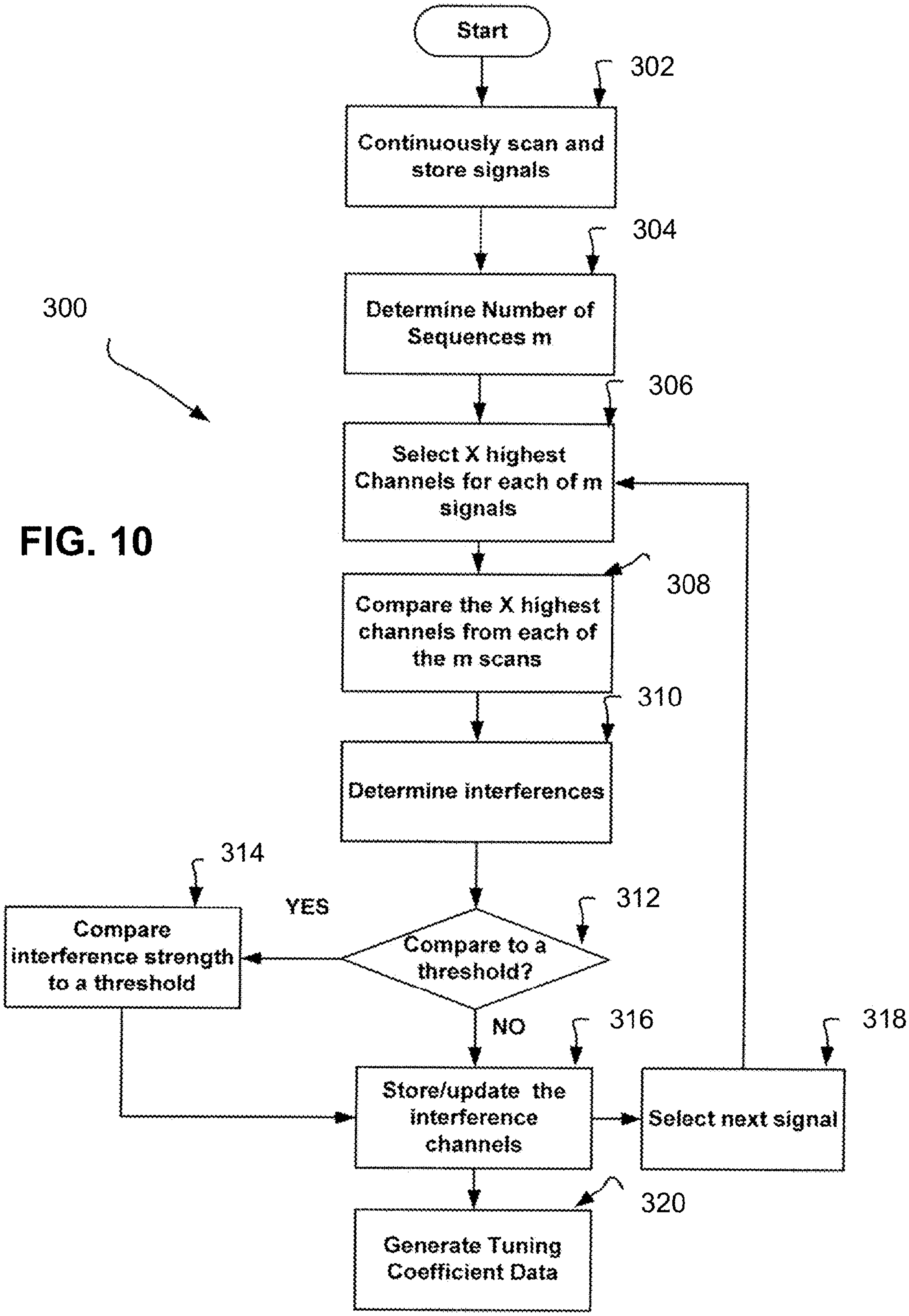
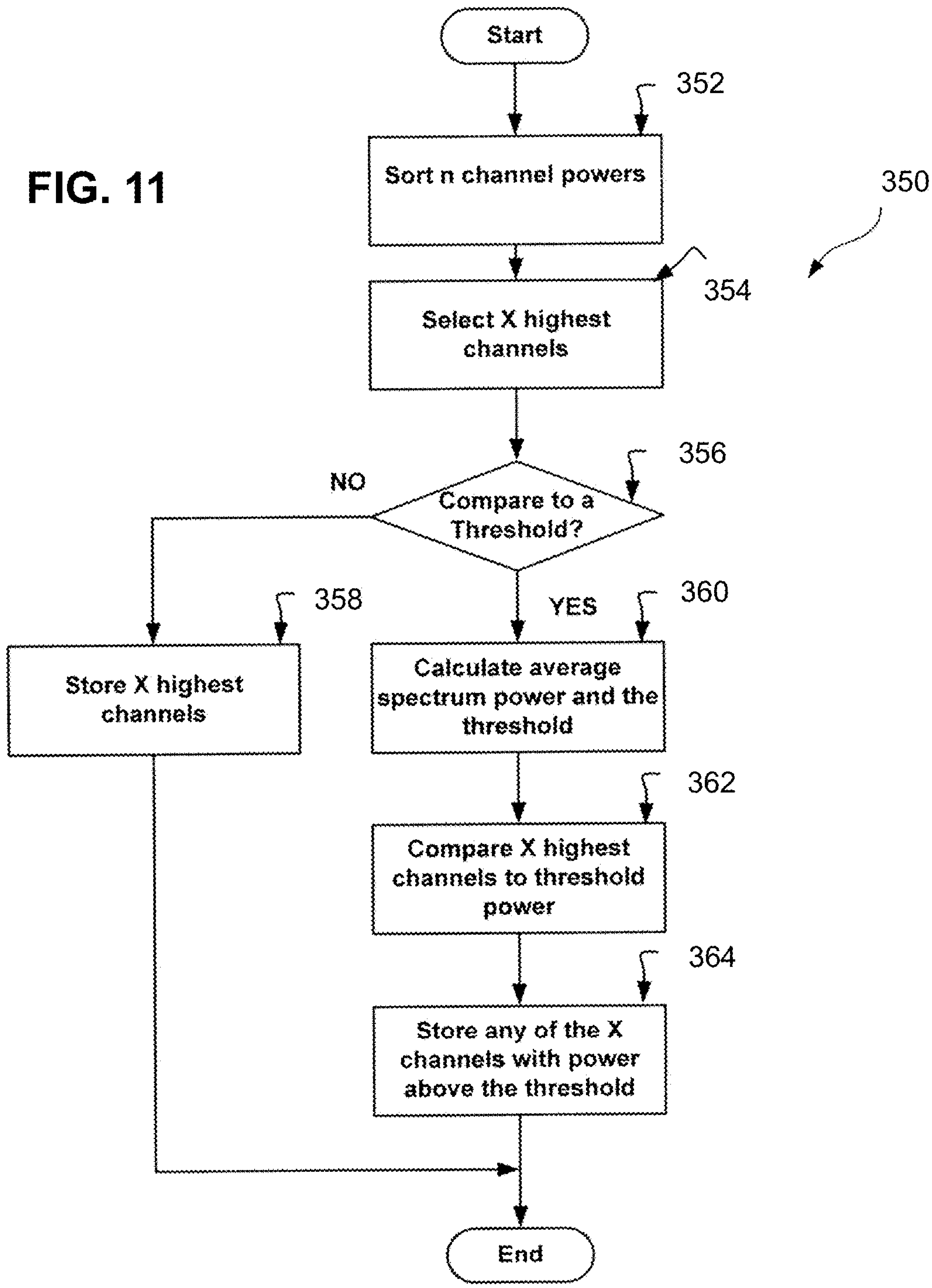

Start
302
Continuously scan and store signals
304
Determine Number of Sequences m
300
306
Select X highest Channels for each of m signals
308
Compare the X highest channels from each of the m scans
310
Determine interferences
314
YES
312
Compare interference strength to a threshold
Compare to a threshold?
NO
316
318
Store/update the interference channels
Select next signal
320
Generate Tuning Coefficient Data

FIG. 10

FIG. 11


350
Start
352
Sort n channel powers
354
Select X highest channels
356
Compare to a Threshold?
NO
YES
358
Store X highest channels
360
Calculate average spectrum power and the threshold
362
Compare X highest channels to threshold power
364
Store any of the X channels with power above the threshold
End

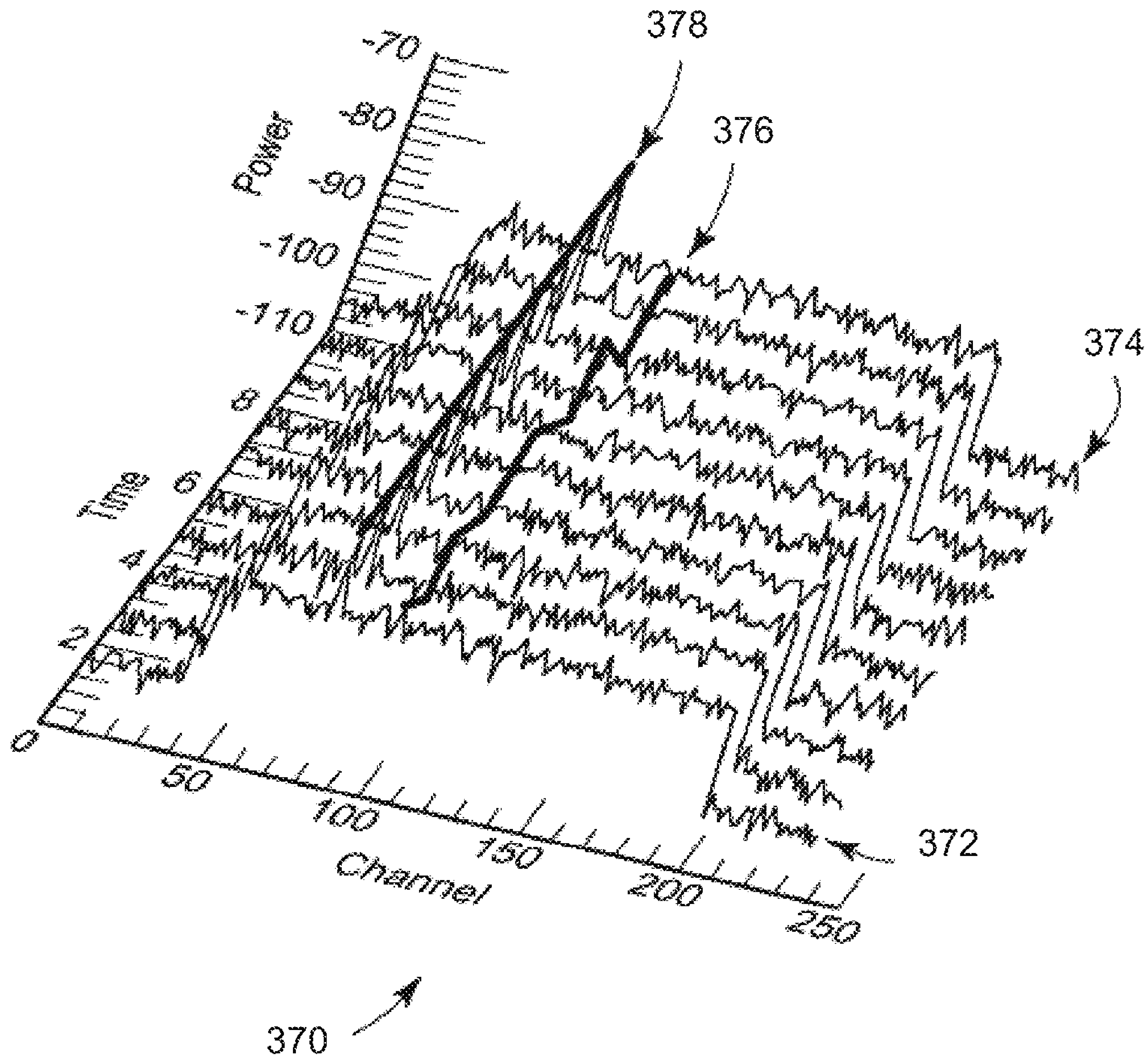

378
376
374
372
370
Power
-70
-80
-90
-100
-110
Time
0
2
4
6
8
Channel
50
100
150
200
250

FIG. 12

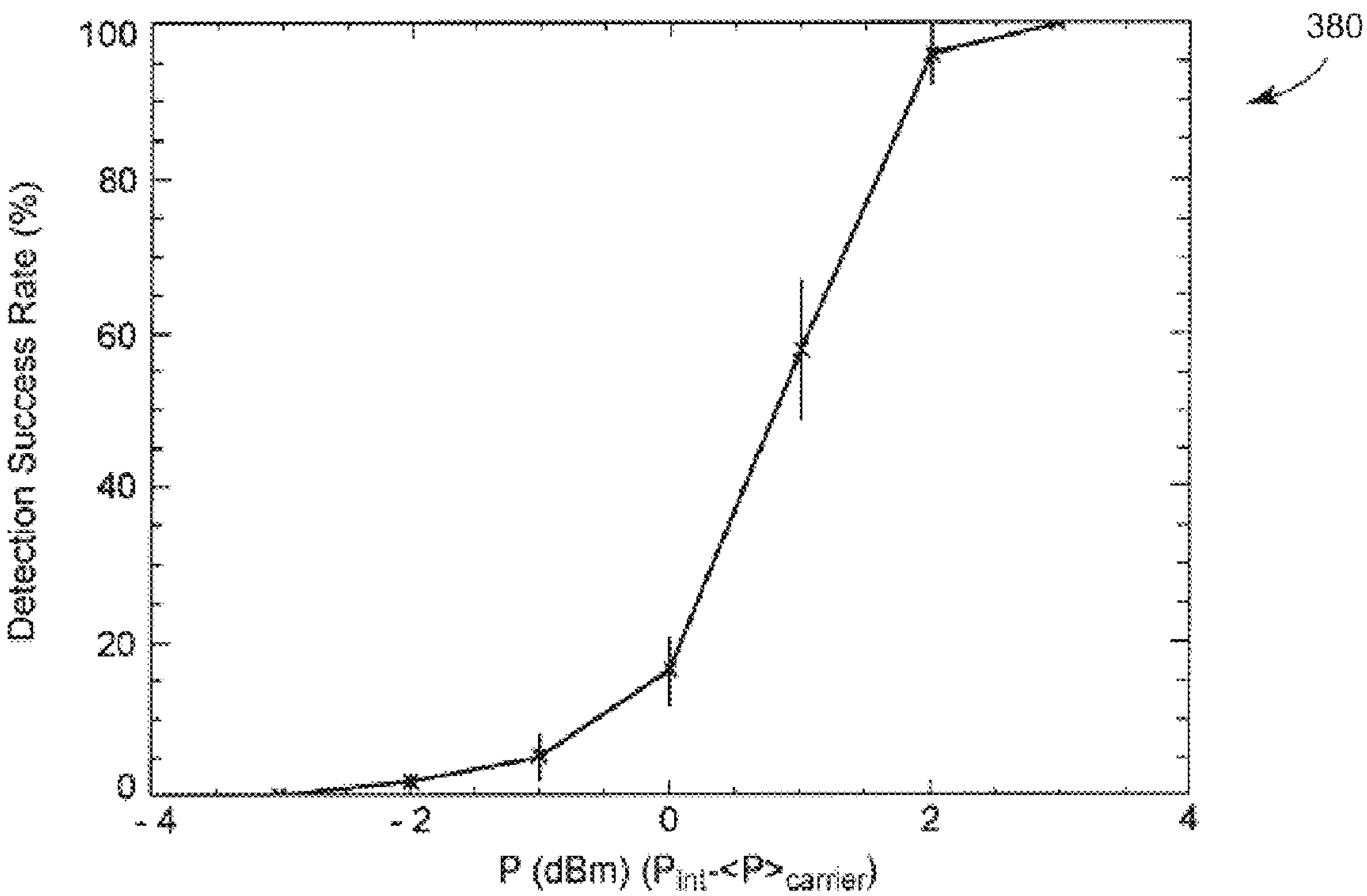

380
100
80
60
40
20
0
-4
-2
0
2
4
Detection Success Rate (%)
P (dBm) (P_int-<P>_carrier)

FIG. 13

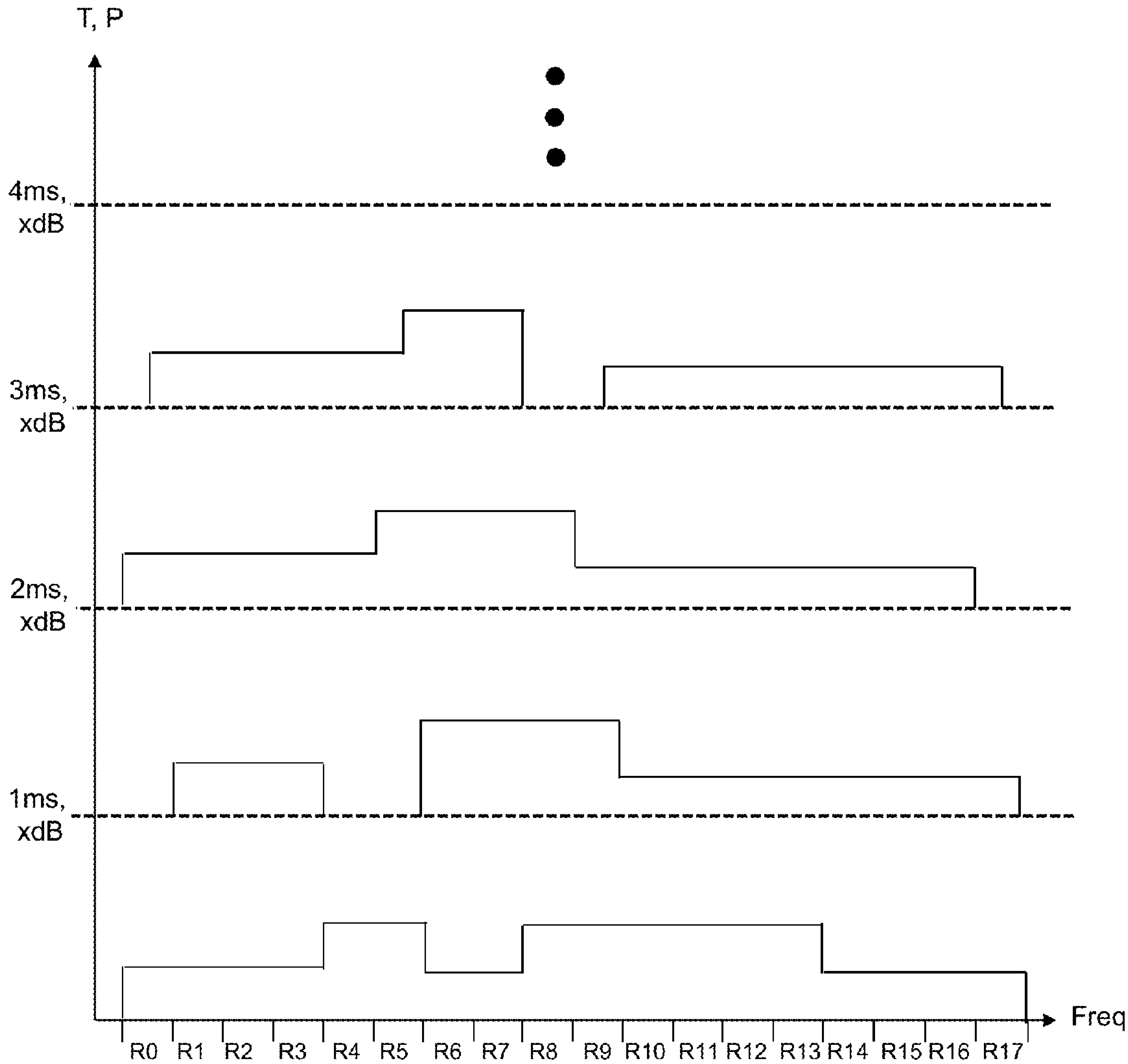

T, P
4ms, xdB
3ms, xdB
2ms, xdB
1ms, xdB
Freq
R0 R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17

FIG. 14

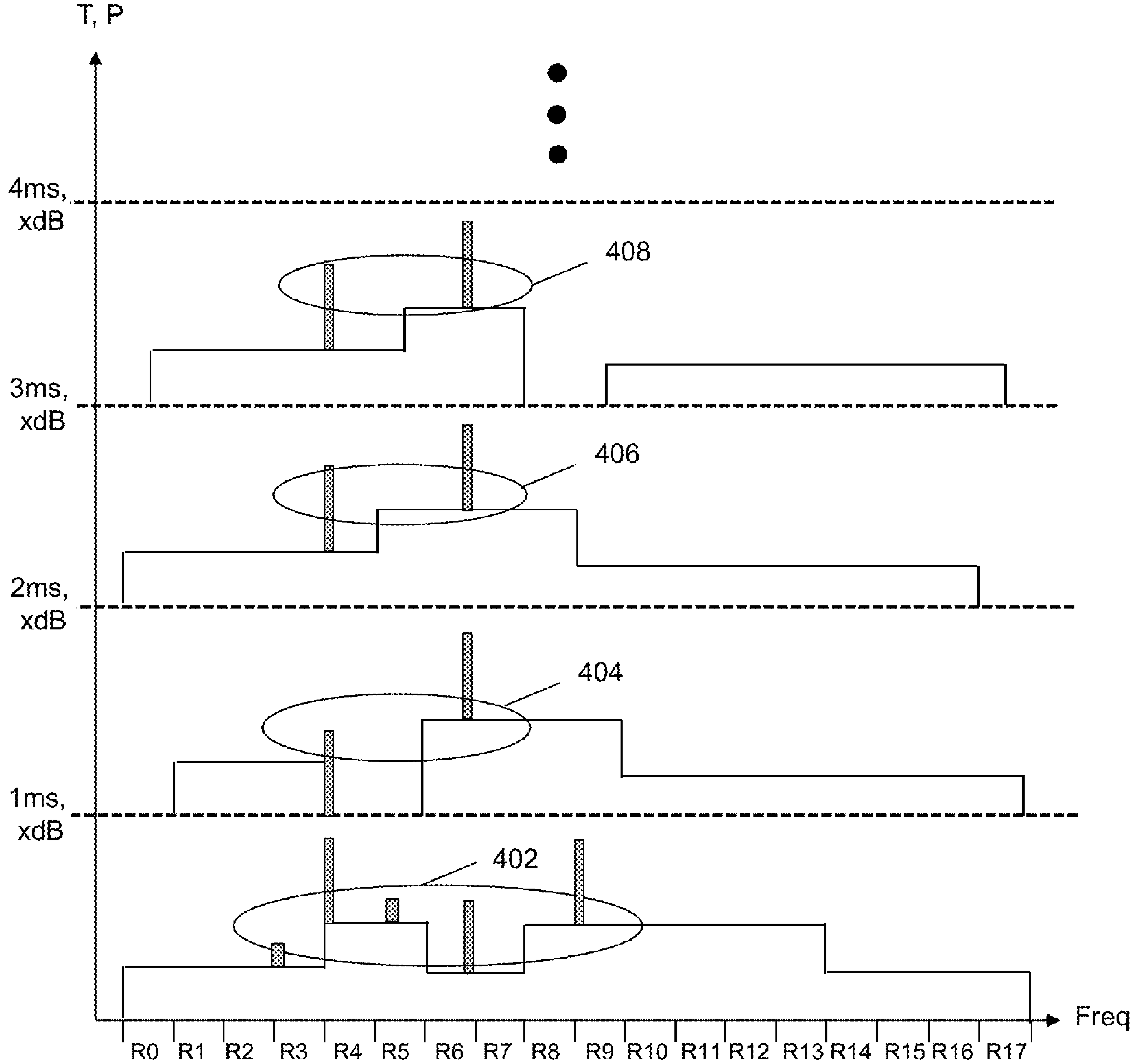
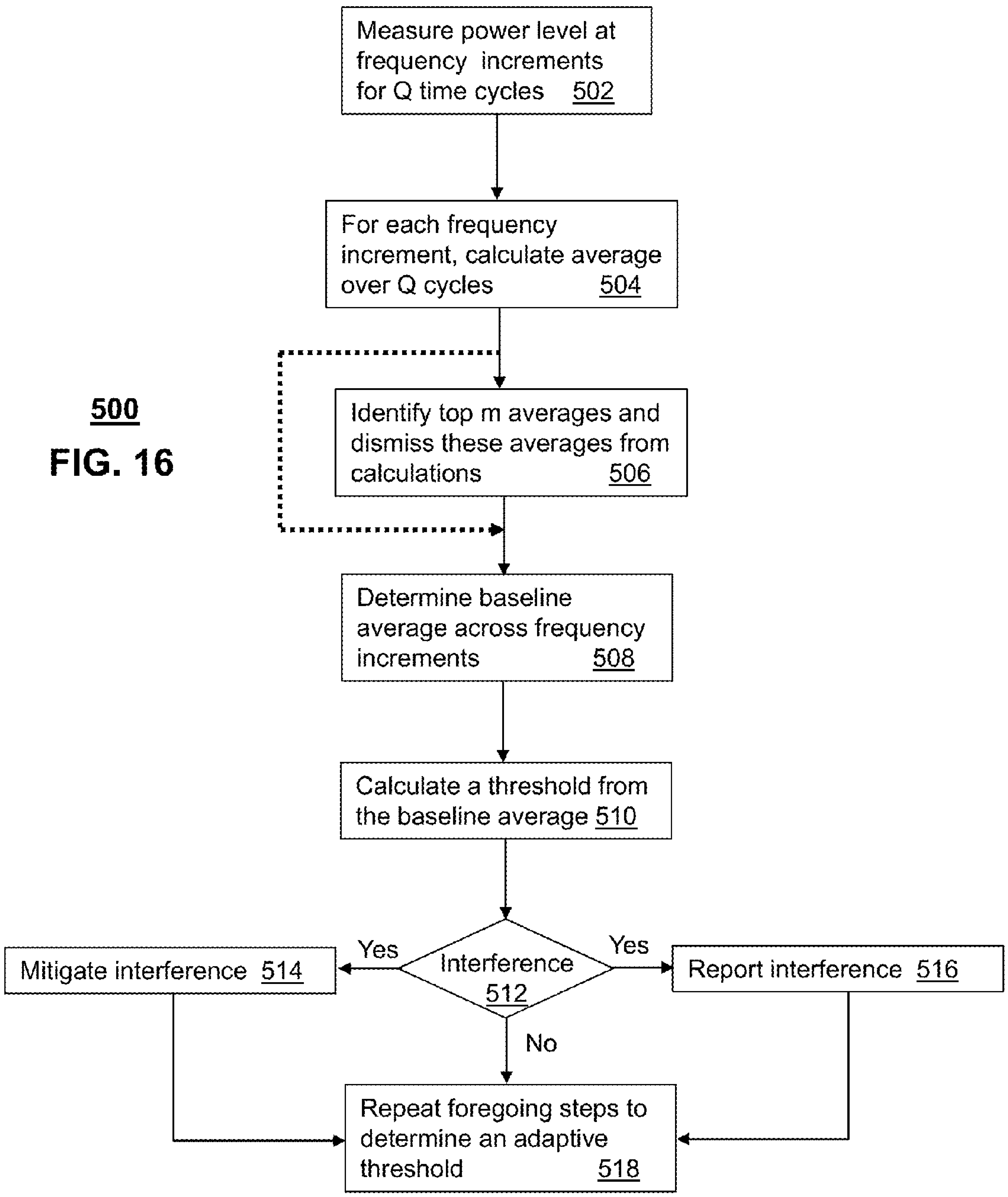
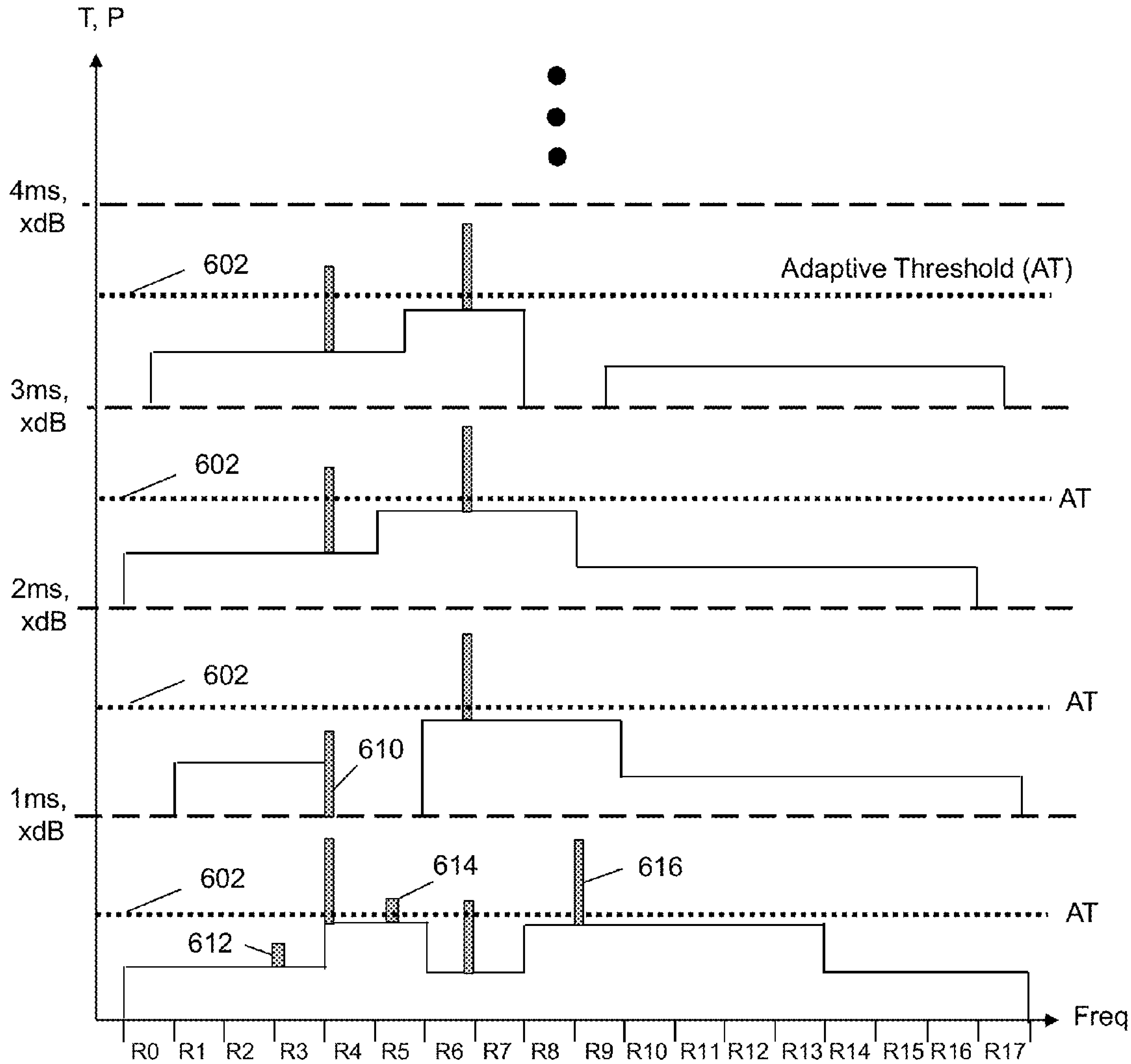

T, P
4ms,
xdB
3ms,
xdB
2ms,
xdB
1ms,
xdB
408
406
404
402
Freq
R0
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17

FIG. 15


Measure power level at frequency increments for Q time cycles 502
For each frequency increment, calculate average over Q cycles 504
Identify top m averages and dismiss these averages from calculations 506
Determine baseline average across frequency increments 508
Calculate a threshold from the baseline average 510
Interference 512
Yes
Yes
No
Mitigate interference 514
Report interference 516
Repeat foregoing steps to determine an adaptive threshold 518

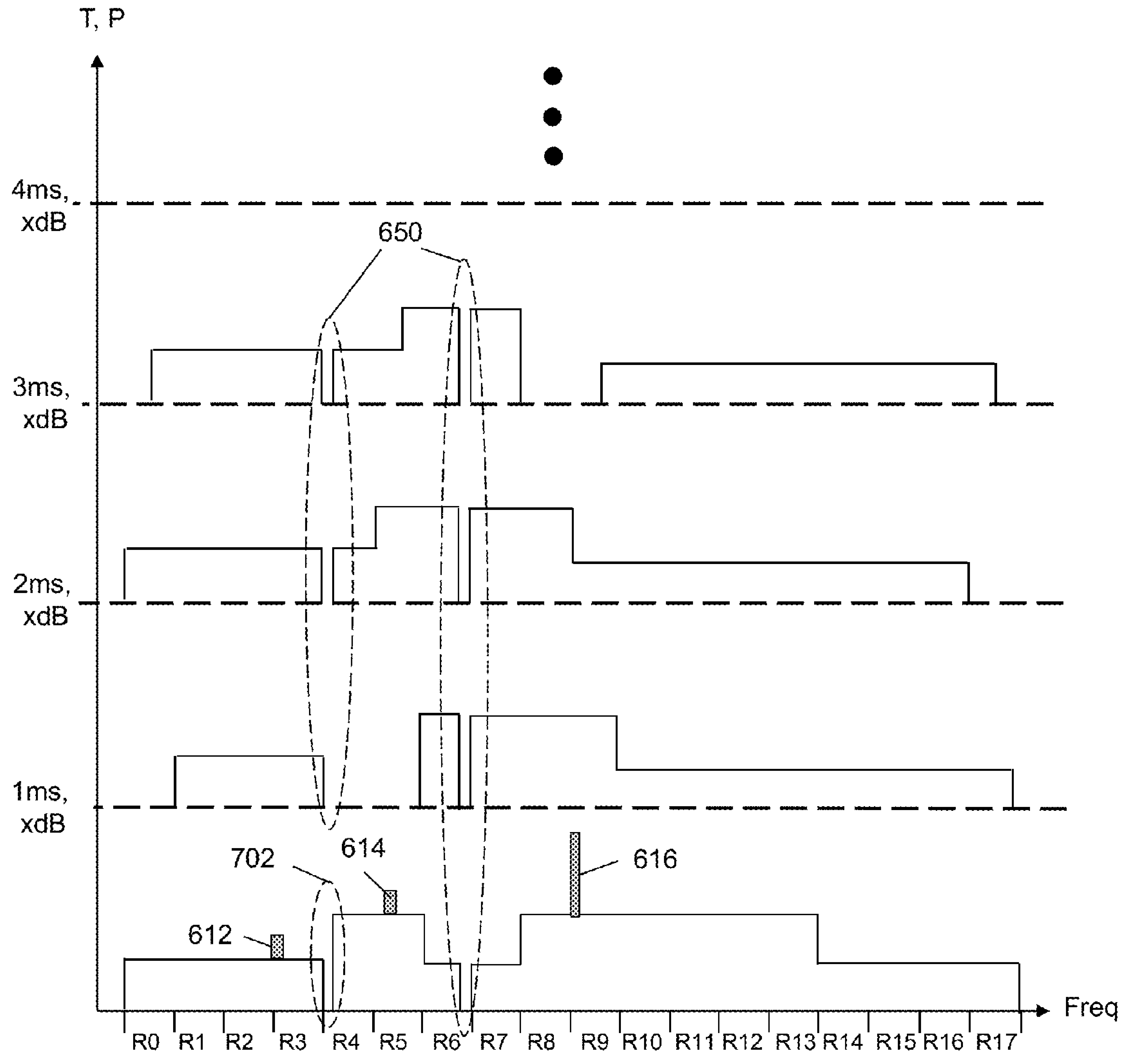
500

FIG. 16



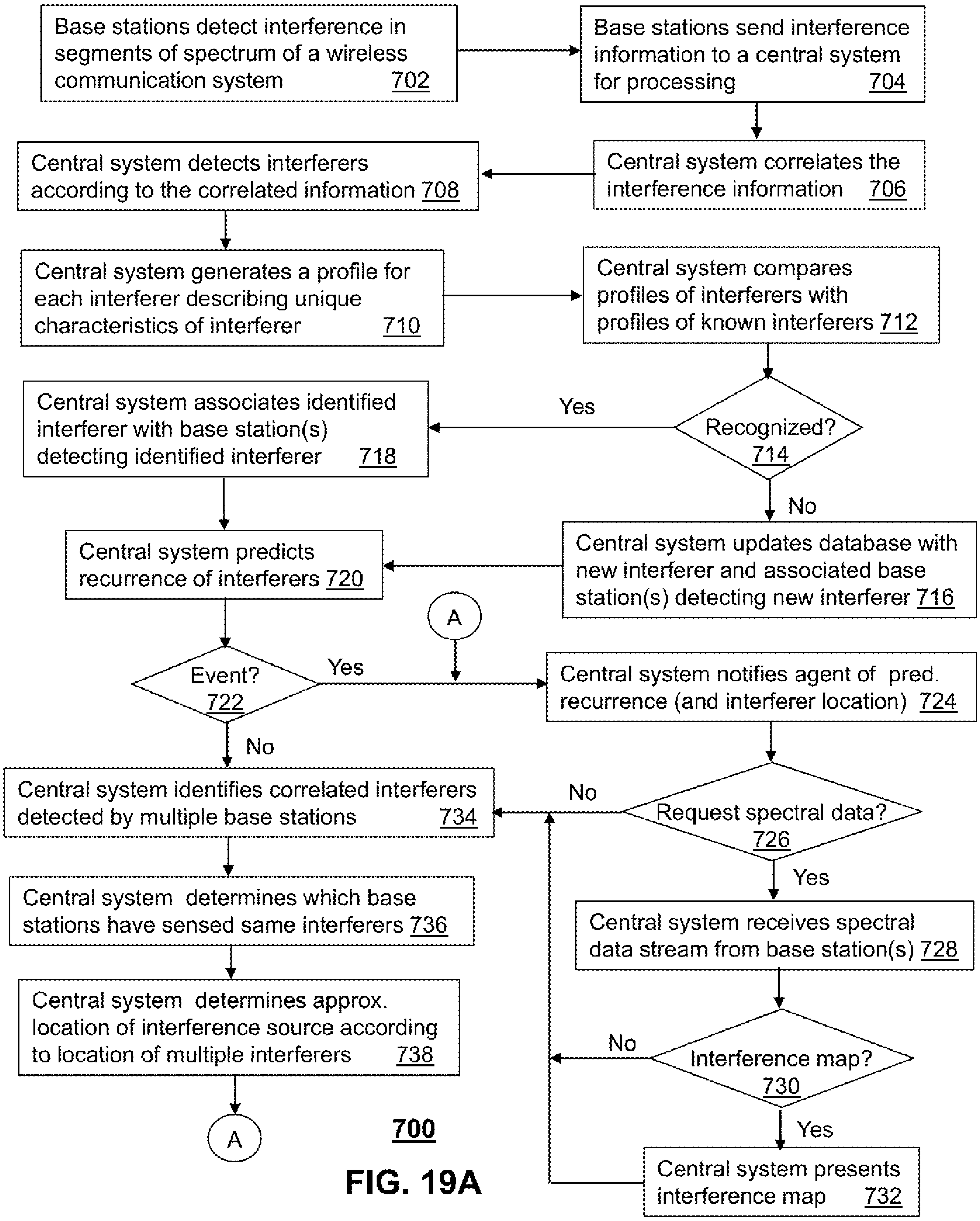
T, P
4ms, xdB
602
Adaptive Threshold (AT)
3ms, xdB
602
AT
2ms, xdB
602
AT
610
1ms, xdB
602
614
616
AT
612
Freq
R0
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17

FIG. 17



T, P
4ms, xdB
3ms, xdB
2ms, xdB
1ms, xdB
650
702
614
612
616
Freq
R0
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17

FIG. 18



Base stations detect interference in segments of spectrum of a wireless communication system 702
Base stations send interference information to a central system for processing 704
Central system correlates the interference information 706
Central system detects interferers according to the correlated information 708
Central system generates a profile for each interferer describing unique characteristics of interferer 710
Central system compares profiles of interferers with profiles of known interferers 712
Recognized? 714
Yes
No
Central system associates identified interferer with base station(s) detecting identified interferer 718
Central system updates database with new interferer and associated base station(s) detecting new interferer 716
Central system predicts recurrence of interferers 720
A
Event? 722
Yes
No
Central system notifies agent of pred. recurrence (and interferer location) 724
Request spectral data? 726
No
Yes
Central system identifies correlated interferers detected by multiple base stations 734
Central system receives spectral data stream from base station(s) 728
Central system determines which base stations have sensed same interferers 736
Interference map? 730
No
Yes
Central system determines approx. location of interference source according to location of multiple interferers 738
Central system presents interference map 732
A
700

FIG. 19A

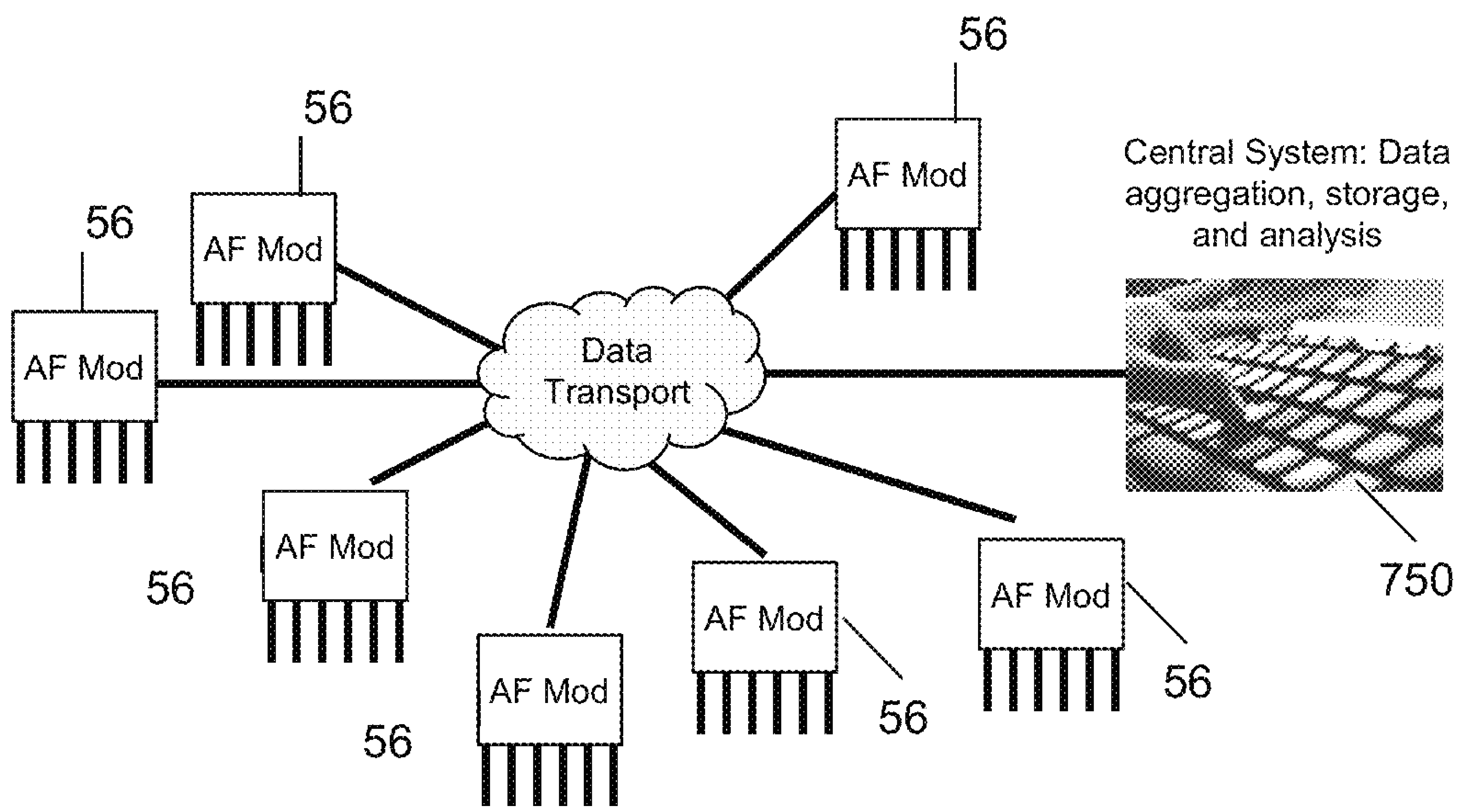

56
56
56
AF Mod
AF Mod
AF Mod
Central System: Data aggregation, storage, and analysis
Data Transport
AF Mod
AF Mod
AF Mod
AF Mod
AF Mod
56
56
56
56
56
750

FIG. 19B

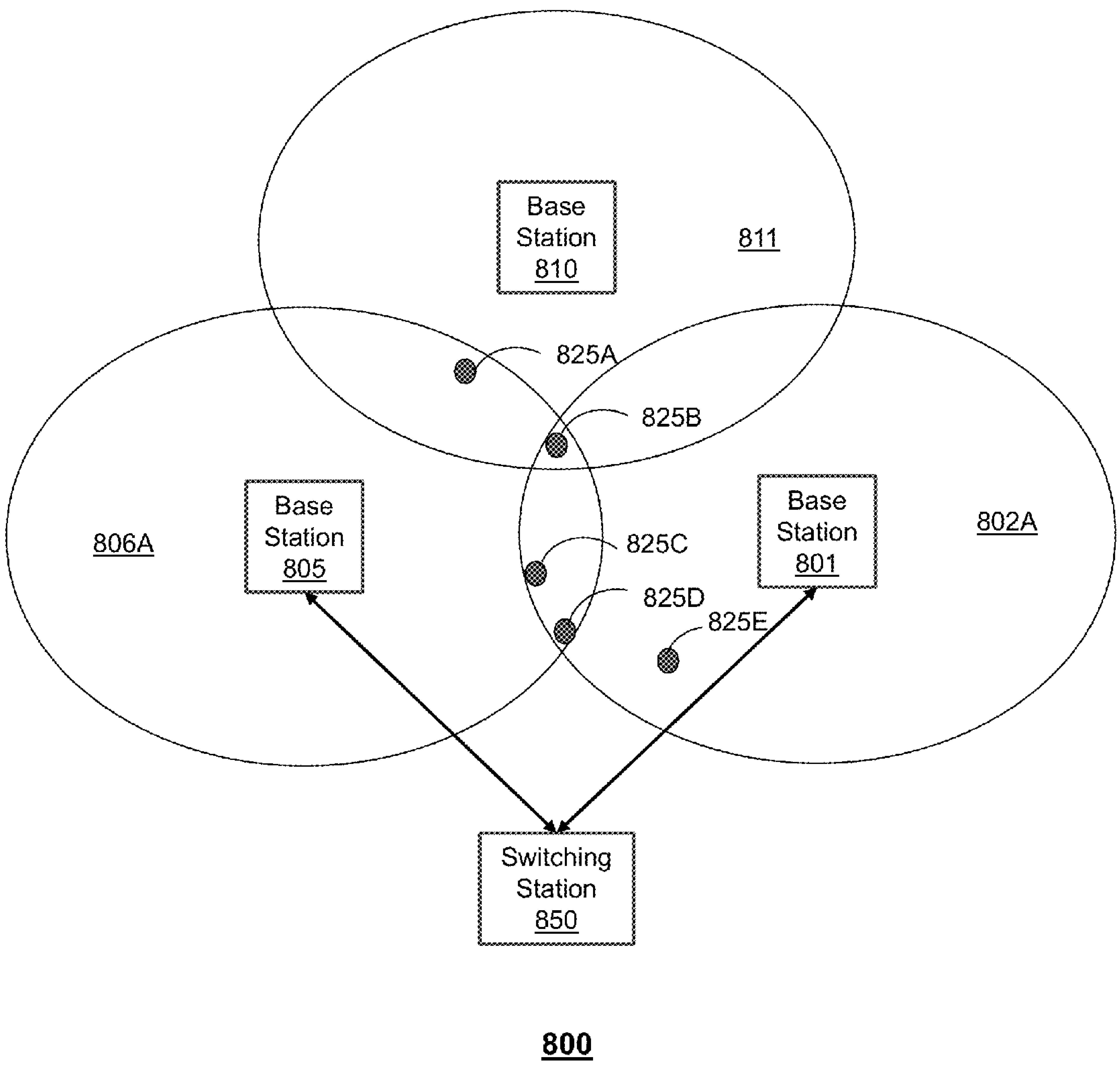
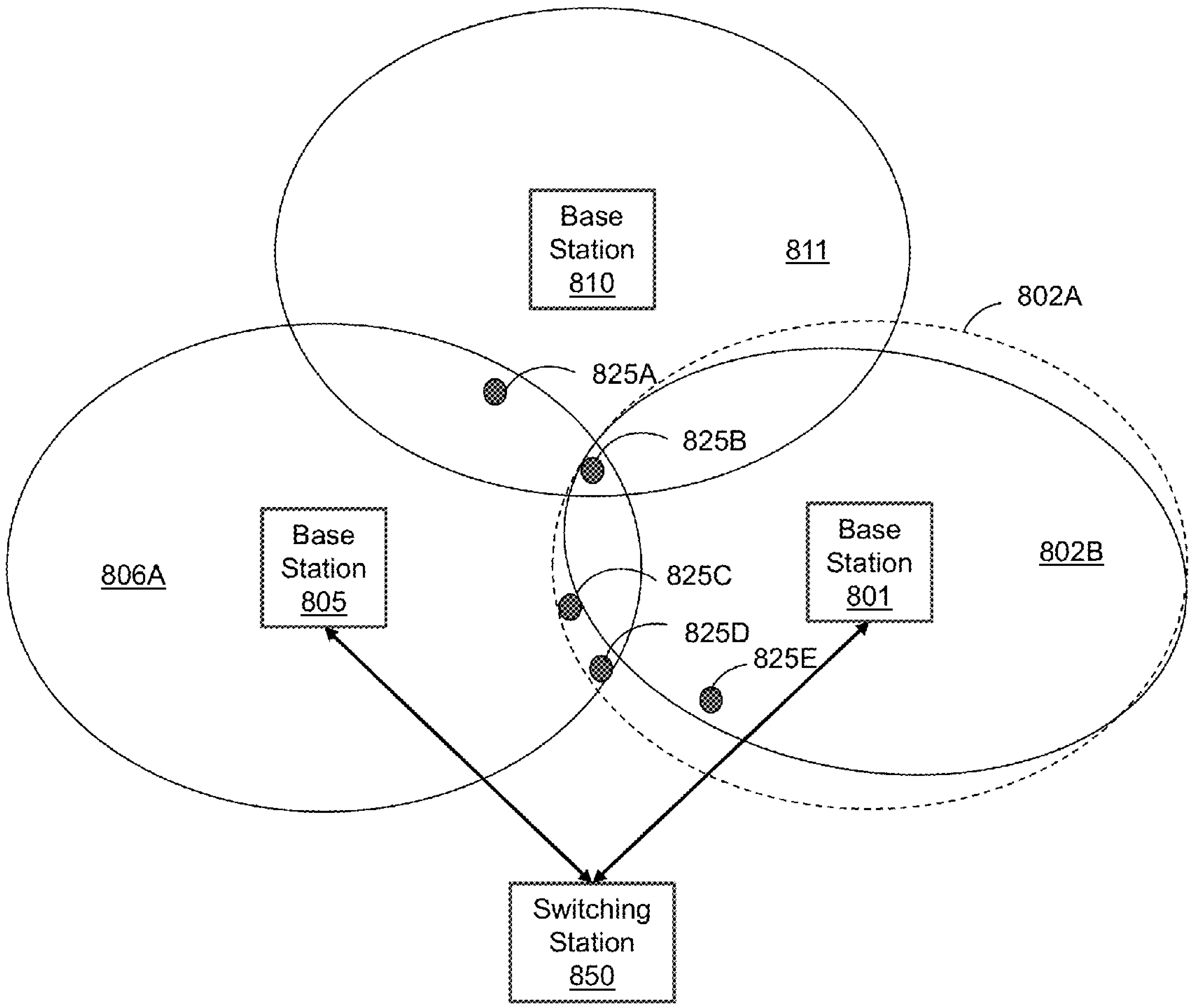

Base
Station
810
811
825A
825B
806A
Base
Station
805
825C
Base
Station
801
802A
825D
825E
Switching
Station
850
800

FIG. 20A


Base Station 810
811
802A
825A
825B
806A
Base Station 805
825C
Base Station 801
802B
825D
825E
Switching Station 850

800

FIG. 20B

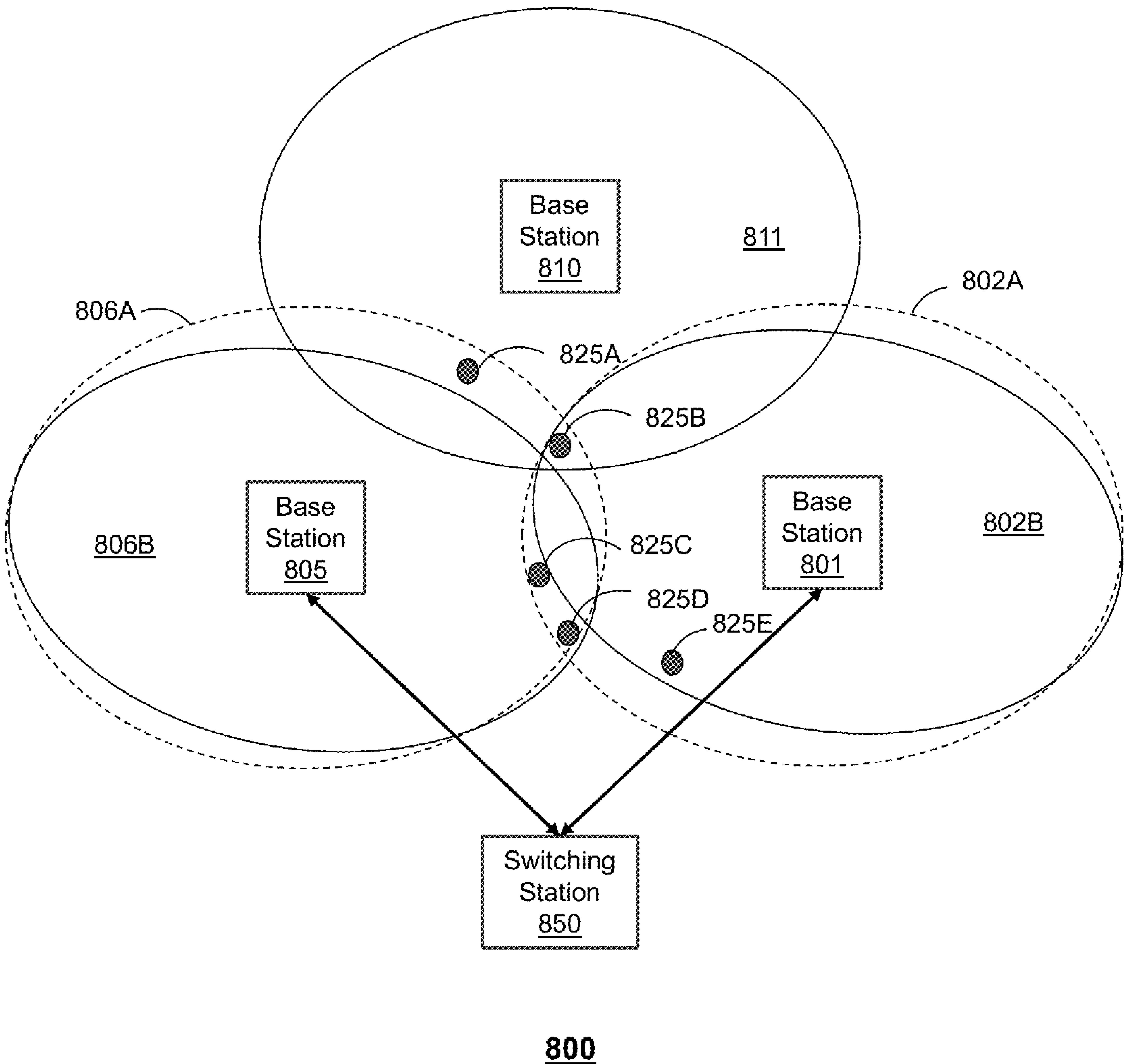
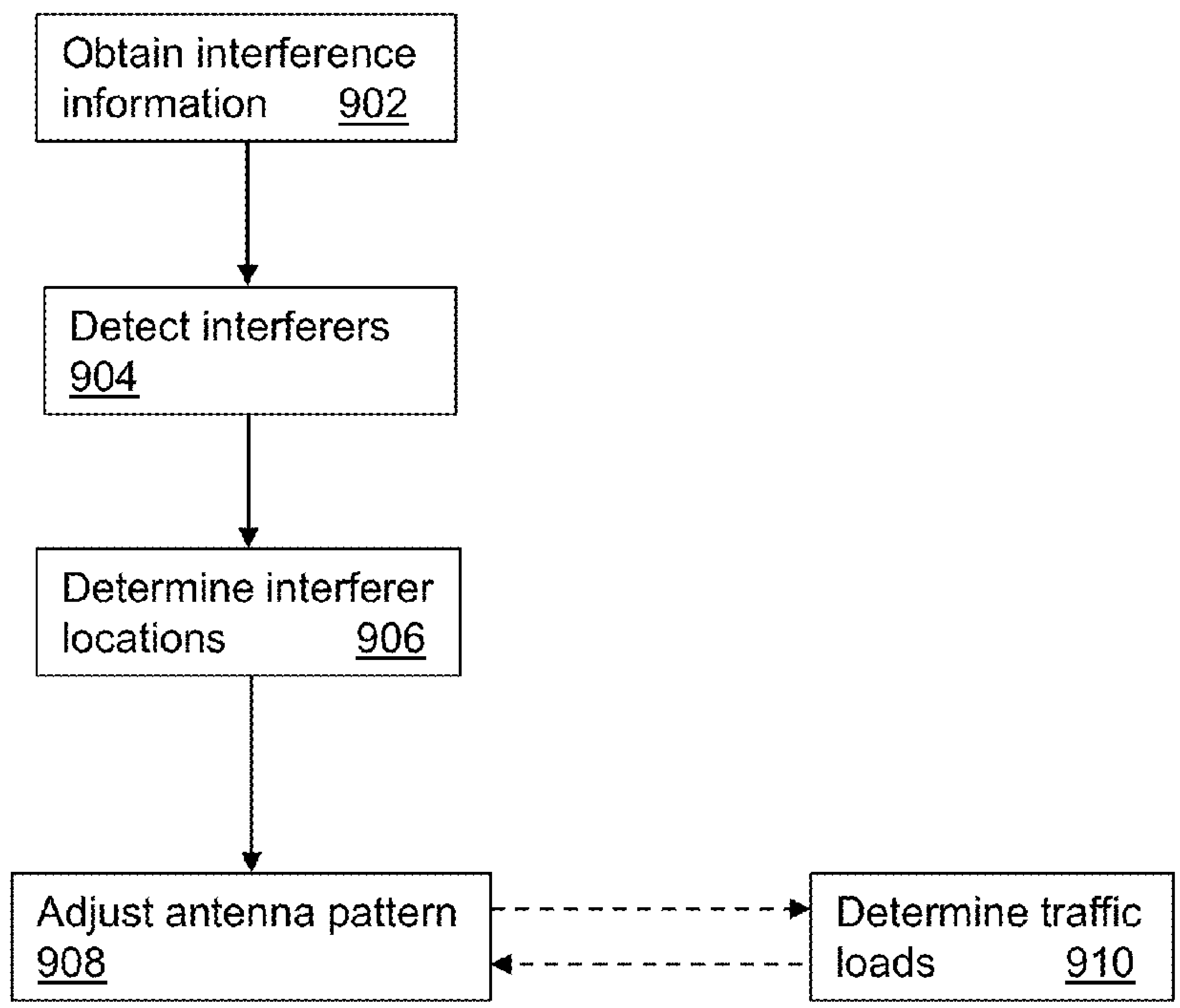
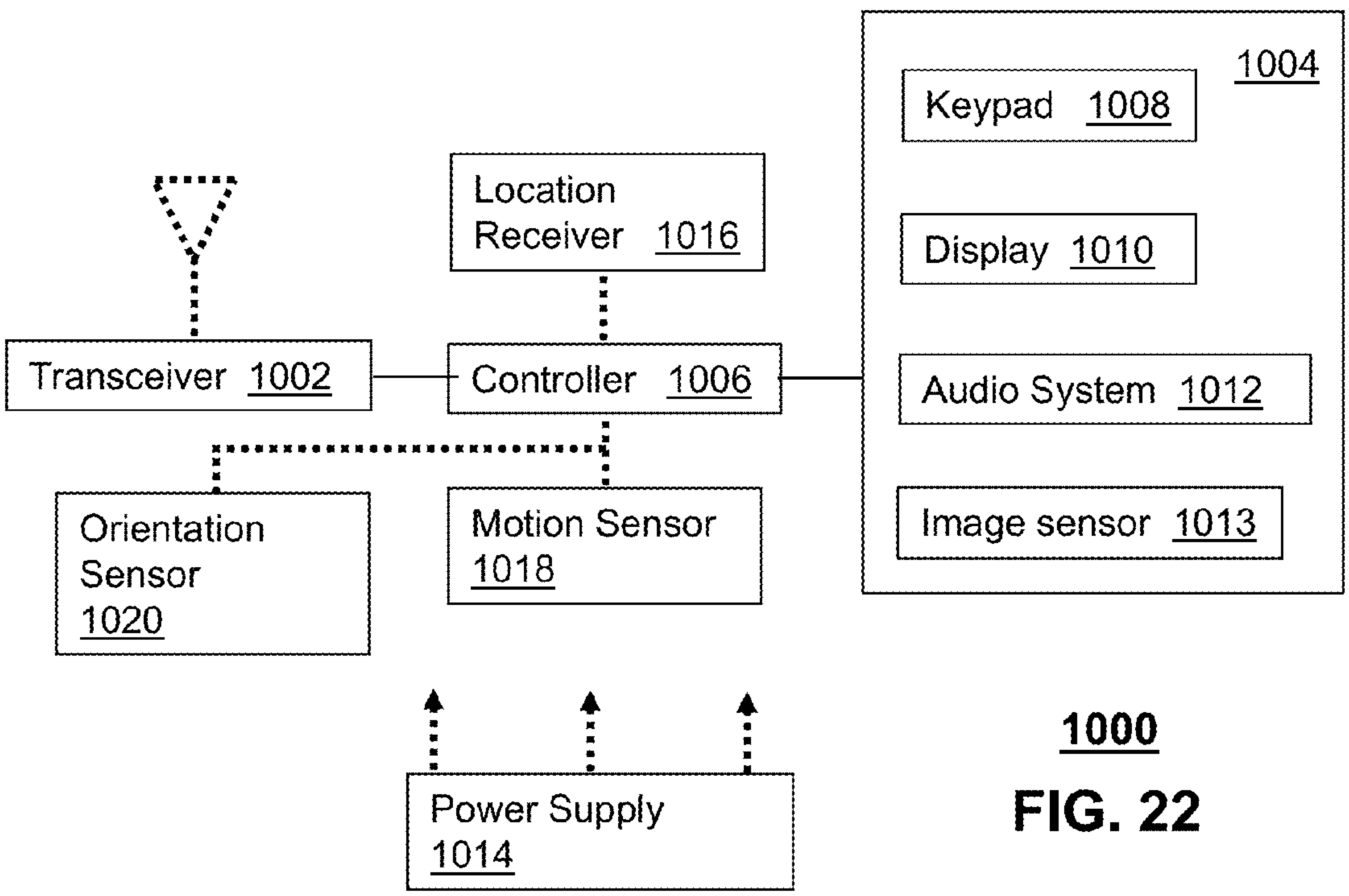

Base
Station
810
811
806A
802A
825A
825B
806B
Base
Station
805
825C
Base
Station
801
802B
825D
825E
Switching
Station
850
800

FIG. 20C

900

FIG. 21


Obtain interference information 902
Detect interferers 904
Determine interferer locations 906
Adjust antenna pattern 908
Determine traffic loads 910


1004
Keypad 1008
Location Receiver 1016
Display 1010
Transceiver 1002
Controller 1006
Audio System 1012
Orientation Sensor 1020
Motion Sensor 1018
Image sensor 1013
Power Supply 1014

1000

FIG. 22

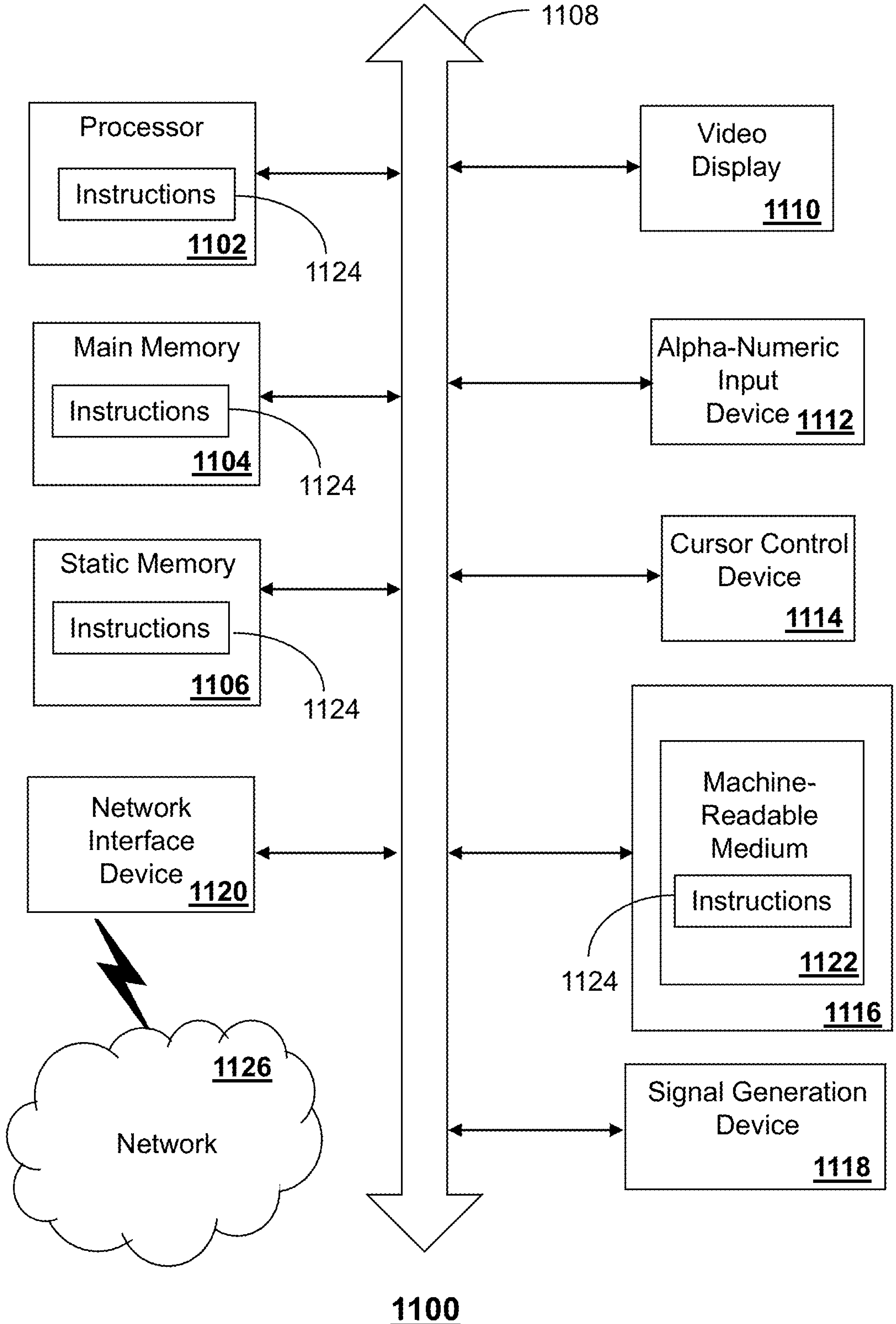

1108
Processor
Instructions
1102
1124
Main Memory
Instructions
1104
1124
Static Memory
Instructions
1106
1124
Network Interface Device 1120
1126
Network
Video Display
1110
Alpha-Numeric Input Device 1112
Cursor Control Device
1114
Machine-Readable Medium
Instructions
1122
1124
1116
Signal Generation Device
1118
1100

FIG. 23

METHOD AND APPARATUS FOR INTERFERENCE MITIGATION UTILIZING ANTENNA PATTERN ADJUSTMENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of priority to U.S. Provisional Application No. 61/792,184 filed on Mar. 15, 2013, entitled, "Method and apparatus for Interference Detection and Mitigation," which is hereby incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

The subject disclosure is related to a method and apparatus for interference mitigation utilizing antenna pattern adjustments.

BACKGROUND

In most communication environments involving short range or long range wireless communications, interference from unexpected wireless sources can impact the performance of a communication system leading to lower throughput, dropped calls, reduced bandwidth which can cause traffic congestion, or other adverse effects, which are undesirable.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. **1** depicts an illustrative embodiment of a communication system;

FIG. **2** depicts an illustrative embodiment of a frequency spectrum of a four carrier CDMA signal;

FIG. **3** depicts an illustrative embodiment of a frequency spectrum of a four carrier CDMA signal showing unequal power balancing between the four CDMA carriers and including a narrowband interferer;

FIG. **4** depicts an illustrative embodiment of a base station of FIG. **1**;

FIG. **5** depicts an illustrative embodiment of a frequency spectrum of a four carrier CDMA signal having four CDMA carriers with suppression of a narrowband interferer that results in falsing;

FIG. **6** depicts an illustrative embodiment of an interference detection and mitigation system;

FIG. **7** depicts an illustrative embodiment of an interference detection and mitigation system;

FIG. **8** depicts an illustrative embodiment of signal processing module of FIG. **7**;

FIG. **9** depicts an illustrative embodiment of plots of a spread spectrum signal;

FIG. **10** depicts an illustrative embodiment of a method for interference detection;

FIG. **11** depicts illustrative embodiments of the method of FIG. **10**;

FIG. **12** depicts illustrative embodiments of a series of spread spectrum signals intermixed with an interference signal;

FIG. **13** depicts an illustrative embodiment of a graph depicting interference detection efficiency of a system of the subject disclosure;

FIG. **14** depicts illustrative embodiments of Long Term Evolution (LTE) time and frequency signal plots;

FIG. **15** depicts illustrative embodiments of LTE time and frequency signal plots intermixed with interference signals;

FIG. **16** depicts an illustrative embodiment of a method for detecting and mitigating interference signals shown in FIG. **15**;

FIG. **17** depicts an illustrative embodiment of adaptive thresholds used for detecting and mitigating interference signals shown in FIG. **15**;

FIG. **18** depicts an illustrative embodiment of resulting LTE signals after mitigating interference according to the method of FIG. **16**;

FIG. **19**A depicts an illustrative embodiment of a method for mitigating interference;

FIG. **19**B depicts an illustrative embodiment of a communication system utilizing the method of FIG. **19**A;

FIG. **20**A depicts an illustrative embodiment of a communication system utilizing antenna pattern adjustment for mitigation of interference;

FIG. **20**B depicts another illustrative embodiment of the communication system of FIG. **20**A utilizing antenna pattern adjustment for mitigation of interference;

FIG. **20**C depicts another illustrative embodiment of the communication system utilizing antenna pattern adjustment for mitigation of interference;

FIG. **21** depicts an illustrative embodiment of a method for mitigating interference utilizing antenna pattern adjustment;

FIG. **22** depicts an illustrative embodiment of a communication device that can utilize in whole or in part embodiments of the subject disclosure for detecting and mitigating interference; and

FIG. **23** is a diagrammatic representation of a machine in the form of a computer system within which a set of instructions, when executed, may cause the machine to perform any one or more of the methods described herein.

DETAILED DESCRIPTION

The subject disclosure describes, among other things, illustrative embodiments for detecting and mitigating interference signals. The detection and mitigation of the interference signals can be performed by way of manipulating one or more antenna patterns based on a location of one or more interferers. Antenna adjustments can be performed to change the traffic loads at different antennas. Other embodiments are included in the subject disclosure.

One or more of the embodiments can detect interference and identify location of end user devices. In this example, based on interference or a lack thereof, antenna pattern adjustments can be performed, such as tilting or moving an antenna at a base station to reduce footprint of end user devices that can use that particular base station or tilting or moving the antenna in the opposite direction to increase footprint of end user devices that can be serviced by that particular base station. In one embodiment, use panorama data can be utilized to determine how to mitigate noise and/or increase traffic load of a base station. In another embodiment, for an adjacent base station that is overloading on traffic, antenna pattern adjustment (e.g., tilting or rotating of antenna) can be utilized to force or otherwise cause traffic of an overloaded base station to move to another base station that has experienced improvement in traffic due to noise mitigation. In one or more embodiments, the antenna pattern adjustment can be performed with or without interference filtering being performed.

One embodiment of the subject disclosure is a method that includes obtaining, by a system having a processor, interference information according to at least one adaptive threshold for detecting signal interference in a plurality of resource blocks in a radio frequency spectrum of a wireless communication system providing communication services to a plurality of communication devices. The method can include correlating, by the system, the interference information to generate correlated information. The method can include detecting, by the system, a plurality of interferers according to the correlated information. The method can include determining, by the system, interferer locations for each of the plurality of interferers. The method can include adjusting, by the system, a first antenna pattern of a first antenna of a first base station based on the interferer locations. The adjusting of the first antenna pattern can change a first coverage area of the first antenna to an adjusted first coverage area. In one embodiment, the adjusting of the first antenna pattern can cause at least one interferer of the plurality of interferers to be located outside of the adjusted first coverage area of the first antenna. In another embodiment, the adjusting of the first antenna pattern can cause at least one communication device of the plurality of communication devices to change from utilizing the first base station to utilizing a second base station for the communication services.

One embodiment of the subject disclosure is a system that includes a memory to store instructions, and a processor coupled to the memory. Execution of the instructions by the processor causes the processor to perform operations including obtaining interference information according to at least one adaptive threshold for detecting signal interference in a plurality of segments of a radio frequency spectrum of a wireless communication system providing communication services. The operations can include generating an interference map for a plurality of interferers according to the interference information. The operations can include adjusting a first antenna pattern of a first antenna at a first location based on the interference map. The adjusting of the first antenna pattern can change a first coverage area of the first antenna to an adjusted first coverage area. In one embodiment, the adjusting of the first antenna pattern can cause at least one interferer of the plurality of interferers to be located outside of the adjusted first coverage area of the first antenna. In another embodiment, the adjusting of the first antenna pattern can cause at least one communication device to change from utilizing the first antenna to utilizing a second antenna at a second location for accessing the communication services.

One embodiment of the subject disclosure includes a machine-readable storage medium, comprising instructions, which when executed by a processor, cause the processor to perform operations including receiving interference information from each of a plurality of communication devices detecting interference information in a plurality of segments in a radio frequency spectrum of a wireless communication system providing communication services. The operations can include correlating the interference information of the plurality of communication devices to generate correlated information. The operations can include identifying a plurality of interferers according to the correlated information. The operations can include approximating a location of the plurality of interferers according to location information provided by the plurality of communication devices. The operations can include adjusting a first antenna pattern of a first antenna at a first location based on the approximating of the location of the plurality of interferers. In one embodiment, the adjusting of the first antenna pattern can cause at least one interferer of the plurality of interferers to be located outside of the adjusted first coverage area of the first antenna.

One embodiment of the subject disclosure includes a method for receiving, by a system comprising a processor, interference information from each of a plurality of communication devices detecting the interference information according to at least one adaptive threshold for detecting signal interference in a plurality of resource blocks in a radio frequency spectrum of a wireless communication system, correlating, by the system, the interference information of the plurality of communication devices to generate correlated information, detecting, by the system, a plurality of interferers according to the correlated information, identifying, by the system, a profile for each of the plurality of interferers that describes characteristics of each of the plurality of interferers, and determining, by the system, a first temporal recurrence of a first interferer of the plurality of interferers according to the interference information associated with the first interferer.

One embodiment of the subject disclosure includes a machine-readable storage medium, comprising instructions, which when executed by a processor, cause the processor to perform operations comprising receiving interference information from each of a plurality of communication devices detecting interference information in a plurality of segments in a radio frequency spectrum of a wireless communication system, correlating the interference information of the plurality of communication devices to generate correlated information, identifying a plurality of interferers according to the correlated information, and approximating a location of the plurality of interferers according to information provided by the plurality of communication devices.

One embodiment of the subject disclosure includes a communication device, comprising a memory to store instructions, and a processor coupled to the memory, wherein execution of the instructions by the processor causes the processor to perform operations comprising receiving interference information from each of the plurality of communication devices detecting interference information in a plurality of segments of a radio frequency spectrum; correlating the interference information of the plurality of communication devices to generate correlated information; identifying a plurality of interferers according to the correlated information; and presenting an interference map of the plurality of interferers according to location information provided by the plurality of communication devices.

Interference signals can be generated from various sources including bi-directional amplifiers, unintended radiation from communication equipment (e.g., faulty transmitters of the carrier or other carriers), wireless microphones, garage door openers and similar production equipment, cross-border cellular (reduced buffer zones), federal and military installations, television transmissions, intermodulation from other transmitters, intermodulation from own faulty components and connectors, and so forth. One or more of the exemplary embodiments can mitigate interference from these sources through avoidance performed by the mobile communication device and/or the base station. The embodiments of the subject disclosure can be performed singly or in combination by a mobile communication device, a stationary communication device, base stations, a wireless hub used by a satellite communication system, and/or a system or systems in communication with the base stations, the wireless hub, and/or mobile communication devices.

The embodiments of the subject disclosure can be performed singly or in combination by a mobile communication device, a stationary communication device, base stations, a wireless hub used by a satellite communication system, and/or a system or systems in communication with the base stations, the wireless hub, and/or mobile communication devices.

As shown in FIG. **1**, an exemplary telecommunication system **10** may include mobile units **12**, **13**A, **13**B, **13**C, and **13**D, a number of base stations, two of which are shown in FIG. **1** at reference numerals **14** and **16**, and a switching station **18** to which each of the base stations **14**, **16** may be interfaced. The base stations **14**, **16** and the switching station **18** may be collectively referred to as network infrastructure.

During operation, the mobile units **12**, **13**A, **13**B, **13**C, and **13**D exchange voice, data or other information with one of the base stations **14**, **16**, each of which is connected to a conventional land line communication network. For example, information, such as voice information, transferred from the mobile unit **12** to one of the base stations **14**, **16** is coupled from the base station to the communication network to thereby connect the mobile unit **12** with, for example, a land line telephone so that the land line telephone may receive the voice information. Conversely, information, such as voice information may be transferred from a land line communication network to one of the base stations **14**, **16**, which in turn can transfer the information to the mobile unit **12**.

The mobile units **12**, **13**A, **13**B, **13**C, and **13**D and the base stations **14**, **16** may exchange information in either narrow band or wide band format. For the purposes of this description, it is assumed that the mobile unit **12** is a narrowband unit and that the mobile units **13**A, **13**B, **13**C, and **13**D are wideband units. Additionally, it is assumed that the base station **14** is a narrowband base station that communicates with the mobile unit **12** and that the base station **16** is a wideband digital base station that communicates with the mobile units **13**A, **13**B, **13**C, and **13**D.

Narrow band format communication takes place using, for example, narrowband 200 kilohertz (KHz) channels. The Global System for Mobile phone systems (GSM™) is one example of a narrow band communication system in which the mobile unit **12** communicates with the base station **14** using narrowband channels. Alternatively, the mobile units **13**A, **13**B, **13**C, and **13**D communicate with the base stations **16** using a form of digital communications such as, for example, code-division multiple access (CDMA), Universal Mobile Telecommunications System. (UMTS), 3GPP Long Term Evolution (LTE®), or other next generation wireless access technologies. CDMA digital communication, for instance, takes place using spread spectrum techniques that broadcast signals having wide bandwidths, such as, for example, 1.2288 megahertz (MHz) bandwidths.

The switching station **18** is generally responsible for coordinating the activities of the base stations **14**, **16** to ensure that the mobile units **12**, **13**A, **13**B, **13**C, and **13**D are constantly in communication with the base station **14**, **16** or with some other base stations that are geographically dispersed. For example, the switching station **18** may coordinate communication handoffs of the mobile unit **12** between the base stations **14** and another base station as the mobile unit **12** roams between geographical areas that are covered by the two base stations.

One particular problem that may arise in the telecommunication system **10** is when the mobile unit **12** or the base station **14**, each of which communicates using narrowband channels, interferes with the ability of the base station **16** to receive and process wideband digital signals from the digital mobile units **13**A, **13**B, **13**C, and **13**D. In such a situation, the narrowband signal transmitted from the mobile unit **12** or the base station **14** may interfere with the ability of the base station **16** to properly receive wideband communication signals.

As will be readily appreciated, the base station **16** may receive and process wideband digital signals from more than one of the digital mobile units **13**A, **13**B, **13**C, and **13**D. For example, the base station **16** may be adapted to receive and process four CDMA carriers **40**A-**40**D that fall within a multi-carrier CDMA signal **40**, as shown in FIG. **2**. In such a situation, narrowband signals transmitted from more than one mobile units, such as, the mobile unit **12**, may interfere with the ability of the base station **16** to properly receive wideband communication signals on any of the four CDMA carriers **40**A-**40**D. For example, FIG. **3** shows a multi-carrier CDMA signal **42** containing four CDMA carriers **42**A, **42**B, **42**C and **42**D adjacent to each other wherein one of the CDMA carriers **42**C has a narrowband interferer **46** therein. As shown in FIG. **3**, it is quite often the case that the signal strengths of the CDMA carrier signals **42**A-**42**D are not equal.

As disclosed in detail hereinafter, a system and/or a method for multiple channel adaptive filtering or interference suppression may be used in a communication system. In particular, such a system or method may be employed in a wideband communication system to protect against, or to report the presence of, narrowband interference, which has deleterious effects on the performance of the wideband communication system. Additionally, such a system and method may be operated to eliminate interference in CDMA carriers having other CDMA carriers adjacent thereto. In one embodiment, the system **100** can detect a location of one or more interferers and can perform antenna pattern adjustment to facilitate mitigation of interference for the devices **12** and **13**A-D. For example, the antenna pattern adjustment can cause the coverage area for the base station **14** and/or **16** to be adjusted so that the location of the interferer is outside of the coverage area or moved more to the boundary of the coverage area. In another embodiment, the antenna pattern adjustment can cause communication devices to shift between use of base stations such that a base station experiencing a higher amount of interference will have its traffic decreased and a base station experiencing a lower amount of interference (e.g., due to mitigation steps taken by that particular base station) will have its traffic increased.

As shown in FIG. **4**, the signal reception path of the base station **16**, which was described as receiving narrowband interference from the mobile unit **12** in conjunction with FIG. **1**, includes an antenna **50** that provides signals to a low noise amplifier (LNA) **52**. The output of the LNA **52** is coupled to a splitter **54** that splits the signal from the LNA **52** into a number of different paths, one of which may be coupled to an adaptive front end **56** and another of which may be coupled to a narrowband receiver **58**. The output of the adaptive front end **56** is coupled to a wideband receiver **60**, which may, for example, be embodied in a CDMA receiver or any other suitable wideband receiver. The narrowband receiver **58** may be embodied in a 15 KHz bandwidth receiver or in any other suitable narrowband receiver. Although only one signal path is shown in FIG. **4**, it will be readily understood to those having ordinary skill in the art that such a signal path is merely exemplary and that, in reality, a base station may include two or more such signal paths that may be used to process main and diversity signals received by the base station **16**.

It will be readily understood that the illustrations of FIG. **4** can also be used to describe the components and functions of other forms of communication devices such as a small base station, a femtocell, a WiFi router or access point, a cellular phone, a smart phone, a laptop computer, a tablet, or other forms of wireless communication devices suitable for applying the principles of the subject disclosure. Accordingly, such communication devices can include variants of the components shown in FIG. **4** and perform the functions that will be described below. For illustration purposes only, the descriptions below will address the base station **16** with an understanding that these embodiments are exemplary and non-limiting to the subject disclosure.

Referring back to FIG. **4**, the outputs of the narrowband receiver **58** and the wideband receiver **60** can be coupled to other systems within the base station **16**. Such systems may perform voice and/or data processing, call processing or any other desired function. Additionally, the adaptive front end module **56** may also be communicatively coupled, via the Internet, telephone lines, cellular network, or any other suitable communication systems, to a reporting and control facility that is remote from the base station **16**. In some networks, the reporting and control facility may be integrated with the switching station **18**. The narrowband receiver **58** may be communicatively coupled to the switching station **18** and may respond to commands that the switching station **18** issues.

One or more of the components **50-60** of the base station **16** shown in FIG. **4**, except for the adaptive front end module **56**, may be found in a wideband cellular base station **16**, the details of which are well known to those having ordinary skill in the art. It will also be appreciated by those having ordinary skill in the art that FIG. **4** does not disclose every system or subsystem of the base station **16** and, rather, focuses on the relevant systems and subsystems to the subject disclosure. In particular, it will be readily appreciated that, while not shown in FIG. **4**, the base station **16** can include a transmission system or other subsystems. It is further appreciated that the adaptive front end module **56** can be an integral subsystem of a wideband cellular base station **16**, or can be a modular subsystem that can be physically placed in different locations of a receiver chain of the base station **16**, such as at or near the antenna **50**, at or near the LNA **52**, or at or near the wideband receiver **60**.

During operation of the base station **16**, the antenna **50** receives CDMA carrier signals that are broadcast from the mobile unit **13**A, **13**B, **13**C and **13**D and couples such signals to the LNA **52**, which amplifies the received signals and couples the amplified signals to the splitter **54**. The splitter **54** splits the amplified signal from the LNA **52** and essentially places copies of the amplified signal on each of its output lines. The adaptive front end module **56** receives the signal from the splitter **54** and, if necessary, filters the CDMA carrier signal to remove any undesired narrowband interference and couples the filtered CDMA carrier signal to the wideband receiver **60**.

As noted previously, FIG. **2** illustrates an ideal frequency spectrum **40** of a CDMA carrier signal that may be received at the antenna **50**, amplified and split by the LNA **52** and the splitter **54** and coupled to the adaptive front end module **56**. If the CDMA carrier signal received at the antenna **50** has a frequency spectrum **40** as shown in FIG. **2** without any narrowband interference, the adaptive front end will not filter the CDMA carrier signal and will simply couple the wideband signal directly through the adaptive front end module **56** to the wideband receiver **60**.

However, as noted previously, it is possible that the CDMA carrier signal transmitted by the mobile units **13A-13**D and received by the antenna **50** has a frequency spectrum as shown in FIG. **3** which contains a multi-carrier CDMA signal **42** that includes not only the four CDMA carriers **42**A, **42**B, **42**C and **42**D from the mobile units **13**A, **13**B, **13**C and **13**D having unequal CDMA carrier strengths, but also includes narrowband interferer **46**, as shown in FIG. **3**, which in this illustration is caused by mobile unit **12**. If a multi-carrier CDMA signal having a multi-carrier CDMA signal **42** including narrowband interferer **46** is received by the antenna **50** and amplified, split and presented to the adaptive front end module **56**, it will filter the multi-carrier CDMA signal **42** to produce a filtered frequency spectrum **43** as shown in FIG. **5**.

The filtered multi-carrier CDMA signal **43** has the narrowband interferer **46** removed, as shown by the notch **46**A. The filtered multi-carrier CDMA signal **43** is then coupled from the adaptive front end module **56** to the wideband receiver **60**, so that the filtered multi-carrier CDMA signal **43** may be demodulated. Although some of the multi-carrier CDMA signal **42** was removed during filtering by the adaptive front end module **56**, sufficient multi-carrier CDMA signal **43** remains to enable the wideband receiver **60** to recover the information that was broadcast by mobile unit(s). Accordingly, in general terms, the adaptive front end module **56** selectively filters multi-carrier CDMA signals to remove narrowband interference therefrom. Further detail regarding the adaptive front end module **56** and its operation is provided below in conjunction with FIGS. **6-20**.

FIG. **3** depicts another example embodiment of the adaptive front end module **56**. As noted earlier, the adaptive front end module **56** can be utilized by any communication device including cellular phones, smartphones, tablets, small base stations, femto cells, WiFi access points, and so on. In the illustration of FIG. **3**, the adaptive front end module **56** can include a radio **60** comprising two stages, a receiver stage **62** and a transmitter stage **64**, each coupled to an antenna assembly **66**, **66'**, which may comprise one of more antennas for the radio **60**. The radio **60** has a first receiver stage coupled to the antenna assembly **66** and includes an adaptive front-end controller **68** that receives the input RF signal from the antenna and performs adaptive signal processing on that RF signal before providing the modified RF signal to an analog-to-digital converter **70**, which then passes the adapted RF signal to a digital RF tuner **72**.

As shown in FIG. **6**, the adaptive front end controller **68** of the receiver stage **62** includes two RF signal samplers **74**, **76** connected between an RF adaptive filter stage **78** that is controlled by controller **80**. The adaptive filter stage **78** may have a plurality of tunable digital filters that can sample an incoming signal and selectively provide bandpass or bandstop signal shaping of an incoming RF signal, whether it is an entire wideband communication signal or a narrowband signal or various combinations of both. A controller **80** is coupled to the samplers **74**, **76** and filter stage **78** and serves as an RF link adapter that along with the sampler **74** monitors the input RF signal from the antenna **66** and determines various RF signal characteristics such as the interferences and noise within the RF signal. The controller **80** is configured to execute any number of a variety of signal processing algorithms to analyze the received RF signal, and determine a filter state for the filter stage **78**.

By providing tuning coefficient data to the filter stage **78**, the adaptive front end controller **68** acts to pre-filter the received RF signal before the signal is sent to the RF tuner **72**, which analyzes the filtered RF signal for integrity and/or for other applications such as cognitive radio applications. After filtering, the radio tuner **72** may then perform channel demodulation, data analysis, and local broadcasting functions. The RF tuner **72** may be considered the receiver side of an overall radio tuner, while RF tuner **72'** may be considered the transmitter side of the same radio tuner. Prior to sending the filtered RF signal, the sampler **76** may provide an indication of the filtered RF signal to the controller **80** in a feedback manner for further adjusting of the adaptive filter stage **78**.

In some examples, the adaptive front-end controller **68** is synchronized with the RF tuner **72** by sharing a master clock signal communicated between the two. For example, cognitive radios operating on a 100 μs response time can be synchronized such that for every clock cycle the adaptive front end analyzes the input RF signal, determines an optimal configuration for the adaptive filter stage **78**, filters that RF signal into the filtered RF signal and communicates the same to the radio tuner **72** for cognitive analysis at the radio. By way of example, cellular phones may be implemented with a 200 μs response time on filtering. By implementing the adaptive front end controller **68** using a field programmable gate array configuration for the filter stage, wireless devices may identify not only stationary interference, but also non-stationary interference, of arbitrary bandwidths on that moving interferer.

In some implementations, the adaptive front-end controller **68** may filter interference or noise from the received incoming RF signal and pass that filtered RF signal to the tuner **72**. In other examples, such as cascaded configurations in which there are multiple adaptive filter stages, the adaptive front-end controller **68** may be configured to apply the filtered signal to an adaptive bandpass filter stage to create a passband portion of the filtered RF signal. For example, the radio tuner **72** may communicate information to the controller **68** to instruct the controller that the radio is only looking at a portion of an overall RF spectrum and thus cause the adaptive front-end controller **68** not to filter certain portions of the RF spectrum and thereby bandpass only those portions. The integration between the radio tuner **72** and the adaptive front-end controller **68** may be particularly useful in dual-band and tri-band applications in which the radio tuner **72** is able to communicate over different wireless standards, such as GSM or UMTS standards.

The algorithms that may be executed by the controller **80** are not limited to interference detection and filtering of interference signals. In some configurations the controller **80** may execute a spectral blind source separation algorithm that looks to isolate two sources from their convolved mixtures. The controller **80** may execute a signal to interference noise ratio (SINR) output estimator for all or portions of the RF signal. The controller **80** may perform bidirectional transceiver data link operations for collaborative retuning of the adaptive filter stage **78** in response to instructions from the radio tuner **72** or from data the transmitter stage **64**. The controller **80** can determine filter tuning coefficient data for configuring the various adaptive filters of stage **78** to properly filter the RF signal. The controller **80** may also include a data interface communicating the tuning coefficient data to the radio tuner **72** to enable the radio tuner **72** to determine filtering characteristics of the adaptive filter **78**.

In one embodiment the filtered RF signal may be converted from a digital signal to an analog signal within the adaptive front-end controller **68**. This allows the controller **68** to integrate in a similar manner to conventional RF filters. In other examples, a digital interface may be used to connect the adaptive front-end controller **68** with the radio tuner **72**, in which case the ADC **70** would not be necessary.

The above discussion is in the context of the receiver stage **62**. Similar elements are shown in the transmitter stage **64**, but bearing a prime. The elements in the transmitter stage **64** may be similar to those of the receiver **62**, with the exception of the digital to analog converter (DAC) **70'** and other adaptations to the other components shown with a prime in the reference numbers. Furthermore, some or all of these components may in fact be executed by the same corresponding structure in the receiver stage **62**. For example, the RF receiver tuner **72** and the transmitter tuner **72'** may be performed by a single tuner device. The same may be true for the other elements, such as the adaptive filter stages **78** and **78'**, which may both be implemented in a single FPGA, with different filter elements in parallel for full duplex (simultaneous) receive and transmit operation.

FIG. **7** illustrates another example implementation of an adaptive front-end controller **100**. Input RF signals are received at an antenna (not shown) and coupled to an initial analog filter **104**, such as low noise amplifier (LNA) block, then digitally converted via an analog to digital converter (ADC) **106**, prior to the digitized input RF signal being coupled to a field programmable gate array (FPGA) **108**. The adaptive filter stage described above may be implemented within the FPGA **108**, which has been programmed to contain a plurality of adaptive filter elements tunable to different operating frequencies and frequency bands, and at least some being adaptive from a bandpass to a bandstop configuration or vice versa, as desired. Although an FPGA is illustrated, it will be readily understood that other architectures such as an application specific integrated circuit (ASIC) or a digital signal processor (DSP) may also be used to implement a digital filter architecture described in greater detail below.

A DSP **110** is coupled to the FPGA **108** and executes signal processing algorithms that may include a spectral blind source separation algorithm, a signal to interference noise ratio (SINR) output estimator, bidirectional transceiver data line operation for collaborative retuning of the adaptive filter stage in response to instructions from the tuner, and/or an optimal filter tuning coefficients algorithm.

FPGA **108** is also coupled to a PCI target **112** that interfaces the FPGA **108** and a PCI bus **114** for communicating data externally. A system clock **118** provides a clock input to the FPGA **108** and DSP **110**, thereby synchronizing the components. The system clock **118** may be locally set on the adaptive front-end controller, while in other examples the system claim **118** may reflect an external master clock, such as that of a radio tuner. The FPGA **108**, DSP **110**, and PCI target **112**, designated collectively as signal processing module **116**, will be described in greater detail below. In the illustrated example, the adaptive front-end controller **100** includes a microcontroller **120** coupled to the PCI bus **114** and an operations, alarms and metrics (OA&M) processor **122**. Although they are shown and described herein as separate devices that execute separate software instructions, those having ordinary skill in the art will readily appreciate that the functionality of the microcontroller **120** and the OA&M processor **122** may be merged into a single processing device. The microcontroller **120** and the OA&M processor **122** are coupled to external memories **124** and **126**, respectively. The microcontroller **120** may include the ability to communicate with peripheral devices, and, as such, the microcontroller **120** may be coupled to a USB port, an Ethernet port, or an RS232 port, among others (though none shown). In operation, the microcontroller **120** may locally store lists of channels having interferers or a list of known typically available frequency spectrum bands, as well as various other parameters. Such a list may be transferred to a reporting and control facility or a base station, via the OA&M processor **122**, and may be used for system diagnostic purposes.

The aforementioned diagnostic purposes may include, but are not limited to, controlling the adaptive front-end controller **100** to obtain particular information relating to an interferer and re-tasking the interferer. For example, the reporting and control facility may use the adaptive front-end controller **100** to determine the identity of an interferer, such as a mobile unit, by intercepting the electronic serial number (ESN) of the mobile unit, which is sent when the mobile unit transmits information on the narrowband channel. Knowing the identity of the interferer, the reporting and control facility may contact infrastructure that is communicating with the mobile unit (e.g., the base station) and may request the infrastructure to change the transmit frequency for the mobile unit (i.e., the frequency of the narrowband channel on which the mobile unit is transmitting) or may request the infrastructure to drop communications with the interfering mobile unit altogether.

Additionally, in a cellular configuration (e.g., a system based on a configuration like that of FIG. **1**) diagnostic purposes may include using the adaptive front-end controller **100** to determine a telephone number that the mobile unit is attempting to contact and, optionally handling the call. For example, the reporting and control facility may use the adaptive front-end controller **100** to determine that the user of the mobile unit was dialing 911, or any other emergency number, and may, therefore, decide that the adaptive front-end controller **100** should be used to handle the emergency call by routing the output of the adaptive front-end controller **100** to a telephone network.

The FPGA **108** can provide a digital output coupled to a digital to analog converter (DAC) **128** that converts the digital signal to an analog signal which may be provided to a filter **130** to generate a filtered RF output to be broadcast from the base station or mobile station. The digital output at the FPGA **108**, as described, may be one of many possible outputs. For example, the FPGA **108** may be configured to output signals based on a predefined protocol such as a Gigabit Ethernet output, an open base station architecture initiative (OBSAI) protocol, or a common public radio interface (CPRI) protocol, among others.

It is further noted that the aforementioned diagnostic purposes may also include creating a database of known interferers, the time of occurrence of the interferers, the frequency of occurrence of the interferers, spectral information relating to the interferers, a severity analysis of the interferers, and so on. The identity of the interferers may be based solely on spectral profiles of each interferer that can be used for identification purposes. Although the aforementioned illustrations describe a mobile unit **12** as an interferer, other sources of interference are possible. Any electronic appliance that generates electromagnetic waves such as, for example, a computer, a set-top box, a child monitor, a wireless access point (using, for example, a communications standard such as WiFi™, ZigBee®, Bluetooth®, etc.) can be a source of interference (Bluetooth® and ZigBee® are trademarks registered by the Bluetooth Special Interest Group and the ZigBee Alliance, respectively). In one embodiment, a database of electronic appliances can be analyzed in a laboratory setting or other suitable testing environment to determine an interference profile for each appliance. The interference profiles can be stored in a database according to an appliance type, manufacturer, model number, and other parameters that may be useful in identifying an interferer. Spectral profiles provided by, for example, the OA&M processor **108** to a diagnostic system can be compared to a database of previously characterized interferers to determine the identity of the interference when a match is detected.

A diagnostic system, whether operating locally at the adaptive front end controller, or remotely at a base station, switching station, or server system, can determine the location of the interferer near the base station (or mobile unit) making the detection, or if a more precise location is required, the diagnostic system can instruct several base stations (or mobile units) to perform triangulation analysis to more precisely locate the source of the interference if the interference is frequent and measureable from several vantage points. With location data, interference identity, timing and frequency of occurrence, the diagnostic system can generate temporal and geographic reports showing interferers providing field personnel a means to assess the volume of interference, its impact on network performance, and it may provide sufficient information to mitigate interference by means other than filtering, such as, for example, interference avoidance by way of antenna steering at the base station, beam steering, retasking an interferer when possible, and so on.

FIG. **8** illustrates further details of an example implementation of a signal processing module **116** that may serve as another embodiment of an adaptive front end controller, it being understood that other architectures may be used to implement a signal detection algorithm. A decoder **150** receives an input from the ADC **106** and decodes the incoming data into a format suitable to be processed by the signal processing module **116**. A digital down converter **152**, such as a polyphase decimator, down converts the decoded signal from the decoder **150**. The decoded signal is separated during the digital down conversion stage into a complex representation of the input signal, that is, into In-Phase (I) and Quadrature-Phase (Q) components which are then fed into a tunable infinite impulse response (IIR)/finite impulse response (FIR) filter **154**. The IIR/FIR filter **154** may be implemented as multiple cascaded or parallel IIR and FIR filters. For example, the IIR/FIR filter **154** may be used with multiple filters in series, such as initial adaptive bandpass filter followed by adaptive bandstop filter. For example, the bandpass filters may be implemented as FIR filters, while the bandstop filters may be implemented as IIR filters. In an embodiment, fifteen cascaded tunable IIR/FIR filters are used to optimize the bit width of each filter. Of course other digital down converters and filters such as cascaded integrator-comb (CIC) filters may be used, to name a few. By using complex filtering techniques, such as the technique described herein, the sampling rate is lowered thereby increasing (e.g., doubling) the bandwidth that the filter **154** can handle. In addition, using complex arithmetic also provides the signal processing module **116** the ability to perform higher orders of filtering with greater accuracy.

The I and Q components from the digital down converter **152** are provided to the DSP **110** which implements a detection algorithm and in response provides the tunable IIR/FIR filter **154** with tuning coefficient data that tunes the IIR and/or FIR filters **154** to specific notch (or bandstop) and/or bandpass frequencies, respectively, and specific bandwidths. The tuning coefficient data, for example, may include a frequency and a bandwidth coefficient pair for each of the adaptive filters, which enables the filter to tune to a frequency for bandpass or bandstop operation and the bandwidth to be applied for that operation. The tuning coefficient data corresponding to a bandpass center frequency and bandwidth may be generated by the detection algorithm and passed to a tunable FIR filter within the IIR/FIR filter **154**. The filter **154** may then pass all signals located within a passband of the given transmission frequency. Tuning coefficient data corresponding to a notch (or bandstop) filter may be generated by the detection algorithm and then applied to an IIR filter within the IIR/FIR filter **154** to remove any narrowband interference located within the passband of the bandpass filter. The tuning coefficient data generated by the detection algorithm are implemented by the tunable IIR/FIR filters **154** using mathematical techniques known in the art. In the case of a cognitive radio, upon implementation of the detection algorithm, the DSP **110** may determine and return coefficients corresponding to a specific frequency and bandwidth to be implemented by the tunable IIR/FIR filter **154** through a DSP/PCI interface **158**. Similarly, the transfer function of a notch (or bandstop) filter may also be implemented by the tunable

IIR/FIR filter **154**. Of course other mathematical equations may be used to tune the IIR/FIR filters **154** to specific notch, bandstop, or bandpass frequencies and to a specific bandwidth.

After the I and Q components are filtered to the appropriate notch (or bandstop) or bandpass frequency at a given bandwidth, a digital upconverter **156**, such as a polyphase interpolator, converts the signal back to the original data rate, and the output of the digital upconverter is provided to the DAC **128**.

A wireless communication device capable to be operated as a dual- or tri-band device communicating over multiple standards, such as over GSM and UMTS may use the adaptive digital filter architecture embodiments as described above. For example, a dual-band device (using both UMTS and GSM) may be preprogrammed within the DSP **110** to transmit first on UMTS, if available, and on GSM only when outside of a UMTS network. In such a case, the IIR/FIR filter **154** may receive tuning coefficient data from the DSP **110** to pass all signals within a UMTS range. That is, the tuning coefficient data may correspond to a bandpass center frequency and bandwidth adapted to pass only signals within the UMTS range. The signals corresponding to a GSM signal may be filtered, and any interference caused by the GSM signal may be filtered using tuning coefficients, received from the DSP **110**, corresponding to a notch (or bandstop) frequency and bandwidth associated with the GSM interference signal.

Alternatively, in some cases it may be desirable to keep the GSM signal in case the UMTS signal fades quickly and the wireless communication device may need to switch communication standards rapidly. In such a case, the GSM signal may be separated from the UMTS signal, and both passed by the adaptive front-end controller. Using the adaptive digital filter, two outputs may be realized, one output corresponding to the UMTS signal and one output corresponding to a GSM signal. The DSP **110** may be programmed to again recognize the multiple standard service and may generate tuning coefficients corresponding to realize a filter, such as a notch (or bandstop) filter, to separate the UMTS signal from the GSM signal. In such examples, an FPGA may be programmed to have parallel adaptive filter stages, one for each communication band.

To implement the adaptive filter stages, in some examples, the signal processing module **116** is pre-programmed with general filter architecture code at the time of production, for example, with parameters defining various filter types and operation. The adaptive filter stages may then be programmed, through a user interface or other means, by the service providers, device manufactures, etc., to form the actual filter architecture (parallel filter stages, cascaded filter stages, etc.) for the particular device and for the particular network(s) under which the device is to be used. Dynamic flexibility can be achieved during runtime, where the filters may be programmed to different frequencies and bandwidths, each cycle, as discussed herein.

One method of detecting a wideband signal having narrowband interference is by exploiting the noise like characteristics of a signal. Due to such noise like characteristics of the signal, a particular measurement of a narrowband channel power gives no predictive power as to what the next measurement of the same measurement channel may be. In other words, consecutive observations of power in a given narrowband channel are un-correlated. As a result, if a given measurement of power in a narrowband channel provides predictive power over subsequent measurements of power in that particular channel, thus indicating a departure from statistics expected of a narrowband channel without interference, such a narrowband channel may be determined to contain interference.

FIG. **9** illustrates an IS-95 CDMA signal **202**, which is a generic Direct Sequence Spread Spectrum (DSSS) signal. The CDMA signal **202** may have a bandwidth of 1.2288 MHz and it may be used to carry up to 41 narrowband channels, each of which has a bandwidth of 30 kHz. One way to identify interference affecting the CDMA signal **202** may be to identify any of such 41 narrowband channels having excess power above an expected power of the CDMA signal **202**. FIG. **9** also illustrates the probability distribution functions (PDFs) **204** of a typical DSSS signal and a complementary cumulative distribution functions (CCDFs) **206** of a typical DSSS signal, which may be used to establish a criteria used to determine narrowband channels disposed within a wideband signal and having excess power.

Specifically, the PDFs **204** include probability distribution of power in a given channel, which is the likelihood p(x) of measuring a power x in a given channel, for a DSSS signal carrying one mobile unit (**212**), for a DSSS signal carrying ten mobile units (**214**), and for a DSSS signal carrying twenty mobile units (**210**). For example, for the PDF **212**, representing a DSSS signal carrying one mobile unit, the distribution p(x) is observed to be asymmetric, with an abbreviated high power tail. In this case, any channel having power higher than the high power tail of the PDF **212** may be considered to have an interference signal.

The CCDFs **206** denote the likelihood that a power measurement in a channel will exceed a given mean power α, by some value α/σ, wherein σ is standard deviation of the power distribution. Specifically, the CCDFs **206** include an instance of CCDF for a DSSS signal carrying one mobile unit (**220**), an instance of CCDF for a DSSS signal carrying ten mobile units (**222**), and an instance of CCDF for a DSSS signal carrying twenty mobile units (**224**). Thus, for example, for a DSSS signal carrying one mobile unit, the likelihood of any narrowband channel having the ratio α/σ of 10 dB or more is 0.01%. Therefore, an optimal filter can be tuned to such a narrowband channel having excess power.

One method of detecting such a narrowband channel having interference is by exploiting the noise like characteristic of a DSSS signal. Due to such noise like characteristic of DSSS signal, a particular measurement of a narrowband channel power gives no predictive power as to what the next measurement of the same measurement channel may be. In other words, consecutive observations of power in a given narrowband channels are un-correlated. As a result, if a given measurement of power in a narrowband channel provides predictive power over subsequent measurements of power in that particular channel, thus indicating a departure from statistics expected of a narrowband channel without interference, such a narrowband channel may be determined to contain interference.

FIG. **10** illustrates a flowchart of an interference detection program **300** that may be used to determine location of interference in a DSSS signal. At block **302** a series of DSSS signals can be scanned by the adaptive front end controller described above and the observed values of the signal strengths can be stored for each of various narrowband channels located in the DSSS signal. For example, at block **302** the adaptive front end controller may continuously scan the 1.2288 MHz DSSS signal **60** for each of the 41 narrowband channels dispersed within it. The adaptive front end controller may be implemented by any analog scanner or digital signal processor (DSP) used to scan and store signal strengths in a DSSS signal. The scanned values of narrowband signal strengths may be stored in a memory of such DSP or in any other computer readable memory. The adaptive front end controller may store the signal strength of a particular narrowband channel along with any information, such as a numeric identifier, identifying the location of that particular narrowband channel within the DSSS signal.

At block **304** the adaptive front end controller can determine the number of sequences m of a DSSS signal that may be required to be analyzed to determine narrowband channels having interference. A user may provide such a number m based on any pre-determined criteria. For example, a user may provide m to be equal to four, meaning that four consecutive DSSS signals need to be analyzed to determine if any of the narrowband channels within that DSSS signal spectrum includes an interference signal. As one of ordinary skill in the art would appreciate, the higher is the selected value of m, the more accurate will be the interference detection. However, the higher the number m is, the higher is the delay in determining whether a particular DSSS signal had an interference present in it, subsequently, resulting in a longer delay before a filter is applied to the DSSS signal to remove the interference signal.

Generally, detection of an interference signal may be performed on a rolling basis. That is, at any point in time, m previous DSSS signals may be used to analyze presence of an interference signal. The earliest of such m interference signals may be removed from the set of DSSS signals used to determine the presence of an interference signal on a first-in-first-out basis. However, in an alternate embodiment, an alternate sampling method for the set of DSSS signals may also be used.

At block **306** the adaptive front end controller can select x narrowband channels having the highest signal strength from each of the m most recent DSSS signals scanned at the block **302**. The number x may be determined by a user. For example, if x is selected to be equal to three, the block **306** may select three highest channels from each of the m most recent DSSS signals. The methodology for selecting x narrowband channels having highest signal strength from a DSSS signal is described in further detail in FIG. **11** below. For example, the adaptive front end controller at block **306** may determine that the first of the m DSSS signals has narrowband channels **10**, **15** and **27** having the highest signal strengths, the second of the m DSSS channels has narrowband channels **15** and **27** and **35** having the highest signal strengths, and the third of the m DSSS channels has the narrowband channels **15**, **27** and **35** having the highest narrowband signal strength.

After having determined the x narrowband channels having the highest signal strengths in each of the m DSSS signals, at block **308** the adaptive front end controller can compare these x narrowband channels to determine if any of these highest strength narrowband channels appear more than once in the m DSSS signals. In case of the example above, the adaptive front end controller at block **308** may determine that the narrowband channels **15** and **27** are present among the highest strength narrowband channels for each of the last three DSSS signals, while channel **35** is present among the highest strength narrowband channels for at least two of the last three DSSS signals.

Such consistent appearance of narrowband channels having highest signal strength over subsequent DSSS signals indicate that narrowband channels **15** and **27**, and probably the narrowband channel **35**, may have an interference signal super-imposed on them. At block **310** the adaptive front end controller may use such information to determine which narrowband channels may have interference. For example, based on the number of times a given narrowband channel appears in the selected highest signal strength channels, the adaptive front end controller at block **310** may determine the confidence level that may be assigned to a conclusion that a given narrowband channel contains an interference signal.

Alternatively, at block **310** the adaptive front end controller may determine a correlation factor for each of the various narrowband channels appearing in the x selected highest signal strength channels and compare the calculated correlation factors with a threshold correlation factor to determine whether any of the x selected channels has correlated signal strengths. Calculating a correlation factor based on a series of observations is well known to those of ordinary skill in the art and therefore is not illustrated in further detail herein. The threshold correlation factor may be given by the user of the interference detection program **300**.

Note that while in the above illustrated embodiment, the correlation factors of only the selected highest signal strength channels are calculated, in an alternate embodiment, correlation factors of all the narrowband channels within the DSSS signals may be calculated and compared to the threshold correlation factor.

Empirically, it may be shown that when m is selected to be equal to three, for a clean DSSS signal, the likelihood of having at least one match among the higher signal strength narrowband channels is 0.198, the likelihood of having at least two matches among the higher signal strength narrowband channels is 0.0106, and the likelihood of having at least three matches among the higher signal strength narrowband channels is 9.38×10^{-5}. Thus, the higher the number of matches, the lesser is the likelihood of having a determination that one of the x channels contains an interference signal (i.e., a false positive interference detection). It may be shown that if the number of scans m is increased to, say four DSSS scans, the likelihood of having such matches in m consecutive scans is even smaller, thus providing higher confidence that if such matches are found to be present, they indicate presence of interference signal in those narrowband channels.

To identify the presence of interference signals with even higher level of confidence, at block **312** the adaptive front end controller may decide whether to compare the signal strengths of the narrowband channels determined to have an interference signal with a threshold. If at block **312** the adaptive front end controller decides to perform such a comparison, at block **314** the adaptive front end controller may compare the signal strength of each of the narrowband channels determined to have an interference with a threshold level. Such comparing of the narrowband channel signal strengths with a threshold may provide added confidence regarding the narrowband channel having an interference signal so that when a filter is configured according to the narrowband channel, the probability of removing a non-interfering signal is reduced. However, a user may determine that such added confidence level is not necessary and thus no such comparison to a threshold needs to be performed. In which case, at block **316** the adaptive front end controller stores the interference signals in a memory.

After storing the information about the narrowband channels having interference signals, at block **318** the adaptive front end controller selects the next DSSS signal from the signals scanned and stored at block **302**. At block **318** the adaptive front end controller may cause the first of the m DSSS signals to be dropped and the newly added DSSS signal is added to the set of m DSSS signals that will be used to determine presence of an interference signal (first-in-first-out). Subsequently, at block **306** the process of determining narrowband channels having interference signals is repeated by the adaptive front end controller. Finally, at block **320** the adaptive front end controller may select and activate one or more filters that are located in the path of the DSSS signal to filter out any narrowband channel identified as having narrowband interference in it.

Now referring to FIG. **11**, a flowchart illustrates a high strength channels detection program **350** that may be used to identify various channels within a given scan of the DSSS signal that may contain an interference signal. The high strength channels detection program **350** may be used to implement the functions performed at block **306** of the interference detection program **300**. In a manner similar to the interference detection program **300**, the high strength channels detection program **350** may also be implemented using software, hardware, firmware or any combination thereof.

At block **352** the adaptive front end controller may sort signal strengths of each of the n channels within a given DSSS signal. For example, if a DSSS signal has 41 narrowband channels, at block **352** the adaptive front end controller may sort each of the 41 narrowband channels according to its signal strengths. Subsequently, at block **354** the adaptive front end controller may select the x highest strength channels from the sorted narrowband channels and store information identifying the selected x highest strength channels for further processing. An embodiment of the high strength channels detection program **350** may simply use the selected x highest strength channels from each scan of the DSSS signals to determine any presence of interference in the DSSS signals. However, in an alternate embodiment, additional selected criteria may be used.

Subsequently, at block **356** the adaptive front end controller can determine if it is necessary to compare the signal strengths of the x highest strength narrowband channels to any other signal strength value, such as a threshold signal strength, etc., where such a threshold may be determined using the average signal strength across the DSSS signal. For example, at block **356** the adaptive front end controller may use a criterion such as, for example: "when x is selected to be four, if at least three out of four of the selected narrowband channels have also appeared in previous DSSS signals, no further comparison in necessary." Another criterion may be, for example: "if any of the selected narrowband channels is located at the fringe of the DSSS signal, the signal strengths of such narrowband channels should be compared to a threshold signal strength." Other alternate criteria may also be provided.

If at block **356** the adaptive front end controller determines that no further comparison of the signal strengths of the selected x narrowband channels is necessary, at block **358** the adaptive front end controller stores information about the selected x narrowband channels in a memory for further processing. If at block **356** the adaptive front end controller determines that it is necessary to apply further selection criteria to the selected x narrowband channels, the adaptive front end controller returns to block **360**. At block **360** the adaptive front end controller may determine a threshold value against which the signal strengths of each of the x narrowband channels are compared based on a predetermined methodology.

For example, in an embodiment, at block **360** the adaptive front end controller may determine the threshold based on the average signal strength of the DSSS signal. The threshold signal strength may be the average signal strength of the DSSS signal or a predetermined value may be added to such average DSSS signal to derive the threshold signal strength.

Subsequently, at block **362** the adaptive front end controller may compare the signal strengths of the selected x narrowband channels to the threshold value determined at block **360**. Only the narrowband channels having signal strengths higher than the selected threshold are used in determining presence of interference in the DSSS signal. Finally, at block **364** the adaptive front end controller may store information about the selected x narrowband channels having signal strengths higher than the selected threshold in a memory. As discussed above, the interference detection program **300** may use such information about the selected narrowband channels to determine the presence of interference signal in the DSSS signal.

The interference detection program **300** and the high strength channel detection program **350** may be implemented by using software, hardware, firmware or any combination thereof. For example, such programs may be stored on a memory of a computer that is used to control activation and deactivation of one or more notch filters. Alternatively, such programs may be implemented using a digital signal processor (DSP) which determines the presence and location of interference channels in a dynamic fashion and activates/deactivates one or more filters.

FIG. **12** illustrates a three dimensional graph **370** depicting several DSSS signals **372-374** over a time period. A first axis of the graph **370** illustrates the number of narrowband channels of the DSSS signals **372-374**, a second axis illustrates time over which a number of DSSS signals **372-374** are scanned, and a third axis illustrates the power of each of the narrowband channels. The DSSS signals **372-374** are shown to be affected by an interference signal **378**.

The interference detection program **370** may start scanning various DSSS signals **372-374** starting from the first DSSS signal **372**. As discussed above at block **304** the adaptive front end controller determines the number m of the DSSS signals **372-374** that are to be scanned. Because the interference signal **378** causes the signal strength of a particular narrowband channel to be consistently higher than the other channels for a number of consecutive scans of the DSSS signals **372-374** at block **210** the adaptive front end controller identifies a particular channel having an interference signal present. Subsequently, at block **320** the adaptive front end controller will select and activate a filter that applies the filter function as described above, to the narrowband channel having interference.

The graph **370** also illustrates the average signal strengths of each of the DSSS signals **372-374** by a line **376**. As discussed above, at block **362** the adaptive front end controller may compare the signal strengths of each of the x selected narrowband channels from the DSSS signals **372-374** with the average signal strength, as denoted by line **376**, in that particular DSSS signal.

Now referring to FIG. **13**, a graph **380** illustrates interference detection success rate of using the interference detection program **370**, as a function of strength of an interference signal affecting a DSSS signal. The x-axis of the graph **380** depicts the strength of interference signal relative to the strength of the DSSS signal, while the y-axis depicts the detection success rate in percentages. As illustrated, when an interference signal has a strength of at least 2 dB higher than the strength of the DSSS signal, such an interference signal is detected with at least ninety five percent success rate.

The foregoing interference detection and mitigation embodiments can further be adapted for detecting and mitigating interference in long-term evolution (LTE) communication systems.

LTE transmission consists of a combination of Resource Blocks (RB's) which have variable characteristics in frequency and time. A single RB can be assigned to a user equipment, specifically, a 180 KHz continuous spectrum utilized for 0.5-1 msec. An LTE band can be partitioned into a number of RBs which could be allocated to individual communication devices for specified periods of time for LTE transmission. Consequently, an LTE spectrum has an RF environment dynamically variable in frequency utilization over time. FIG. **14** depicts an illustrative LTE transmission.

LTE utilizes different media access methods for downlink (orthogonal frequency-division multiple access; generally, referred to as OFDMA) and uplink (single carrier frequency-division multiple access; generally, referred to as SC-FDMA). For downlink communications, each RB contains 12 sub-carriers with 15 KHz spacing. Each sub-carrier can be used to transmit individual bit information according to the OFDMA protocol. For uplink communications, LTE utilizes a similar RB structure with 12 sub-carriers, but in contrast to downlink, uplink data is pre-coded for spreading across 12 sub-carriers and is transmitted concurrently on all 12 sub-carriers.

The effect of data spreading across multiple sub-carriers yields a transmission with spectral characteristics similar to a CDMA/UMTS signal. Hence, similar principles of narrow band interference detection can be applied within an instance of SC-FDMA transmission from an individual communication device—described herein as user equipment (UE). However, since each transmission consists of unknown RB allocations with unknown durations, such a detection principle can only be applied separately for each individual RB within a frequency and specific time domain. If a particular RB is not used for LTE transmission at the time of detection, the RF spectrum will present a thermal noise which adheres to the characteristics of a spread spectrum signal, similar to a CDMA/UMTS signal.

Co-channel, as well as other forms of interference, can cause performance degradation to SC-FDMA and OFDMA signals when present. FIG. **15** depicts an illustration of an LTE transmission affected by interferers **402**, **404**, **406** and **408** occurring at different points in time. Since such LTE transmissions do not typically have flat power spectral densities (see FIG. **14**), identification of interference as shown in FIG. **15** can be a difficult technical problem. The subject disclosure, presents a method to improve the detection of narrowband interference in SC-FDMA/OFDM channels through a time-averaging algorithm that isolates interference components in the channel and ignores the underlying signal.

Time averaging system (TAS) can be achieved with a boxcar (rolling) average, in which the TAS is obtained as a linear average of a Q of previous spectrum samples, with Q being a user-settable parameter. The Q value determines the "strength" of the averaging, with higher Q value resulting in a TAS that is more strongly smoothed in time and less dependent on short duration transient signals. Due to the frequency-hopped characteristic of SC-FDMA/OFDMA signals, which are composed of short duration transients, the TAS of such signals is approximately flat. It will be appreciated that TAS can also be accomplished by other methods such as a forgetting factor filter.

In one embodiment, an adaptive threshold can be determined by a method **500500** as depicted in FIG. **16**. Q defines how many cycles of t_i to use (e.g., 100 cycles can be represented by t_1 thru t_{100}). The adaptive front end module **56** of FIG. **6** can be configured to measure power in 30 KHz increments starting from a particular RB and over multiple time cycles. For illustration purposes, the adaptive front end module **56** is assumed to measure power across a 5 MHz spectrum. It will be appreciated that the adaptive front end module **56** can be configured for other increments (e.g., 15 KHz or 60 KHz), and a different RF spectrum bandwidth. With this in mind, the adaptive front end module **56** can be configured at frequency increment f**1** to measure power at t**1**, t**2**, thru tq (q representing the number of time cycles, i.e., Q). At f**1**+30 kHz, the adaptive front end module **56** measures power at t**1**, t**2**, thru tn. The frequency increment can be defined by f**0**+(z−1)*30 KHz=fz, where f**0** is a starting frequency, where z=1 . . . x, and z defines increments of 30 KHz increment, e.g., f**1**=f(z=1) first 30 KHz increment, f**2**=f(z=2) second 30 KHz increment, etc.

The adaptive front end module **56** repeats these steps until the spectrum of interest has been fully scanned for Q cycles, thereby producing the following power level sample sets:

$$S_{f1\ (t1\ thru\ tq)}: s_{1,t1,f1}, s_{2,t2,f1}, \ldots\ , s_{q,tq,f1}$$

$$S_{f2\ (t1\ thru\ tq)}: s_{1,t1,f2}, s_{2,t2,f2}, \ldots\ , s_{q,tq,f2}$$

$$\ldots$$

$$S_{fx\ (t1\ thru\ tq)}: s_{1,t1,fz}, s_{2,t2,fx}, \ldots\ , s_{q,tq,fx}$$

The adaptive front end module **56** in step **504**, calculates averages for each of the power level sample sets as provided below:

$$a1(f1) = (s_{1,t1,f1} + s_{2,t2,f1}, \ldots\ , +s_{q,tq,f1})/q$$

$$a2(f2) = (s_{1,t1,f2} + s_{2,t2,f2}, \ldots\ , s_{q,tq,f2})/q$$

$$\ldots$$

$$ax(fx) = (s_{1,t1,fx} + s_{2,t2,fx}, \ldots\ , s_{2,tq,fx})/q$$

In one embodiment, the adaptive front end module **56** can be configured to determine at step **506** the top "m" averages (e.g., the top 3 averages) and dismiss these averages from the calculations. The variable "m" can be user-supplied or can be empirically determined from field measurements collected by one or more base stations utilizing an adaptive front end module **56**. This step can be used to avoid skewing a baseline average across all frequency increments from being too high, resulting in a threshold calculation that may be too conservative. If step **506** is invoked, a baseline average can be determined in step **508** according to the equation: Baseline Avg=(a**1**+a**2**+ . . . +az−averages that have been dismissed)/(x−m). If step **506** is skipped, the baseline average can be determined from the equation: Baseline Avg=(a**1**+a**2**+ . . . +az)/x. Once the baseline average is determined in step **508**, the adaptive front end module **56** can proceed to step **510** where it calculates a threshold according to the equation: Threshold=ydB offset+Baseline Avg. The ydB offset can be user defined or empirically determined from field measurements collected by one or more base stations utilizing an adaptive front end module **56**.

Once a cycle of steps **502** through **510** have been completed, the adaptive front end module **56** can monitor at step **512** interference per frequency increment of the spectrum being scanned based on any power levels measured above the threshold **602** calculated in step **510** as shown in FIG. **17**. Not all interferers illustrated in FIG. **17** exceed the threshold, such as the interferer with reference **610**. Although this interferer has a high power signature, it was not detected because it occurred during a resource block (R**4**) that was not in use. As such, the interferer **510** fell below the threshold **602**. In another illustration, interferer s **612** also fell below the threshold **602**. This interferer was missed because of its low power signature even though the RB from which it occurred (R**3**) was active.

Method **500** can utilize any of the embodiments in the illustrated flowcharts described above to further enhance the interference determination process. For example, method **500** of FIG. **16** can be adapted to apply weights to the power levels, and/or perform correlation analysis to achieve a desired confidence level that the proper interferers are addressed. For example, with correlation analysis, the adaptive front end module **56** can be configured to ignore interferers **614** and **616** of FIG. **17** because their frequency of occurrence is low. Method **500** can also be adapted to prioritize interference mitigation. Prioritization can be based on frequency of occurrence of the interferers, time of day of the interference, the affect the interference has on network traffic, and/or other suitable factors for prioritizing interference to reduce its impact on the network. Prioritization schemes can be especially useful when the filtering resources of the adaptive front end module **56** can only support a limited number of filtering events.

When one or more interferers are detected in step **512**, the adaptive front end module **56** can mitigate the interference at step **514** by configuring one or more filters to suppress the one or more interferers as described above. When there are limited resources to suppress all interferers, the adaptive front end module **56** can use a prioritization scheme to address the most harmful interference as discussed above. FIG. **18** provides an illustration of how the adaptive front end module **56** can be suppress interferers based on the aforementioned algorithms of the subject disclosure. For example, interferers **612**, **614** and **616** can be ignored by the adaptive front end module **56** because their correlation may be low, while interference suppression is applied for all other interferers as shown by reference **650**.

In one embodiment, the adaptive front end module **56** can submit a report to a diagnostic system that includes information relating to the interferers detected. The report can including among other things, a frequency of occurrence of the interferer, spectral data relating to the interferer, an identification of the base station from which the interferer was detected, a severity analysis of the interferer (e.g., bit error rate, packet loss rate, or other traffic information detected during the interferer), and so on. The diagnostic system can communicate with other base stations with other operable adaptive front end module **56** to perform macro analysis of interferers such as triangulation to locate interferers, identity analysis of interferers based on a comparison of spectral data and spectral profiles of known interferers, and so on.

In one embodiment, the reports provided by the adaptive front end module **56** can be used by the diagnostic system to in some instance perform avoidance mitigation. For example, if the interferer is known to be a communication device in the network, the diagnostic system can direct a base station in communication with the communication device to direct the communication device to another channel so as to remove the interference experienced by a neighboring base station. Alternatively, the diagnostic system can direct an affected base station to utilize beam steering and or mechanical steering of antennas to avoid an interferer. When avoidance is performed, the mitigation step **514** can be skipped or may be invoked less as a result of the avoidance steps taken by the diagnostic system.

Once mitigation and/or an interference report has been processed in steps **514** and **516**, respectively, the adaptive front end module **56** can proceed to step **518**. In this step, the adaptive front end module **56** can repeat steps **502** thru **510** to calculate a new baseline average and corresponding threshold based on Q cycles of the resource blocks. Each cycle creates a new adaptive threshold that is used for interference detection. It should be noted that when Q is high, changes to the baseline average are smaller, and consequently the adaptive threshold varies less over Q cycles. In contrast, when Q is low, changes to the baseline average are higher, which results in a more rapidly changing adaptive threshold.

Generally speaking, one can expect that there will be more noise-free resource blocks than resource blocks with substantive noise. Accordingly, if an interferer is present (constant or ad hoc), one can expect the aforementioned algorithm described by method **500** will produce an adaptive threshold (i.e., baseline average+offset) that will be lower than interferer's power level due to mostly noise-free resource blocks driving down baseline average. Although certain communication devices will have a high initial power level when initiating communications with a base station, it can be further assumed that over time the power levels will be lowered to a nominal operating condition. A reasonably high Q would likely also dampen disparities between RB's based on the above described embodiments.

It is further noted that the aforementioned algorithms can be modified while maintaining an objective of mitigating detected interference. For instance, instead of calculating a baseline average from a combination of averages a**1**(f**1**) through ax(fx) or subsets thereof, the adaptive front end controller **56** can be configured to calculate a base line average for each resource block according to a known average of adjacent resource blocks, an average calculated for the resource block itself, or other information that may be provided by, for example, to a resource block scheduler (e.g., a software application and/or hardware component of the base station) that may be helpful in calculating a desired baseline average for each resource block or groups of resource blocks. For instance, the resource block schedule can inform the adaptive front end module **56** as to which resource blocks are active and at what time periods. This information can be used by the adaptive front end module **56** determine individualized baseline averages for each of the resource blocks or groups thereof. Since baseline averages can be individualized, each resource block can also have its own threshold applied to the baseline average of the resource block. Accordingly, thresholds can vary between resource blocks for detecting interferers.

It is further noted that the aforementioned mitigation and detection algorithms can be implemented by any communication device including cellular phones, smartphones, tablets, small base stations, macro base stations, femto cells, WiFi access points, and so on. Small base stations (commonly referred to as small cells) can represent low-powered radio access nodes that can operate in licensed and/or unlicensed spectrum that have a range of 10 meters to 1 or 2 kilometers, compared to a macrocell (or macro base station) which might have a range of a few tens of kilometers. Small base stations can be used for mobile data offloading as a more efficient use of radio spectrum.

FIG. **19**A depicts an illustrative embodiment of a method **700** for mitigating interference such as shown in FIG. **15**. Method **700** can be performed singly or in combination by a mobile communication device, a stationary communication device, base stations, and/or a system or systems in communication with the base stations and/or mobile communication devices. FIG. **19**B depicts an illustrative embodiment of a communication system operating according to method **700**. In this illustration, a central system **750** can collect interference information from adaptive filter modules **56** across a network of base stations interconnected by a data transport system.

With this in mind, method **700** can begin with step **702**, where a number of base stations utilizing one or more adaptive filter modules **56** detect interference in segments of spectrum, such as for example resource blocks, and send interference information to the central system **750** for processing at step **704**. At step **706**, the central system **750** can correlate the interference information and determine from the correlated data the existence of interferers at step **708**. Recurring interferers can be detected from the correlated data by utilizing a correlation algorithm such as regression analysis. In addition to correlation analysis, the central system **750** can generate a profile for each interferer at step **710**. The profile can describe unique characteristics of the interferer such as its spectral shape, its amplitude, its phase, its time of occurrence, its frequency of occurrence, a geographic location of the base stations and/or the adaptive filter modules **56** detecting the interferer, network traffic levels at a time of detection of the interferer, identities of the base stations performing the detection, and so on.

At step **708**, the central system **750** can compare the profiles generated for each interferer with profiles of known interferers. The profiles of known interferers can be stored in a database created by a service provider that tracks the identity of interferers. The database can be created from interferers characterized in a lab setting, and/or can be developed from data collected from adaptive filter modules **56** which is analyzed for accuracy and utility to identify interferers. Interferers can be characterized by spectral shape, time of occurrence, frequency of occurrence, phase, geographic location of occurrence, and so on. At step **714**, the central system **750** can determine if any matches exist. A match need not be a perfect match. For example, a user-defined setting can be established where 70% or more similarity between characteristics of the profile of a detected interferer and a known profile would be sufficient to establish a match. Other user-defined settings may be established according to performance and/or business objectives of a service provider. The database can also characterize interferers by identity (e.g., a certain product type associated with the interferer), a source party in control of the interferer, a behavioral pattern of recurrence of interference from the source party and so on.

If a match exists at step **714**, the central system **750** can associate at step **718** the identified interferer with base stations detecting the identified interferer. Such an association can be stored in the database for future reference at step **714** when new interference information is processed by the central system **750**. In addition to identifying interferers, the central system **750** can predict recurrences of interferers at step **720**. The central system **750** can perform this task by processing present and past interference information received from the base stations at step **704** and by utilizing predictive algorithms such as regression. The predictions can include a prediction of which of the detected interferers will have a recurrence, and in some instances, an expected time and date of recurrence of the interferer.

At step **722**, the central system **750** can determine if a user-defined event has been triggered by the predictions of step **720**. A user-defined event can be, for example, a trigger that is activated when the predicted recurrences exceed a threshold of recurrences, when a particular known interferer resurfaces, when predicting that network traffic will be adversely impacted at one or more base stations affected by the recurrence of interferers at the predicted time of recurrence, or any other suitable trigger important to a service provider. User-defined events such as these can be established by the service provider to achieve quality of service, reduced dropped calls, or other business objectives.

When a user-defined event is detected, the central system **750** can notify a field agent or other suitable personnel at step **724** of the predicted recurrence of the interferer and can provide other important information associated with the interferer such as its identity, base stations detecting the interferer and so on. The field agent at step **726** can request spectral data associated with the interferer from one or more base stations that detected the interferer. At step **728** the central system **750** can receive a stream of spectral data collected in real-time by the base stations or spectral data collected over a period of time in accordance with the request generated by the field agent. The streamed spectral data can be presented to the field agent by the central system **750** at step **728** by way of frequency plots or other suitable presentation methods to enable the field agent to analyze the interferer. The presentation can take place at a computer terminal remote from the affected base stations without requiring the field agent to travel to their respective locations. To further assist the field agent, the agent can request at step **730** that the central system **750** present an interference map at step **732**.

The interference map can be a geographic map that shows all interferers in the region where the affected base stations are located, or at a macro view, the interference map can cover geographic regions from various vantage points such as villages, towns, cities, states or a nation. The field agent can direct the central station **750** to zoom in and out of desired views of any geographic region defined by the field agent utilizing graphical tools suitable for such tasks. The interference map can present the interference map according to time intervals so that the field agent can visualize the behavior of interferers at different times of the day. The interference map can also depict characteristics of the interferers by selecting an interferer with a mouse pointer or simply placing the mouse pointer over the interferer thereby causing a pop screen with relevant information associated with the interferer such as amplitude, phase, time of occurrence, frequency of occurrence, number of dropped packets when the interferer was detected, number of dropped communication sessions (voice or data) when the interferer was detected, and so on.

Referring back to step **722**, when the user-defined event is not detected, the central system **750** can identify at step **734** correlated interferers detected by multiple base stations. That is, in step **734**, the central system **750** can detect from correlation data it has gathered from the base stations when multiple base stations are sensing the same interferer. Once the central system **750** has detected like interferers from the correlation data, it can determine at step **736** which base stations have sensed the same interferers and their respective geographic locations. With the geographic location of the base stations, the central system **750** can determine utilizing triangulation techniques an approximate (or precise) location of an interference source associated with each interferer and at step **724** notify the field agent of the locations of interference sources. The field agent can if desirable analyze the spectral information provided by the base stations as described in steps **726**-**732**, and/or can generate field tickets directed to field personnel to investigate, and if possible, mitigate the interference by removal of the source, shielding of the source, or perform other suitable mitigation techniques.

It is contemplated that the steps of method **700** can be rearranged and/or individually modified without departing from the scope of the claims of the subject disclosure. Consequently, the steps of method **700** can be performed by a mobile communication device, a base station, a central system, or any combination thereof. For example, method **700** can be adapted so that it is performed by mobile communication devices. Mobile communication devices can be instructed by base stations to detect interference and provide interference information to the base stations or central system **750**. Alternatively, or in combination, the mobile devices can be adapted to perform such tasks autonomously, and at random intervals. The interference information can include spectral, temporal, and location information provided by mobile communication devices utilizing a GPS receiver to assist in triangulating a location of source interferers. Interference information such as this can be collected by the central system **750** and processed according to method **700** as depicted in FIG. **19**A.

FIG. **20**A depicts a communication system **800** having a group of base stations **801**, **805**, **810**. While the example depicts three base stations, any number and configuration of base stations can be utilized. Additionally, base stations **801**, **805**, **810** are exemplary structures that provide antennas for access to communication services, however, the base stations can be other structures that provide the antennas for communication services access, such as WiFi access points, femtocells, satellite hubs, and so forth.

The system **800** can be utilized with any number of communication devices (not shown) that are accessing communication services. The communication devices can be various types of devices, such as mobile devices (e.g., a smart phone, tablet, vehicle communication system, and so forth), fixed wireless communication devices, and so forth. The communication services can be of various types (e.g., voice, video, audio text, and/or data communications) and can utilize various communication protocols or technologies, such as LTE communication services.

In FIG. **20**A, each of base stations **801**, **805** and **810** can have a corresponding coverage area **802**A, **806**A and **811**, respectively, for enabling or otherwise facilitating communication devices within the coverage areas to access the communication services. The coverage areas can be a function of various criteria or parameters associated with an antenna of the base station, such as a direction (e.g., rotation and/or tilting) of the antenna, power, beam steering, and so forth. The base stations **801**, **805** and **810** can be coupled with various components or structure to facilitate enabling the communication services, such as a switching station **850**.

In one embodiment, interferers **825**A-**825**E can be present within the coverage areas **802**A, **806**A and **811**. The source of the interferers can be various types, such as bi-directional amplifiers, faulty transmitters, federal and military installations, television transmissions, intermodulation from other transmitters, intermodulation from own faulty components and connectors, and so forth. The interferers **825**A-**825**E can be detected, identified or otherwise located by various means, such as by collecting interference information from a group of communication devices (not shown) operating in the coverage areas **802**A, **806**A and **811**. In this example, the collected interference information can be analyzed (e.g., correlating information from different devices) in a centralized fashion (such as at a processor that is in communication with one or more of the base stations **801**, **805**, **811**) or in a distributed fashion (such as at processors at each of the base stations). In one embodiment, the antennas can be smart antennas that have a processor integrated therein to analyze the interference information and adjust antenna patterns as described herein. The communication devices providing the interference information can be various types, such as cellular phones, laptops, other base stations, femtocells, WiFi access point devices, and so forth. In one embodiment, a profile for each of the interferers **802**A, **806**A and **811** can be accessed or otherwise identified, which describes characteristics of the corresponding interferer. In this example, temporal recurrences can be determined for a particular interferer according to the interference information corresponding to the particular interferer, where the profile of each interferer is generated by analyzing signal interference associated with each interferer according to one or more of spectral shape, amplitude, phase, time of occurrence, frequency of occurrence, geographic location of occurrence, or network traffic levels at a time of detection of the signal interference. In one embodiment, the obtaining of the interference information can be according to at least one adaptive threshold for detecting signal interference in a plurality of segments of a radio frequency spectrum, such as signal interference in LTE communications. In another embodiment, the interference information received from the plurality of communication devices can be correlated to generate correlated information, and the interferers can be detected according to the correlated information.

The system **800** enables interferer locations to be utilized for adjusting, modifying or otherwise manipulating antenna pattern(s) of an antenna(s), such as of base station **801** and/or base station **805**. As an example and referring additionally to FIG. **20**B, the antenna pattern associated with base station **801** can be adjusted based on interferer locations resulting in an adjusted coverage area **802**B (which is contrasted with the previous coverage area **802**A shown in dashed lines). The adjustment of the antenna pattern for base station **801** can be performed in a number of different ways singularly or in combination, including rotation of the antenna, tilting of the antenna, power adjustments at the antenna, beam steering at the antenna, and so forth. The exemplary embodiments can utilize any method for adjusting the antenna pattern at base station **801** that results in the adjusted coverage area **802**B. The adjusting of the antenna of base station **801** can result in one or more communication devices changing or switching from utilizing the base station **801** to utilizing the base station **805** for accessing the communication services. In one embodiment, the adjusting of the antenna of base station **801** can result in one or more interferers being displaced outside of the adjusted coverage area **802**B of base station **801**, such as interferers **825**C and **825**D which are no longer positioned within the adjusted coverage area **802**B.

In one or more embodiments, traffic loads associated with the base stations **801**, **805** and/or **810** can be determined, where the adjusting of the antenna pattern(s) (e.g., of base station **801** and/or **805**) is based on the determining of the traffic loads. In this example, the adjusting of the antenna pattern at base station **801** can cause an increase in the traffic load at the base station **801** and a decrease in the traffic load at base station **805** or vice versa depending on the mitigation of signal interference that has occurred. For instance, traffic loads can be distributed or altered such that a base station which has experienced a signal interference mitigation (e.g., due to the antenna pattern of that base station being adjusted so as to remove one or more interferers from the coverage area of that base station) can receive a higher traffic load than another base station that is experiencing the same or a higher level of signal interference.

Referring additionally to FIG. **20**C, a second antenna pattern adjustment can be performed at base station **805** resulting in the adjusted coverage area **806**B. This second antenna pattern adjustment can cause one or more communication devices to utilize a different base station (e.g., base station **801** and/or base station **810**). In one or more embodiments, the adjusting of the second antenna pattern can cause one or more interferers (e.g., interferers **825**A and **825**B) to be displaced outside of the adjusted second coverage area **806**B.

In one or more embodiments, interferers can be displaced to a position closer to the fringe of the coverage area, such as interferer **825**E staying within the adjusted coverage area **802**B but being closer to the boundary of the adjusted coverage area **802**B. In one or more embodiments, temporal recurrences of the interferers can be determined; and a location of each interferer can be determined based on device location information received from a plurality of communication devices that are detecting the interference information according to at least one adaptive threshold, where an interference map (including interferer locations) is generated based on the temporal recurrences and the estimating of the location of each of the interferers.

The adjustment of antenna pattern(s) can be performed alone to mitigate signal interference (e.g., interference filtering may not be utilized by base stations in some embodiments) or can be performed in combination with other mitigation steps, including interference filtering. Examples of other mitigation steps that can be performed, such as by a mobile communication device and/or by a base station, are described in U.S. patent application Ser. No. 13/960,872 filed Aug. 12, 2013, the disclosure of which is hereby incorporated by reference herein.

In one embodiment, combinations of mitigation steps can be employed by the mobile communication device and/or the base station. For example, the mobile device can receive mitigation instructions from the base station to adjust both of its transmit power and transmit signals out of phase from the interferer. In another example, the base station can perform beam steering, such as of received and/or transmitted signals, in an effort to avoid the interferer while also adjusting time parameters for a resource block during an LTE session.

In another embodiment, mitigation steps can be performed in parallel by the mobile communication device and the base station. For instance, the base station can perform beam steering while the mobile communication device transmits its signals at an adjusted phase and/or adjusted power level. The particular combination of mitigation steps (whether performed individually by one of the mobile communication device or base station or whether performed in parallel or in series) can vary based on a number of factors, such as the level of interference, the type of communication session (e.g., LTE session), the device capability, network conditions, type of communication (e.g., voice call), and so forth. The beam steering can include beam steering for transmitted and/or received signals. In one example, the beam steering is based on directing a null to a desired space.

In one embodiment, data can be collected based on success of each of the mitigation steps which is correlated to various factors such as the type of interferer, network conditions, level of interference, and so forth. This correlation can then be used for determining the mitigations step(s) and/or determining an order of the mitigation steps. In one embodiment, profiles associated with known recurring interferers can be provisioned with mitigation step(s) and/or an order of mitigation steps based on the data collected which indicates past successful mitigation of the known recurring interferer. This provisioning can be correlated with various factors such as capabilities of a mobile communication device, network status and so forth. As an example, the profile for a particular interferer can include a first set of mitigation steps for a first type of mobile phone that has first capabilities (e.g., power capabilities, antenna steering capabilities, and so forth) and can include a second set of mitigation steps for a second type of mobile phone that has second capabilities. In another embodiment, the selection of mitigation step(s) can be based on a subscriber service agreement for the mobile communication device, such as a QoS requirement or service provider specifications.

In one embodiment, the mobile communication device and/or the base station can first attempt to avoid or otherwise mitigate the interference (e.g., as described with respect to method **900**) without performing filtering, but if the mitigation does not achieve a desired result (e.g., does not satisfy an interference threshold) then subsequently the mobile communication device and/or the base station can perform interference filtering.

In one embodiment, the mitigation step(s) can be selected by the base station subject to approval by the mobile communication device or vice-versa. As an example, the base station can detect a recurring interferer and can transmit mitigation instructions to the mobile communication device to raise power to mitigate the interference. In this example, the mobile communication device can transmit a request to the base station for alternative mitigation step(s) such as if the mobile communication device determines that it has low battery power. Continuing with this example, the base station can then select an alternative mitigation step, such as advising the mobile communication device to transmit signals out of phase from the interference. In this example, the base station and mobile communication device can negotiate to reach a mitigation plan that satisfies both the base station and the mobile communication device.

In one embodiment, the mitigation step(s) can be selected to achieve a collective mitigation of interference for a group of mobile communication devices that are each experiencing interference from the same interferer. For example, a base station can detect interference from an interferer being experienced by a first mobile communication device and can transmit mitigation instructions to the first mobile communication device to adjust its power and/or phase of transmitted signals. The base station can then detect a group of additional mobile communication devices experiencing the interference from the interferer and can perform antenna pattern adjustment to avoid the interferer.

In one embodiment, mitigation step(s) being implemented by one or both of the mobile communication device and the base station can be changed during a communication session based on a number of factors, including resource changes, network status, and so forth. As an example, a base station can detect a recurring interference and can initially perform antenna pattern adjustment to mitigate the interference for a mobile communication device utilizing the base station during a communication session. As the session continues over time, the base station may detect a large increase in network traffic or other event that requires a significant increase in resource usage for the base station. Continuing with this example, the base station can then transmit mitigation instructions to the mobile communication device to cause the mobile communication device to perform its own mitigation steps, such as power or transmit phase adjustments, so that the base station no longer needs to perform beam steering. As another example, a base station can initially transmit mitigation instructions to a mobile communication device that causes the mobile communication device to raise its power in a resource block during an LTE communication session. As the session continues over time, the mobile communication device may detect that power conservation is warranted due to low battery power and can transmit a request to the base station for an alternative mitigation step. Continuing with this example, the base station can then perform antenna pattern adjustment to mitigate the interference so that the mobile communication device can return to its original power level.

FIG. **21** depicts a method **900** for adjusting an antenna in response to detected signal interference. The method **900** can be employed for any number of detected interference sources, any number of antennas, and/or any number of communication devices that are accessing communication services via the antennas. The communication devices can be various types of devices, such as mobile devices (e.g., a smart phone, tablet, vehicle communication system, and so forth), fixed wireless communication devices, and so forth. The antennas can be part of one or more base stations or can be associated with other devices or systems, such as WiFi access points, mobile communication devices acting as access points, and so forth. The communication services can be of various types (e.g., voice, video, audio, text, and/or data communications) and can utilize various communication protocols or technologies, such as LTE communication services. The method **900** is described from the perspective of a system that includes at least one processor for performing (directly or indirectly) the steps of method **900**. The system can be located or otherwise associated with various devices or components, such as the system being part of: a base station, a switching station, an antenna, a mobile communication device, a central office, and so forth.

At **902**, the system can obtain interference information associated with detecting signal interference in a wireless communication network. As an example, interference information can be obtained according to at least one adaptive threshold for detecting the signal interference in a plurality of resource blocks in a radio frequency spectrum of a wireless communication network which provides communication services to communication devices. As another example, the interference information can be received from a plurality of communication devices (e.g., mobile devices) that are operating in the wireless communication network.

At **904**, interferers can be detected based on the interference information. In one embodiment, the interference information from the different communication devices can be correlated to generate correlated information where the interferers are detected based on the correlated information. In another embodiment, a profile for each of the interferers can be identified where each profile describes characteristics of a corresponding one or more of the interferers. In this example, a first temporal recurrence of a first interferer of the interferers can be identified according to the interference information associated with the first interferer. The profile of each of the interferers can be generated by analyzing the signal interference associated with each of the interferers according to various criteria, such as spectral shape, amplitude, phase, time of occurrence, frequency of occurrence, geographic location of occurrence, and/or network traffic levels at a time of detection of the signal interference.

At **906**, interferer locations can be determined or otherwise approximated for each of the interferers. As an example, temporal recurrences of the interferers can be identified and a location of each of the interferers can be determined based on device location information, such as received from the plurality of communication devices that are detecting the interference information according to the at least one adaptive threshold. In one embodiment, an interference map of the interferers can be generated according to the temporal recurrences and/or the estimating of the location of each of the plurality of interferers. In another embodiment, an interference map that indicates the location of interferers in a geographic region can be generated according to method **700**.

At **908**, a first antenna pattern of a first antenna can be adjusted. The antenna pattern adjustment can be based on various factors including the interferer locations. The adjusting of the first antenna pattern can change a first coverage area of the first antenna to an adjusted first coverage area, and the adjusting of the first antenna pattern can cause one or more communication devices to change from utilizing the first antenna (e.g., at a first base station) to utilizing a second antenna (e.g., at a second base station) for accessing the communication services. The adjusting of the first antenna pattern can be performed in various ways, such as one or more of adjusting a direction of the first antenna (e.g., rotating or tilting the first antenna), beam steering, power adjustments, and so forth.

In one embodiment, the adjusting of the first antenna pattern can cause one or more interferers to be located outside of the adjusted first coverage area of the first antenna. In one embodiment, the adjusting of the first antenna pattern can be performed without filtering the signal interference (e.g., adjusting the first antenna at a first base station without the first base station performing signal filtering directed to the signal interference).

In one embodiment at **910**, traffic loads can be monitored and utilized in the adjusting of antenna pattern(s). For example, traffic loads associated with first and second antennas (e.g., located at first and second base stations, respectively) can be determined. The adjusting of the first antenna pattern of the first antenna (and/or the second antenna pattern of the second antenna) can be based on the determining of the traffic loads, where the antenna pattern(s) adjustment can be selected in order to cause a decrease (e.g., by a particular amount) in the traffic load at the first antenna (e.g., the first base station) and an increase (e.g., by a particular amount) in the traffic load at the second antenna (e.g., the second base station).

In one embodiment, a second antenna pattern of a second antenna of a second base station can be adjusted based on the interferer locations, where the adjusting of the second antenna pattern changes a second coverage area of the second antenna to an adjusted second coverage area, wherein the adjusting of the second antenna pattern causes at least one interferer of the interferers to be located outside of the adjusted second coverage area of the second antenna, and where a first coverage area of the first antenna of a first base station overlaps the second coverage area of the second antenna of the second base station. In one embodiment, the system performing method **900** can receive device location information from each communication device, where the adjusting of the first antenna pattern is based on the device location information.

In one embodiment, method **900** can be utilized for particular types of identified interferers but not be utilized for other types of interferers. For example, interference mitigation via antenna pattern adjustment and/or out of phase transmissions may be utilized without any filtering where a recurring interference from a military installation is detected but filtering without any of the above-described avoidance techniques may be implemented when the interferer is identified as small production equipment (e.g., garage door opener).

An illustrative embodiment of a communication device **1000** is shown in FIG. **22**. Communication device **1000** can serve in whole or in part as an illustrative embodiment of the devices depicted in FIGS. **1**, **4**, **6-8** and **20**A-**20**C. In one embodiment, the communication device **1000** can be configured, for example, to perform operations such as measuring a power level in at least a portion of a plurality of resource blocks occurring in a radio frequency spectrum, where the measuring occurs for a plurality of time cycles to generate a plurality of power level measurements, calculating a baseline power level according to at least a portion of the plurality of power levels, determining a threshold from the baseline power level, and monitoring at least a portion of the plurality of resource blocks for signal interference according to the threshold. In other embodiments, the communication device **1000** can adjust antenna patterns to facilitate interference mitigation and/or to adjust traffic distributions such as increasing traffic towards a base station that has decreased its signal interference. Other embodiments described in the subject disclosure can be used by the communication device **1000**.

To enable these features, communication device **1000** can comprise a wireline and/or wireless transceiver **1002** (herein transceiver **1002**), a user interface (UI) **1004**, a power supply **1014**, a location receiver **1016**, a motion sensor **1018**, an orientation sensor **1020**, and a controller **1006** for managing operations thereof. The transceiver **1002** can support short-range or long-range wireless access technologies such as Bluetooth®, ZigBee®, WiFi™, Digital Enhanced Cordless Telecommunications (DECT™), or cellular communication technologies, just to mention a few. Cellular technologies can include, for example, CDMA-1X, UMTS/HSDPA, GSM/GPRS, TDMA/EDGE, EV/DO, Worldwide Interoperability for Microwave Access (WiMAX™), SDR, LTE, as well as other next generation wireless communication technologies as they arise. The transceiver **1002** can also be adapted to support circuit-switched wireline access technologies (such as PSTN), packet-switched wireline access technologies (such as TCP/IP, VoIP, etc.), and combinations thereof.

The UI **1004** can include a depressible or touch-sensitive keypad **1008** with a navigation mechanism such as a roller ball, a joystick, a mouse, or a navigation disk for manipulating operations of the communication device **1000**. The keypad **1008** can be an integral part of a housing assembly of the communication device **1000** or an independent device operably coupled thereto by a tethered wireline interface (such as a USB cable) or a wireless interface supporting for example Bluetooth. The keypad **1008** can represent a numeric keypad commonly used by phones, and/or a QWERTY keypad with alphanumeric keys. The UI **1004** can further include a display **1010** such as monochrome or color LCD (Liquid Crystal Display), OLED (Organic Light Emitting Diode) or other suitable display technology for conveying images to an end user of the communication device **1000**. In an embodiment where the display **1010** is touch-sensitive, a portion or all of the keypad **1008** can be presented by way of the display **1010** with navigation features.

The display **1010** can use touch screen technology to also serve as a user interface for detecting user input. As a touch screen display, the communication device **1000** can be adapted to present a user interface with graphical user interface (GUI) elements that can be selected by a user with a touch of a finger. The touch screen display **1010** can be equipped with capacitive, resistive or other forms of sensing technology to detect how much surface area of a user's finger has been placed on a portion of the touch screen display. This sensing information can be used to control the manipulation of the GUI elements or other functions of the user interface. The display **1010** can be an integral part of the housing assembly of the communication device **1000** or an independent device communicatively coupled thereto by a tethered wireline interface (such as a cable) or a wireless interface.

The UI **1004** can also include an audio system **1012** that utilizes audio technology for conveying low volume audio (such as audio heard in proximity of a human ear) and high volume audio (such as speakerphone for hands free operation). The audio system **1012** can further include a microphone for receiving audible signals of an end user. The audio system **1012** can also be used for voice recognition applications. The UI **1004** can further include an image sensor **1013** such as a charged coupled device (CCD) camera for capturing still or moving images.

The power supply **1014** can utilize common power management technologies such as replaceable and rechargeable batteries, supply regulation technologies, and/or charging system technologies for supplying energy to the components of the communication device **1000** to facilitate long-range or short-range portable applications. Alternatively, or in combination, the charging system can utilize external power sources such as DC power supplied over a physical interface such as a USB port or other suitable tethering technologies.

The location receiver **1016** can utilize location technology such as a global positioning system (GPS) receiver capable of assisted GPS for identifying a location of the communication device **1000** based on signals generated by a constellation of GPS satellites, which can be used for facilitating location services such as navigation. The motion sensor **1018** can utilize motion sensing technology such as an accelerometer, a gyroscope, or other suitable motion sensing technology to detect motion of the communication device **1000** in three-dimensional space. The orientation sensor **1020** can utilize orientation sensing technology such as a magnetometer to detect the orientation of the communication device **1000** (north, south, west, and east, as well as combined orientations in degrees, minutes, or other suitable orientation metrics).

The communication device **1000** can use the transceiver **1002** to also determine a proximity to a cellular, WiFi, Bluetooth, or other wireless access points by sensing techniques such as utilizing a received signal strength indicator (RSSI) and/or signal time of arrival (TOA) or time of flight (TOF) measurements. The controller **1006** can utilize computing technologies such as a microprocessor, a digital signal processor (DSP), programmable gate arrays, application specific integrated circuits, and/or a video processor with associated storage memory such as Flash, ROM, RAM, SRAM, DRAM or other storage technologies for executing computer instructions, controlling, and processing data supplied by the aforementioned components of the communication device **400**.

Other components not shown in FIG. **22** can be used in one or more embodiments of the subject disclosure. For instance, the communication device **1000** can include a reset button (not shown). The reset button can be used to reset the controller **1006** of the communication device **1000**. In yet another embodiment, the communication device **1000** can also include a factory default setting button positioned, for example, below a small hole in a housing assembly of the communication device **1000** to force the communication device **1000** to re-establish factory settings. In this embodiment, a user can use a protruding object such as a pen or paper clip tip to reach into the hole and depress the default setting button. The communication device **1000** can also include a slot for adding or removing an identity module such as a Subscriber Identity Module (SIM) card. SIM cards can be used for identifying subscriber services, executing programs, storing subscriber data, and so forth.

The communication device **1000** as described herein can operate with more or less of the circuit components shown in FIG. **22**. These variant embodiments can be used in one or more embodiments of the subject disclosure.

It should be understood that devices described in the exemplary embodiments can be in communication with each other via various wireless and/or wired methodologies. The methodologies can be links that are described as coupled, connected and so forth, which can include unidirectional and/or bidirectional communication over wireless paths and/or wired paths that utilize one or more of various protocols or methodologies, where the coupling and/or connection can be direct (e.g., no intervening processing device) and/or indirect (e.g., an intermediary processing device such as a router).

FIG. **23** depicts an exemplary diagrammatic representation of a machine in the form of a computer system **1100** within which a set of instructions, when executed, may cause the machine to perform any one or more of the methods described above. One or more instances of the machine can operate, for example, as the devices of FIGS. **1**, **4**, **6**-**8** and **20**A-**20**C. For example, the machine can perform one or more of obtaining interference information (such as according to at least one adaptive threshold for detecting signal interference in a plurality of resource blocks in a radio frequency spectrum of a wireless communication system providing communication services to a plurality of communication devices), correlate the interference information to generate correlated information, detect a plurality of interferers according to the correlated information, determine interferer locations for each of the plurality of interferers, or adjust a first antenna pattern of a first antenna of a first base station based on the interferer locations.

In some embodiments, the machine may be connected (e.g., using a network **1126**) to other machines. In a networked deployment, the machine may operate in the capacity of a server or a client user machine in server-client user network environment, or as a peer machine in a peer-to-peer (or distributed) network environment.

The machine may comprise a server computer, a client user computer, a personal computer (PC), a tablet PC, a smart phone, a laptop computer, a desktop computer, a control system, a network router, switch or bridge, or any machine capable of executing a set of instructions (sequential or otherwise) that specify actions to be taken by that machine. It will be understood that a communication device of the subject disclosure includes broadly any electronic device that provides voice, video or data communication. Further, while a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methods discussed herein.

The computer system **1100** may include a processor (or controller) **1102** (e.g., a central processing unit (CPU), a graphics processing unit (GPU, or both), a main memory **1104** and a static memory **1106**, which communicate with each other via a bus **1108**. The computer system **1100** may further include a display unit **1110** (e.g., a liquid crystal display (LCD), a flat panel, or a solid state display. The computer system **1100** may include an input device **1112** (e.g., a keyboard), a cursor control device **1114** (e.g., a mouse), a disk drive unit **1116**, a signal generation device **1118** (e.g., a speaker or remote control) and a network interface device **1120**. In distributed environments, the embodiments described in the subject disclosure can be adapted to utilize multiple display units **1110** controlled by two or more computer systems **1100**. In this configuration, presentations described by the subject disclosure may in part be shown in a first of the display units **1110**, while the remaining portion is presented in a second of the display units **1110**.

The disk drive unit **1116** may include a tangible computer-readable storage medium **1122** on which is stored one or more sets of instructions (e.g., software **1124**) embodying any one or more of the methods or functions described herein, including those methods illustrated above. The instructions **1124** may also reside, completely or at least partially, within the main memory **1104**, the static memory **1106**, and/or within the processor **1102** during execution thereof by the computer system **1100**. The main memory **1104** and the processor **1102** also may constitute tangible computer-readable storage media.

Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays and other hardware devices that can likewise be constructed to implement the methods described herein. Application specific integrated circuits and programmable logic array can use downloadable instructions for executing state machines and/or circuit configurations to implement embodiments of the subject disclosure. Applications that may include the apparatus and systems of various embodiments broadly include a variety of electronic and computer systems. Some embodiments implement functions in two or more specific interconnected hardware modules or devices with related control and data signals communicated between and through the modules, or as portions of an application-specific integrated circuit. Thus, the example system is applicable to software, firmware, and hardware implementations.

In accordance with various embodiments of the subject disclosure, the operations or methods described herein are intended for operation as software programs or instructions running on or executed by a computer processor or other computing device, and which may include other forms of instructions manifested as a state machine implemented with logic components in an application specific integrated circuit or field programmable gate array. Furthermore, software implementations (e.g., software programs, instructions, etc.) including, but not limited to, distributed processing or component/object distributed processing, parallel processing, or virtual machine processing can also be constructed to implement the methods described herein. It is further noted that a computing device such as a processor, a controller, a state machine or other suitable device for executing instructions to perform operations or methods may perform such operations directly or indirectly by way of one or more intermediate devices directed by the computing device.

While the tangible computer-readable storage medium **822** is shown in an example embodiment to be a single medium, the term "tangible computer-readable storage medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "tangible computer-readable storage medium" shall also be taken to include any non-transitory medium that is capable of storing or encoding a set of instructions for execution by the machine and that cause the machine to perform any one or more of the methods of the subject disclosure. The term "non-transitory" as in a non-transitory computer-readable storage includes without limitation memories, drives, devices and anything tangible but not a signal per se.

The term "tangible computer-readable storage medium" shall accordingly be taken to include, but not be limited to: solid-state memories such as a memory card or other package that houses one or more read-only (non-volatile) memories, random access memories, or other re-writable (volatile) memories, a magneto-optical or optical medium such as a disk or tape, or other tangible media which can be used to store information. Accordingly, the disclosure is considered to include any one or more of a tangible computer-readable storage medium, as listed herein and including art-recognized equivalents and successor media, in which the software implementations herein are stored.

Although the present specification describes components and functions implemented in the embodiments with reference to particular standards and protocols, the disclosure is not limited to such standards and protocols. Each of the standards for Internet and other packet switched network transmission (e.g., TCP/IP, UDP/IP, HTML, HTTP) represent examples of the state of the art. Such standards are from time-to-time superseded by faster or more efficient equivalents having essentially the same functions. Wireless standards for device detection (e.g., RFID), short-range communications (e.g., Bluetooth®, WiFi, Zigbee®), and long-range communications (e.g., WiMAX, GSM, CDMA, LTE) can be used by computer system **1100**.

The illustrations of embodiments described herein are intended to provide a general understanding of the structure of various embodiments, and they are not intended to serve as a complete description of all the elements and features of apparatus and systems that might make use of the structures described herein. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The exemplary embodiments can include combinations of features and/or steps from multiple embodiments. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. Figures are also merely representational and may not be drawn to scale. Certain proportions thereof may be exaggerated, while others may be minimized. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense.

Although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, can be used in the subject disclosure. In one or more embodiments, features that are positively recited can also be excluded from the embodiment with or without replacement by another component or step. The steps or functions described with respect to the exemplary processes or methods can be performed in any order. The steps or functions described with respect to the exemplary processes or methods can be performed alone or in combination with other steps or functions (from other embodiments or from other steps that have not been described).

Less than all of the steps or functions described with respect to the exemplary processes or methods can also be performed in one or more of the exemplary embodiments. Further, the use of numerical terms to describe a device, component, step or function, such as first, second, third, and so forth, is not intended to describe an order or function unless expressly stated so. The use of the terms first, second, third and so forth, is generally to distinguish between devices, components, steps or functions unless expressly stated otherwise. Additionally, one or more devices or components described with respect to the exemplary embodiments can facilitate one or more functions, where the facilitating (e.g., facilitating access or facilitating establishing a connection) can include less than every step needed to perform the function or can include all of the steps needed to perform the function.

In one or more embodiments, a processor (which can include a controller or circuit) has been described that performs various functions. It should be understood that the processor can be multiple processors, which can include distributed processors or parallel processors in a single machine or multiple machines. The processor can be used in supporting a virtual processing environment. The virtual processing environment may support one or more virtual machines representing computers, servers, or other computing devices. In such virtual machines, components such as microprocessors and storage devices may be virtualized or logically represented. The processor can include a state machine, application specific integrated circuit, and/or programmable gate array including a Field PGA. In one or more embodiments, when a processor executes instructions to perform "operations", this can include the processor performing the operations directly and/or facilitating, directing, or cooperating with another device or component to perform the operations.

The Abstract of the Disclosure is provided with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

What is claimed is:

1. A method, comprising:

obtaining, by a system comprising a processor, interference information according to at least one adaptive threshold for detecting signal interference in a plurality of resource blocks in a radio frequency spectrum of a wireless communication system providing communication services to a plurality of communication devices and having a plurality of base stations, wherein the interference is caused by a plurality of interferers external to the base stations, and wherein the interference information is provided to the system from the plurality of base stations;

correlating, by the system, the interference information to generate correlated information;

detecting, by the system, a plurality of interferers according to the correlated information;

determining, by the system, interferer locations for each of the plurality of interferers;

predicting, by the system and in accordance with the correlated information, recurrent interference caused by a detected interferer of the plurality of interferers; and

adjusting, by the system, a first antenna pattern of a first antenna of a first base station based on the interferer locations,

wherein the adjusting of the first antenna pattern changes a first coverage area of the first antenna to an adjusted first coverage area, and

wherein the adjusting of the first antenna pattern causes at least one interferer of the plurality of interferers to be located outside of the adjusted first coverage area of the first antenna.

2. The method of claim **1**, wherein the obtaining of the interference information is from the plurality of communication devices that are detecting the interference information according to the at least one adaptive threshold for detecting signal interference in the plurality of resource blocks in the radio frequency spectrum of the wireless communication system.

3. The method of claim **1**, wherein the adjusting of the first antenna pattern causes at least one communication device of the plurality of communication devices to change from utilizing the first base station to utilizing a second base station for the communication services.

4. The method of claim 3, wherein the adjusting of the first antenna pattern is performed without the first base station filtering the signal interference.

5. The method of claim 3, wherein the second base station experiences a decrease in the signal interference, and further comprising:

determining traffic loads associated with the first and second base stations, wherein the adjusting of the first antenna pattern is based on the determining of the traffic loads, and wherein the adjusting of the first antenna pattern causes a decrease in the traffic load at the first base station and an increase in the traffic load at the second base station.

6. The method of claim 5, comprising:

adjusting, by the system, a second antenna pattern of a second antenna of the second base station based on the interferer locations, wherein the adjusting of the second antenna pattern changes a second coverage area of the second antenna to an adjusted second coverage area, wherein the adjusting of the second antenna pattern causes at least one interferer of the plurality of interferers to be located outside of the adjusted second coverage area of the second antenna, and wherein the first coverage area of the first antenna of the first base station overlaps the second coverage area of the second antenna of the second base station.

7. The method of claim 1, comprising:

receiving, by the system, device location information from each of the plurality of communication devices, wherein the adjusting of the first antenna pattern is based on the device location information.

8. The method of claim 1, comprising:

identifying, by the system, a profile for each of the plurality of interferers that describes characteristics of each of the plurality of interferers; and

determining, by the system, a first temporal recurrence of a first interferer of the plurality of interferers according to the interference information associated with the first interferer,

wherein the profile of each of the plurality of interferers is generated by analyzing the signal interference associated with each of the plurality of interferers according to spectral shape, amplitude, phase, time of occurrence, frequency of occurrence, geographic location of occurrence, network traffic levels at a time of detection of the signal interference, or any combination thereof.

9. The method of claim 1, wherein the determining of the interferer locations comprises:

determining temporal recurrences of the plurality of interferers;

estimating a location of each of the plurality of interferers based on device location information received from the plurality of communication devices that are detecting the interference information according to the at least one adaptive threshold; and

generating an interference map of the plurality of interferers according to the temporal recurrences and the estimating of the location of each of the plurality of interferers.

10. A system, comprising:

a memory to store instructions; and

a processor coupled to the memory, wherein execution of the instructions by the processor causes the processor to perform operations comprising:

obtaining interference information provided to the system according to at least one adaptive threshold for detecting signal interference in a plurality of segments of a radio frequency spectrum of a wireless communication system providing communication services and having a plurality of antennas at a plurality of antenna locations, wherein the interference is caused by a plurality of interferers external to the plurality of antenna locations;

generating an interference map for the plurality of interferers according to the interference information;

predicting, in accordance with the interference map, recurrent interference caused by a detected interferer of the plurality of interferers; and

adjusting a first antenna pattern of a first antenna at a first location of the plurality of antenna locations based on the interference map,

wherein the adjusting of the first antenna pattern changes a first coverage area of the first antenna to an adjusted first coverage area, and

wherein the adjusting of the first antenna pattern causes at least one interferer of the plurality of interferers to be located outside of the adjusted first coverage area of the first antenna.

11. The system of claim 10, wherein the adjusting of the first antenna pattern causes at least one communication device to change from utilizing the first antenna to utilizing a second antenna at a second location of the plurality of antenna locations for accessing the communication services.

12. The system of claim 11, wherein the first location comprises a first base station, wherein the second location comprises a second base station, and wherein each segment of the plurality of segments conforms to a long term evolution protocol.

13. The system of claim 10, wherein the obtaining of the interference information comprises receiving the interference information from a plurality of communication devices that are detecting the interference information in the plurality of segments of the radio frequency spectrum, and wherein the operations further comprise:

correlating the interference information of the plurality of communication devices to generate correlated information; and

detecting the plurality of interferers according to the correlated information, wherein the generating of the interference map is based on the correlated information.

14. The system of claim 11, wherein the operations further comprise:

determining traffic loads associated with the first and second locations, wherein the adjusting of the first antenna pattern is based on the determining of the traffic loads, and wherein the adjusting of the first antenna pattern causes a decrease in the traffic load at the first location and an increase in the traffic load at the second location.

15. The system of claim 10, wherein the operations further comprise:

adjusting a second antenna pattern of the second antenna based on the interference map, wherein the adjusting of the second antenna pattern changes a second coverage area of the second antenna to an adjusted second coverage area, wherein the adjusting of the second antenna pattern causes at least one interferer of the plurality of interferers to be located outside of the adjusted second coverage area of the second antenna, and wherein the first coverage area of the first antenna overlaps the second coverage area of the second antenna.

16. The system of claim 10, wherein the operations further comprise:

determining temporal recurrences of the plurality of interferers; and

estimating a location of each of the plurality of interferers based on device location information received from a plurality of communication devices that are detecting the interference information according to the at least one adaptive threshold,

wherein the generating of the interference map is based on the temporal recurrences and the estimating of the location of each of the plurality of interferers.

17. A non-transitory machine-readable storage medium, comprising instructions, which when executed by a processor, cause the processor to perform operations comprising:

receiving interference information from each of a plurality of communication devices detecting interference information according to an adaptive threshold in a plurality of segments in a radio frequency spectrum of a wireless communication system providing communication services and having a plurality of antennas at a plurality of antenna locations, wherein the interference is caused by a plurality of interferers external to the plurality of antenna locations;

correlating the interference information of the plurality of communication devices to generate correlated information;

identifying a plurality of interferers according to the correlated information;

approximating a location of each of the plurality of interferers according to location information provided by the plurality of communication devices;

predicting, in accordance with the correlated information, recurrent interference caused by an identified interferer of the plurality of interferers; and

adjusting a first antenna pattern of a first antenna at a first location based on the approximating of the location of the plurality of interferers,

wherein the adjusting of the first antenna pattern changes a first coverage area of the first antenna to an adjusted first coverage area, and

wherein the adjusting of the first antenna pattern causes at least one interferer of the plurality of interferers to be located outside of the adjusted first coverage area of the first antenna.

18. The non-transitory machine-readable storage medium of claim 17, wherein the adjusting of the first antenna pattern causes at least one communication device to change from utilizing the first antenna to utilizing a second antenna at a second location for accessing the communication services.

19. The non-transitory machine-readable storage medium of claim 18, wherein the operations further comprise:

adjusting a second antenna pattern of the second antenna based on the approximating of the location of the plurality of interferers, wherein the adjusting of the second antenna pattern changes a second coverage area of the second antenna to an adjusted second coverage area, wherein the adjusting of the second antenna pattern causes at least one interferer of the plurality of interferers to be located outside of the adjusted second coverage area of the second antenna, and wherein the first coverage area of the first antenna overlaps the second coverage area of the second antenna.

20. The non-transitory machine-readable storage medium of claim 18, wherein the operations further comprise:

determining traffic loads associated with the first and second locations, wherein the adjusting of the first antenna pattern is based on the determining of the traffic loads, and wherein the adjusting of the first antenna pattern causes a decrease in the traffic load at the first location and an increase in the traffic load at the second location.

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