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Almasoud

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(54) **WIRELESS COMMUNICATION SYSTEM USING HYBRID COOPERATIVE AND NONCOOPERATIVE SENSING**

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(51) **Int. Cl.**

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***H04W 16/14*** (2009.01)
***H04W 48/16*** (2009.01)
*H04W 48/10* (2009.01)

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

CPC .............. ***H04W 16/14*** (2013.01); ***H04W 48/16*** (2013.01); *H04W 48/10* (2013.01)

(58) **Field of Classification Search**

USPC ........ 455/447–456.1, 515–517, 67.11, 67.13, 455/63.1

See application file for complete search history.

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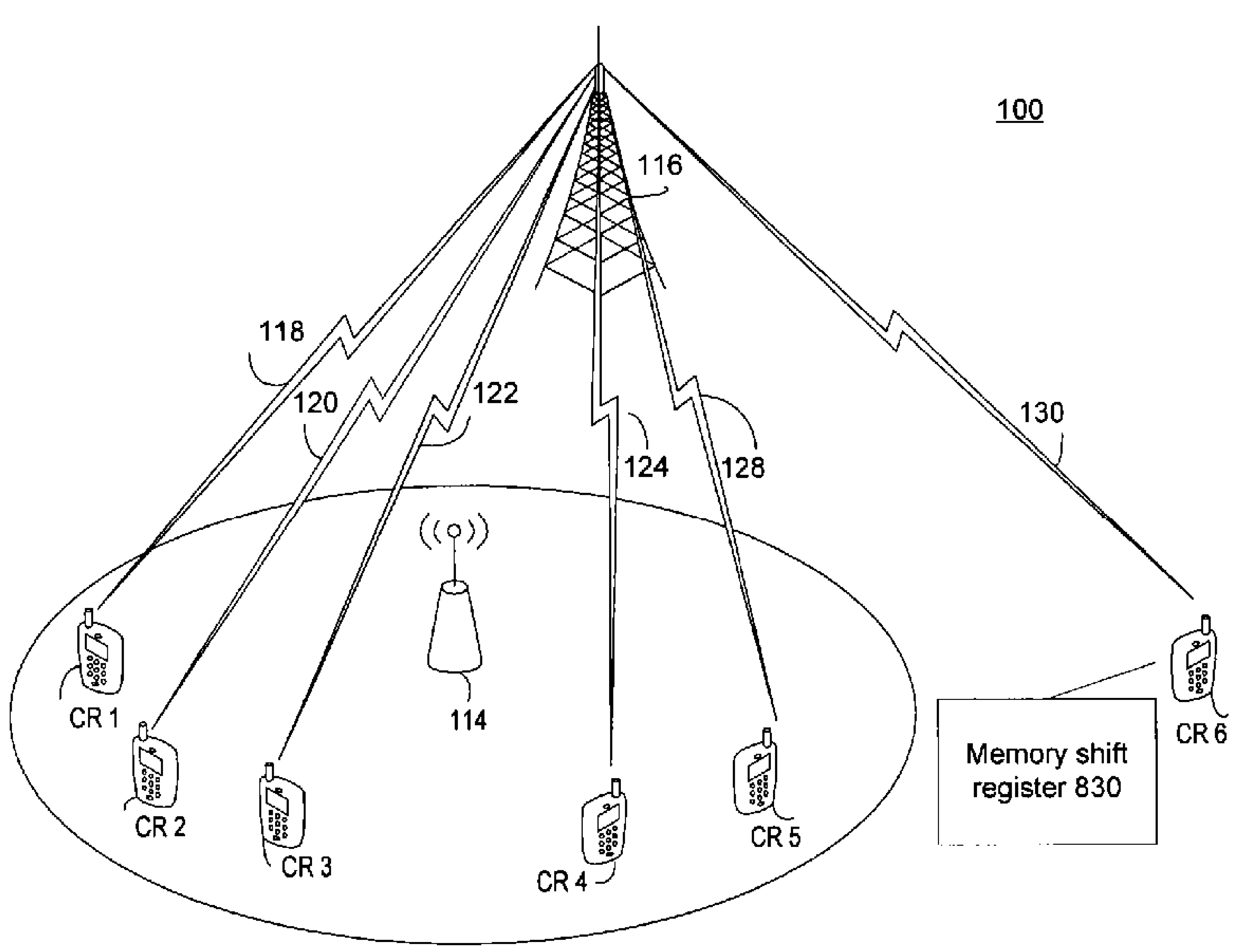
(57) **ABSTRACT**

A combination of cooperative and non-cooperative sensing methods improves spectrum utilization by switching network nodes not interfering with both primary system and cooperative secondary users to non-cooperative mode. The method then keeps record of the number of times the result of spectrum sensing of a network node matches or differs from the result of cooperative sensing. Also, the method sets thresholds to shift register values to determine when to switch back and forth between cooperative and non cooperative sensing modes, and sending control messages to let a non cooperative user access the spectrum. In the present disclosure two antenna are considered for each network node to separate the two types of control messages or broadcast and reply messages.

**20 Claims, 9 Drawing Sheets**



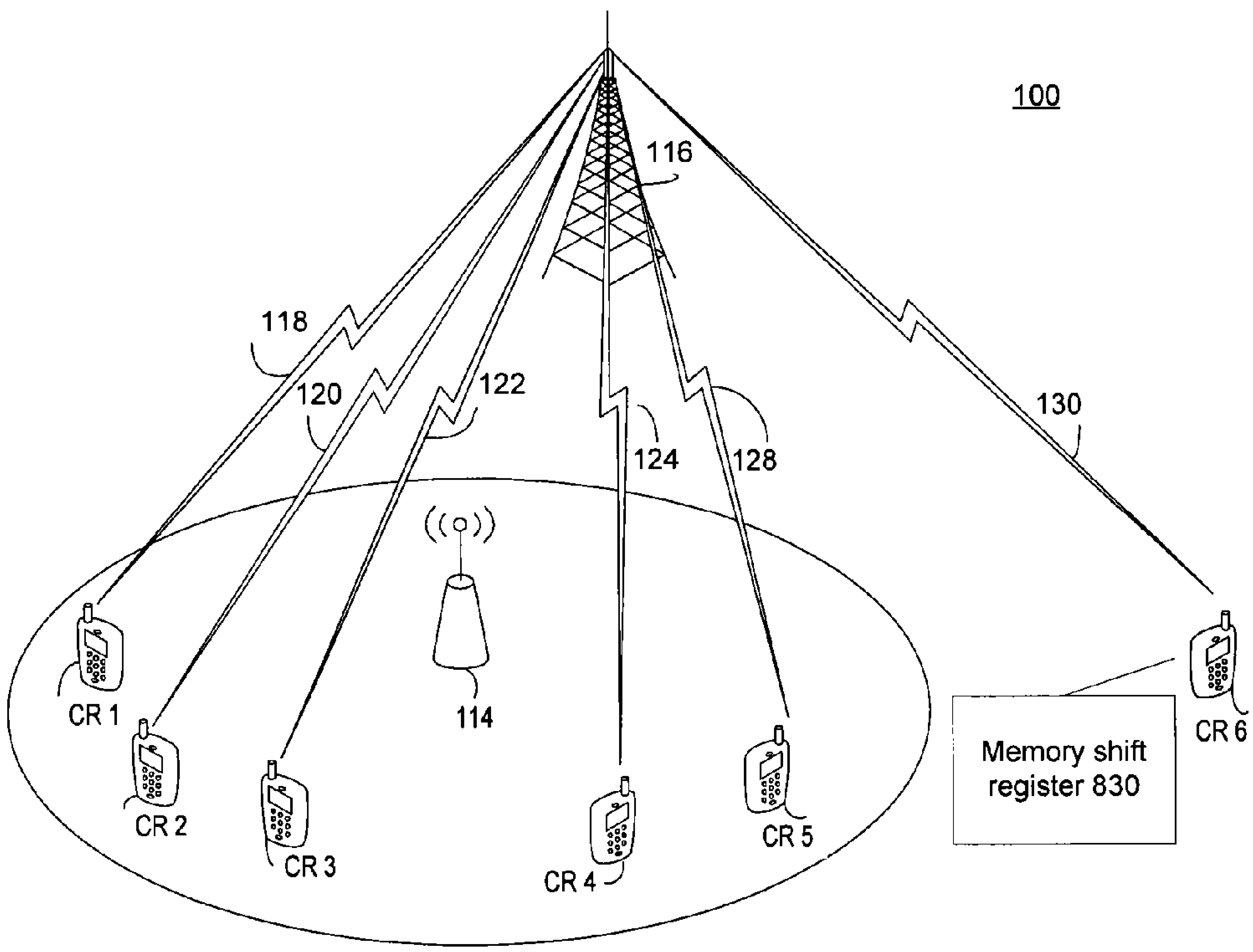

100
116
118
120
122
124
128
130
114
CR 1
CR 2
CR 3
CR 4
CR 5
CR 6
Memory shift register 830

FIG. 1

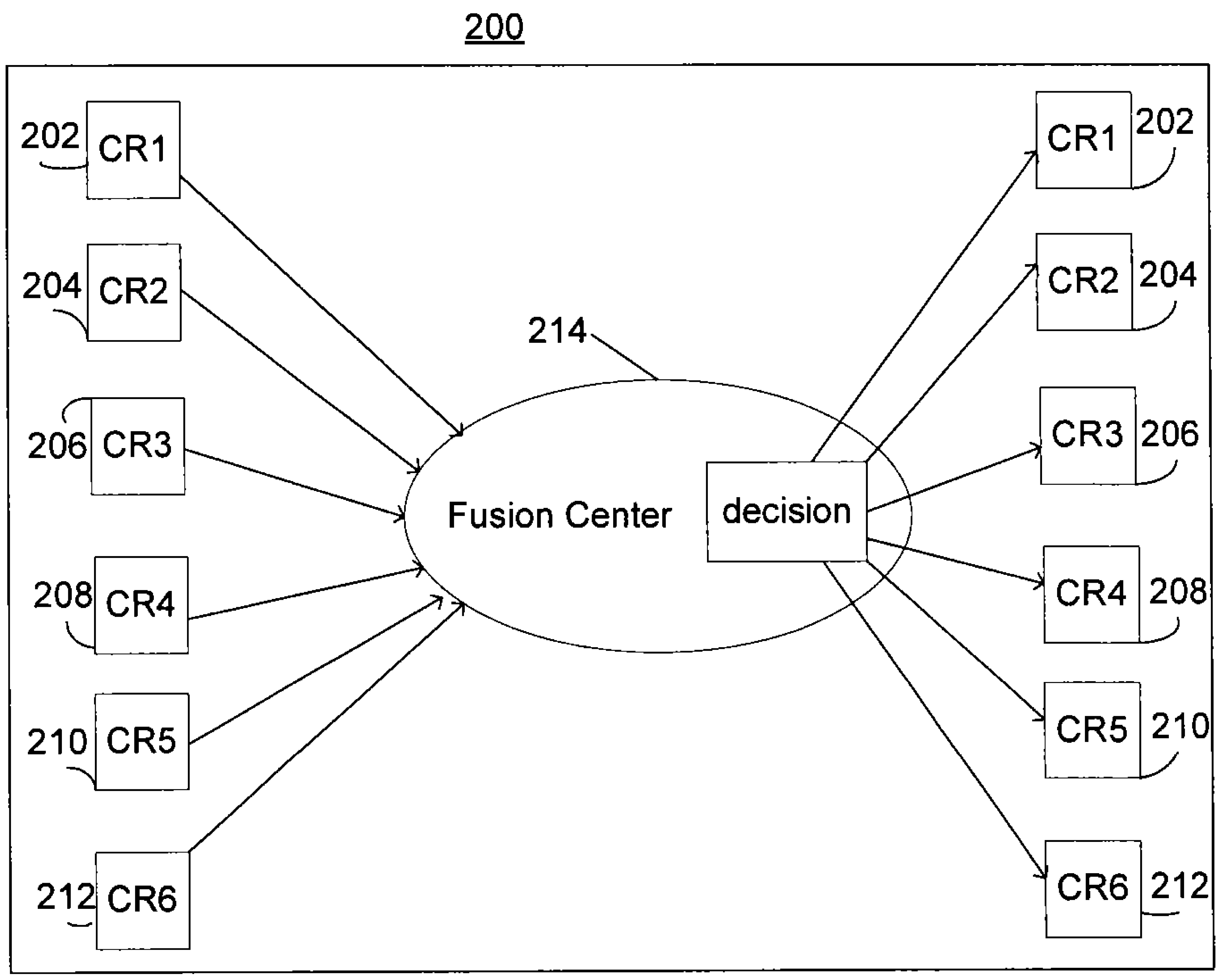

200
202
CR1
204
CR2
206
CR3
208
CR4
210
CR5
212
CR6
214
Fusion Center
decision
CR1
202
CR2
204
CR3
206
CR4
208
CR5
210
CR6
212

FIG. 2

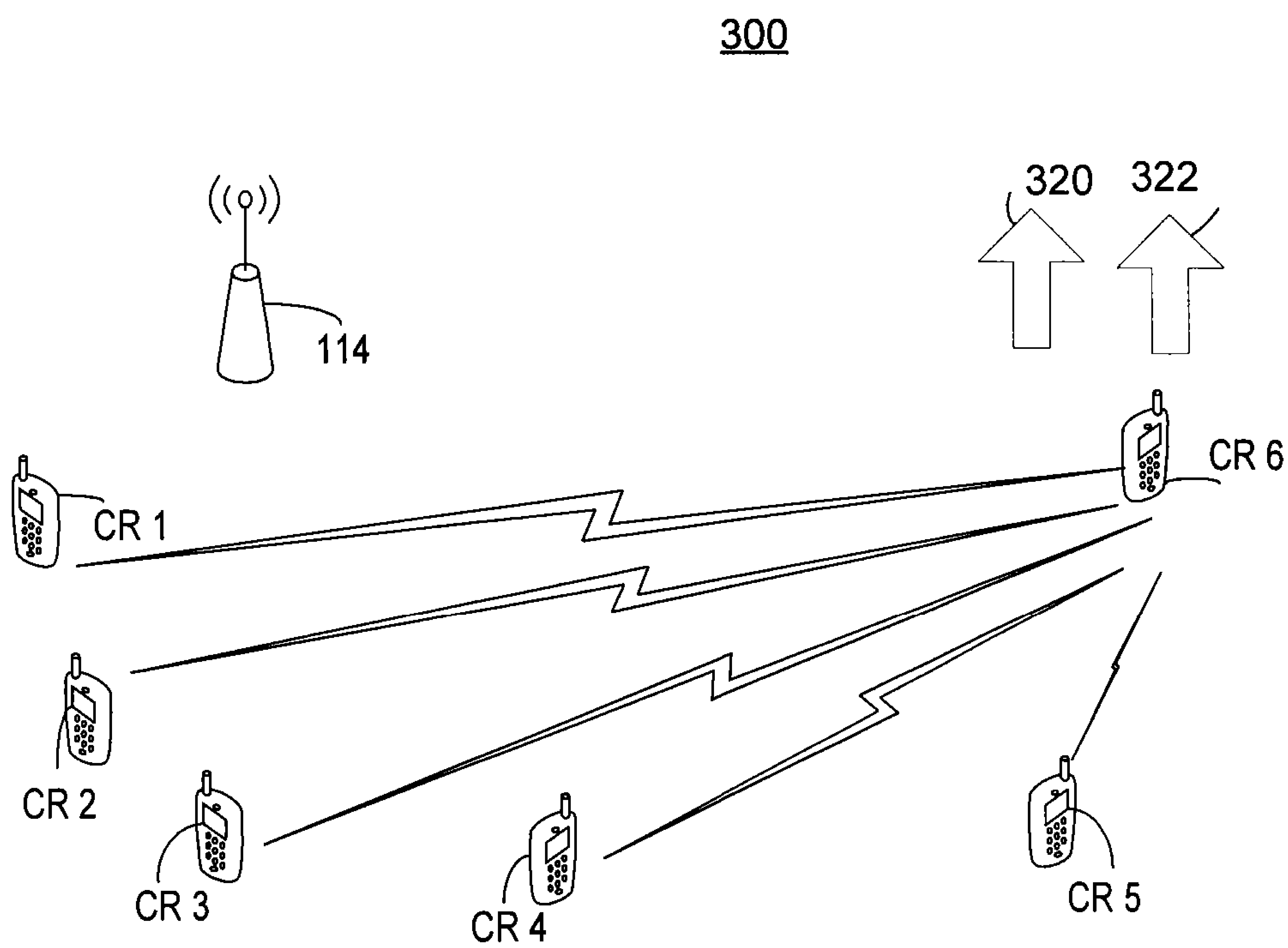



FIG. 3

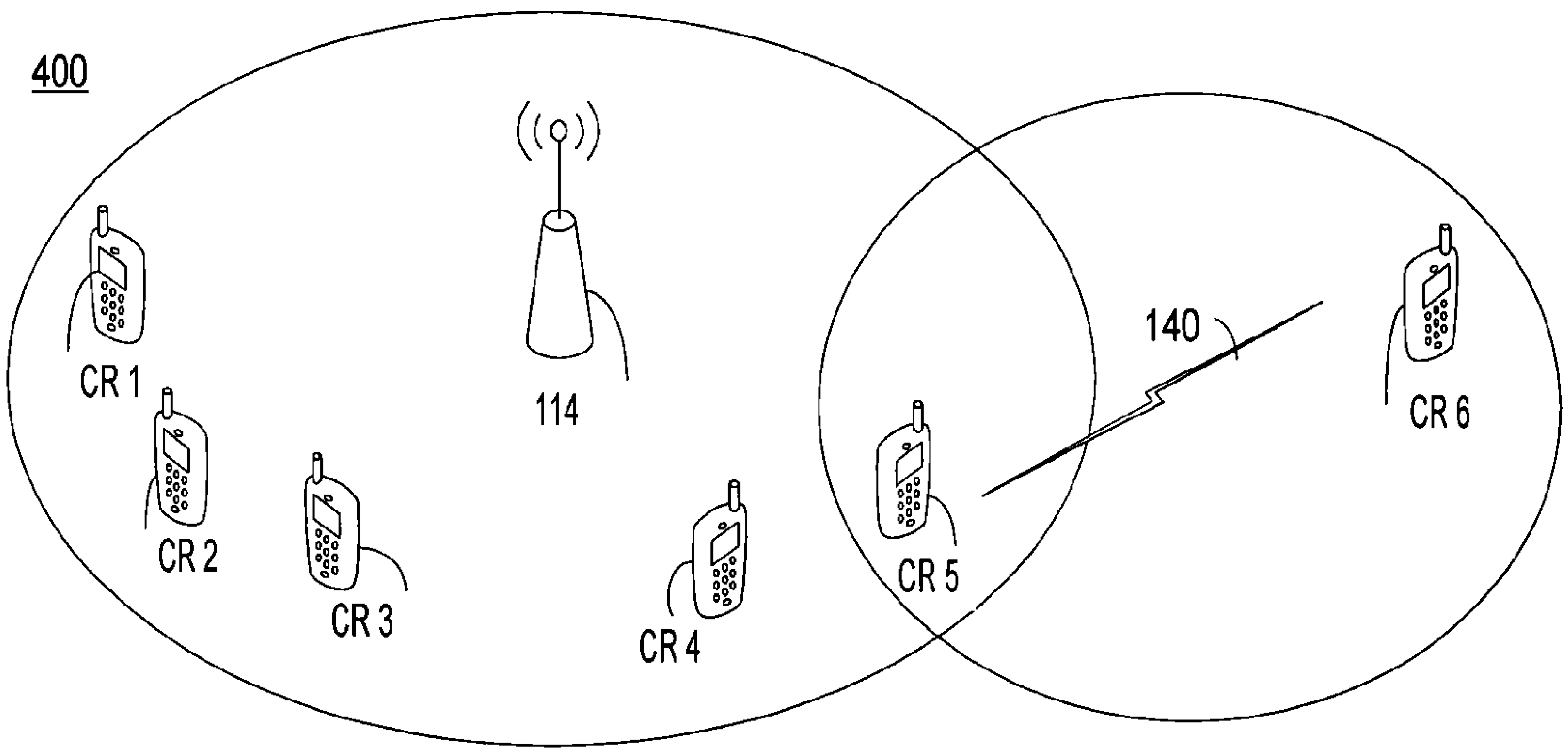



FIG. 4

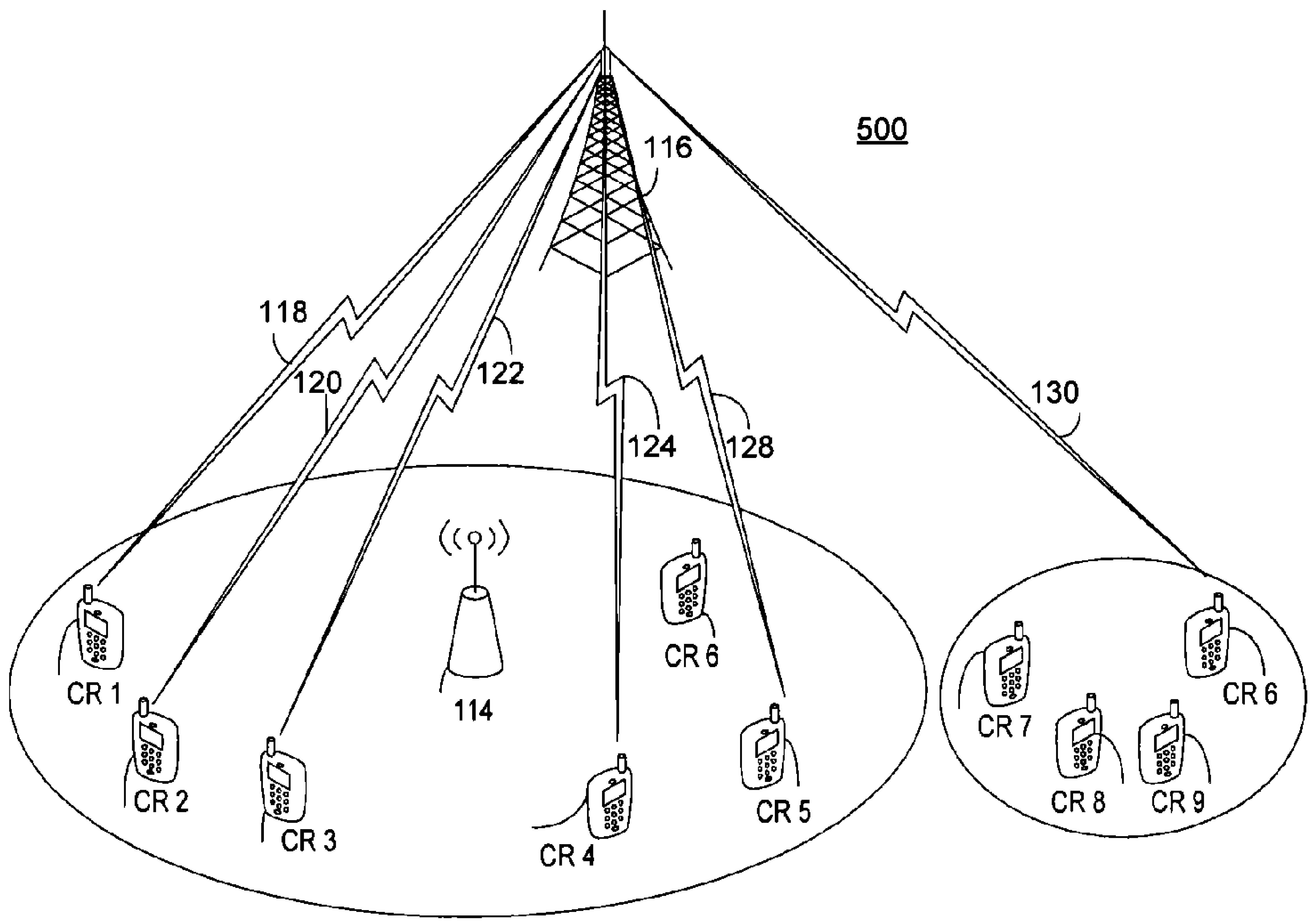

500
116
118
120
122
124
128
130
114
CR 1
CR 2
CR 3
CR 4
CR 5
CR 6
CR 7
CR 8
CR 9
CR 6

FIG. 5

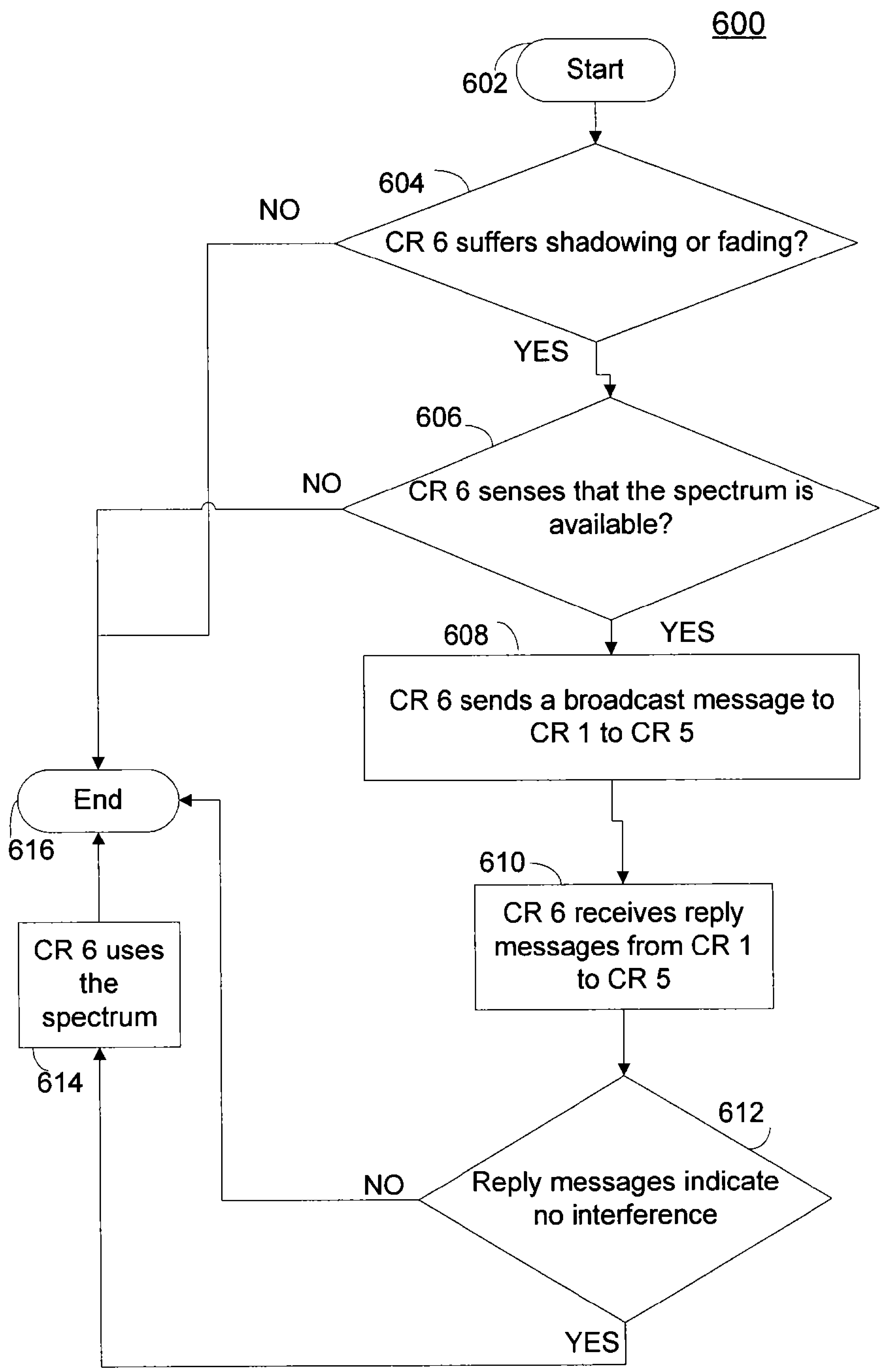

600
602
Start
604
NO
CR 6 suffers shadowing or fading?
YES
606
NO
CR 6 senses that the spectrum is available?
608
YES
CR 6 sends a broadcast message to CR 1 to CR 5
End
616
610
CR 6 receives reply messages from CR 1 to CR 5
CR 6 uses the spectrum
614
612
NO
Reply messages indicate no interference
YES

FIG. 6

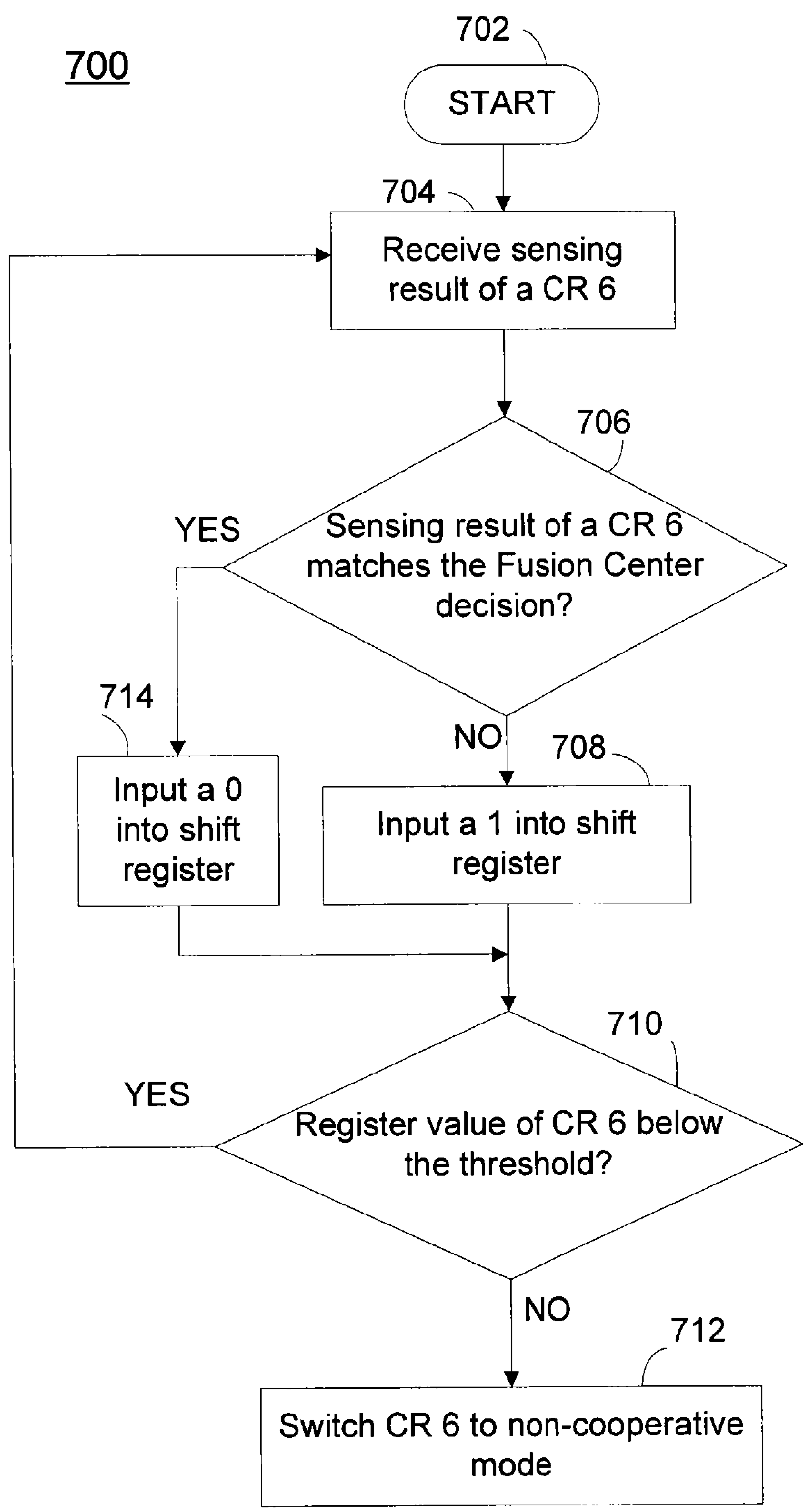

700
702
START
704
Receive sensing result of a CR 6
706
Sensing result of a CR 6 matches the Fusion Center decision?
YES
NO
714
Input a 0 into shift register
708
Input a 1 into shift register
710
YES
Register value of CR 6 below the threshold?
NO
712
Switch CR 6 to non-cooperative mode

FIG. 7

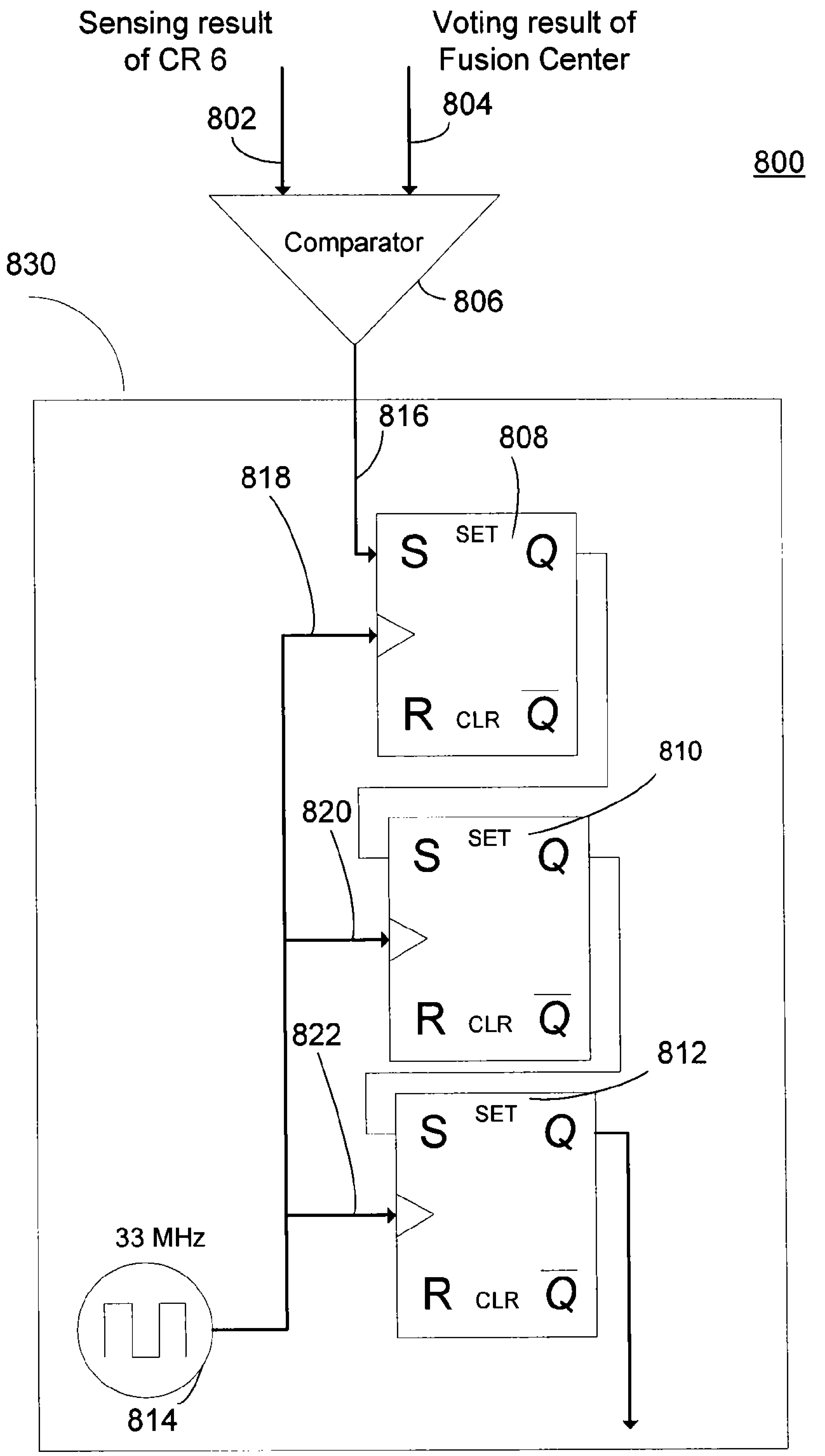

Sensing result of CR 6
Voting result of Fusion Center
802
804
800
Comparator
830
806
816
808
818
S
SET
Q
R
CLR
Q
810
820
S
SET
Q
R
CLR
Q
822
812
S
SET
Q
33 MHz
R
CLR
Q
814

FIG. 8

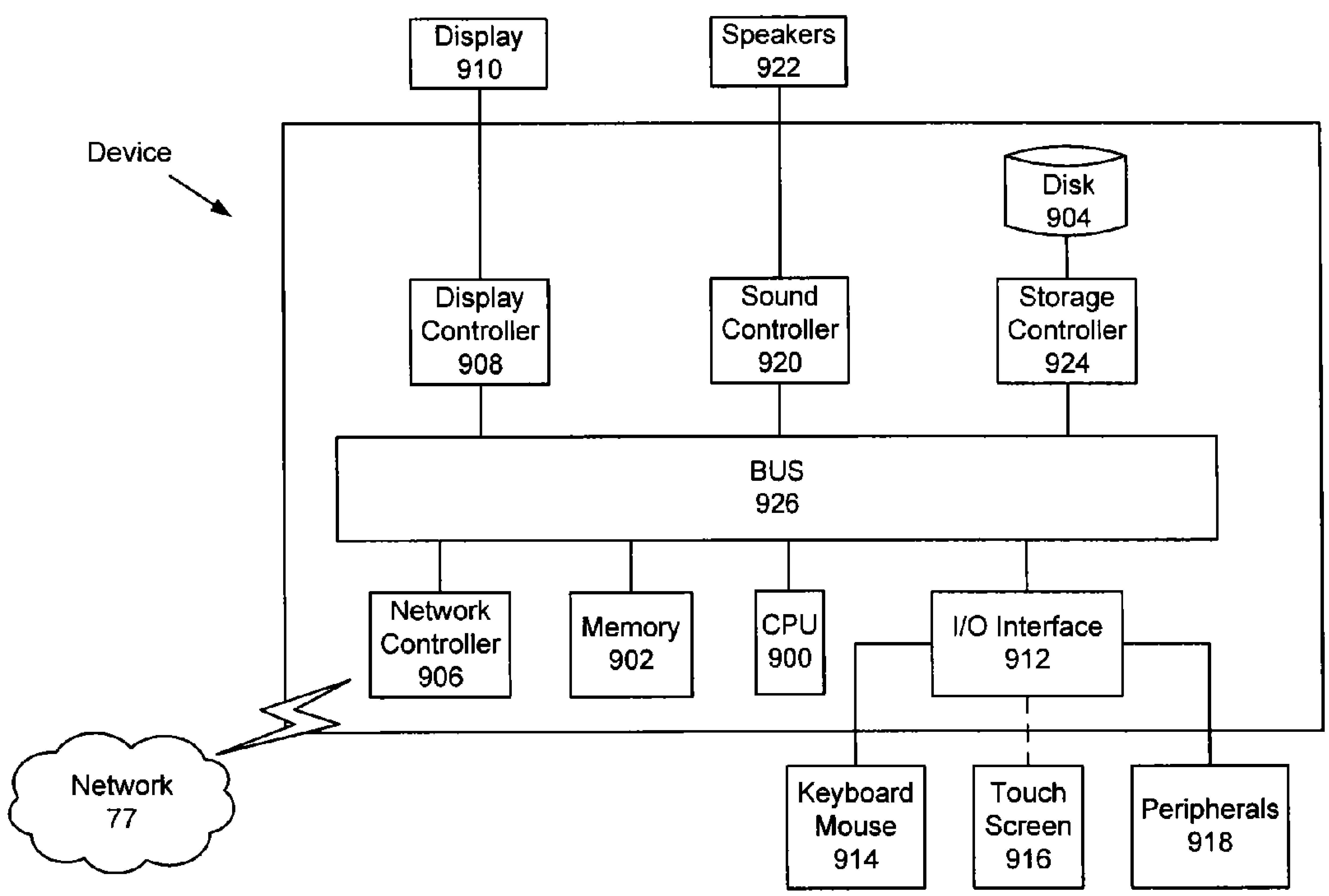

Display
910
Speakers
922
Device
Disk
904
Display
Controller
908
Sound
Controller
920
Storage
Controller
924
BUS
926
Network
Controller
906
Memory
902
CPU
900
I/O Interface
912
Network
77
Keyboard
Mouse
914
Touch
Screen
916
Peripherals
918

FIG. 9

# WIRELESS COMMUNICATION SYSTEM USING HYBRID COOPERATIVE AND NONCOOPERATIVE SENSING

## GRANT OF NON-EXCLUSIVE RIGHT

This application was prepared with financial support from the Saudi Arabian Cultural Mission, and in consideration therefore the present inventor(s) has granted The Kingdom of Saudi Arabia a non-exclusive right to practice the present invention.

## TECHNICAL FIELD

The present disclosure relates to hybrid cooperative and non-cooperative sensing in wireless networks.

## DESCRIPTION OF THE RELATED ART

The "background" description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description which may not otherwise qualify as prior art at the time of filing, are neither expressly or impliedly admitted as prior art against the present invention.

In cooperative sensing, all users, or cognitive radios (CRs), sense the spectrum, and send their observation of the status of the spectrum to a central entity (such as a base station or lead CR) that makes a decision based on voting results. One example may be majority vote on the observation of CRs. Then, the central entity sends the result back to all CRs. CRs receive the spectrum decision from the central entity and follow that decision. The voting is accumulated at a fusion center.

However, it may happen that for example in a wireless network with six cognitive radios, five cognitive radios are blocked due to interference from a transmitting primary user. All six CRs will cooperate in the sensing process during which the first five CRs find the spectrum to be busy and CR**6** finds that the spectrum is idle. The voting, for example majority voting, of spectrum voting process will indicate that the spectrum is busy, and hence, CR**6**, which is not under the influence of primary user or is not interfering with the primary user, cannot use the spectrum, due to the vote of other five CRs even though the spectrum is really available for CR6.

## SUMMARY

The foregoing paragraphs have been provided by way of general introduction, and are not intended to limit the scope of the following claims. The described embodiments, together with further advantages, will be best understood by reference to the following detailed description taken in conjunction with the accompanying drawings.

A combination of cooperative and non-cooperative sensing methods is disclosed, which improves spectrum utilization by switching network nodes not interfering with both primary system and cooperative secondary CRs to a non-cooperative mode. The method then keeps record of the number of times the result of spectrum sensing of a network node matches or differs from the result of cooperative sensing. Also, the method sets thresholds in shift registers to determine when to switch back and forth between cooperative and non cooperative sensing modes, and sends control messages to let a non cooperative CR access the spectrum.



The present disclosure uses two antenna for each network node to separate the two types of control messages or broadcast and reply messages.

## BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will be better understood from reading the description which follows and from examining the accompanying figures. These are provided solely as non-limiting examples of embodiments. In the drawings:

FIG. **1** is an example cognitive radio network that uses cooperative spectrum sensing with cognitive radios;

FIG. **2** is a block diagram that shows a voting flow in the fusion center or central entity;

FIG. **3** is a diagram of a network that shows feedback messages from neighbors of a CR**6** sent to the CR**6**;

FIG. **4** is a diagram of a network that shows a CR**6** affecting or interfering with only one cooperative CR;

FIG. **5** is a diagram of a network that shows CR**6** discovering that there is no primary or cooperative CRs which will be affected by the transmission from CR**6**;

FIG. **6** is a flow chart that shows the mechanism for protecting a primary system and cooperative CRs from interference by a non-cooperative CR **6**;

FIG. **7** is a flow chart that shows using a shift register and a threshold by a CR to determine when to switch to non-cooperative mode;

FIG. **8** is a diagram that shows how the value of a shift register of a non-cooperative user is incremented; and

FIG. **9** is a block diagram of a computer system upon which an embodiment of the present invention may be implemented.

## DETAILED DESCRIPTION

The description provided here is intended to enable any person skilled in the art to understand, make and use this invention. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principals defined herein may be applied to these modified embodiments and applications without departing from the scope of this invention. In each of the embodiment, the various actions could be performed by program instruction running on one or more processors, by specialized circuitry or by a combination of both. Moreover, the invention can additionally be considered to be embodied, entirely or partially, within any form of computer readable carrier containing instructions that will cause the executing device to carry out the technique disclosed herein. The present invention is thus, not intended to be limited to the disclosed embodiments, rather it is be accorded the widest scope consistent with the principles and features disclosed herein.

Details of functions and configurations well known to a person skilled in this art are omitted to make the description of the present invention clear. The same drawing reference numerals will be understood to refer to the same elements throughout the drawings.

The present disclosure may be applied to any type of wireless network. One aspect of the present disclosure includes a type of wireless networks called cognitive radio (CR) networks only for the purpose of explanation.

FIG. **1** illustrates an example of a cooperative spectrum sensing system. There are a plurality of cognitive radios (CR**1**-CR**6**) cooperating in spectrum sensing.

Moreover, FIG. **1** illustrates a non-limiting example of a cooperative spectrum sensing, in which there are a plurality of cognitive radios (CRs) CR **1** to CR **6** cooperating in spectrum sensing. A base station **116** communicates wirelessly with

CRs CR **1** to CR **6** through sending signals **118-130**. In FIG. **1**, there is also a primary user **114**. A fusion center **214** (in FIG. **2**) may also be included in base station **116**.

FIG. **2** is a block diagram of a non-limiting example of a cooperative spectrum sensing system, according to certain embodiments. There is a plurality of cognitive radios (CRs) CR **1** to CR **6** (**202-212**) cooperating in spectrum sensing as shown in FIG. **2**. CRs **202** to **212** in FIG. **2** send their spectrum sensing results or votes to the fusion center **214**. The fusion center **214** then combines the votes and makes a decision. The voting results may be obtained by different rules, for example majority voting rule. The fusion center **214** then sends the decision to CRs **202** to **212** to inform them whether the spectrum is available or not.

Returning to FIG. **1**, for example CR**6** may observe the spectrum status to be different than the other cooperative CR's, because CR**6** is far away from the transmission footprint of primary user **114**. As a result, if CR**6** uses the spectrum, it may not cause any interference to the primary user **114** or other cooperative CRs CR **1** to CR **5**. In this example, CR**6** should switch to non-cooperative sensing since it is far away from the other five cooperative CRs CR **1** to CR **6** and the primary user **114**, and it will not cause interference to them if it uses the spectrum. Hence, the present disclosure provides improvement of spectrum utilization by allowing CRs to opt-in or opt-out of cooperative sensing based on detection of mutual interference.

In one embodiment, referring to FIG. **3**, the present disclosure utilizes two antennas for each CR **1** to CR **6**: one antenna **320** is configured for transmission over a certain channel and the other antenna **322** is configured to send control messages, comprising the broadcast message and the replies, over a control channel. The reason for this control channel is to prevent the broadcast message sent by a non-cooperative CR to cause any interference to a primary user or a cooperative CR. Control messages allow non-cooperative CRs to access the spectrum at the right time and place while achieving the coexistence of cooperative and non-cooperative CRs.

FIG. **3** illustrates a non-limiting example of feedback messages from neighboring CRs **1** to CR **5** of a CR**6** sent to the CR**6**. The feedback messages, in this example, inform the CR**6** that its transmission will cause interference to a primary user **114** and some cooperative CRs. Hence, according to the present disclosure, CR**6** must avoid accessing the spectrum in this situation, and heeds the warnings in the feedback messages.

Referring now to FIG. **4**, FIG. **4** illustrates a non-limiting example of a CR **6** affecting or interfering with only one cooperative CR or a CR **5** with interference signal **140**. As a result, in one embodiment, according to the present disclosure CR **6** should avoid accessing the spectrum, in this example.

Referring now to FIG. **5**, FIG. **5** illustrates a non-limiting example of CR**6** discovering that the transmission from CR **6** will not affect the primary user **114** or cooperative CRs CR **1** to CR **5**. Hence, in the embodiment CR**6** uses the spectrum and transmits to CR **7**, CR **8** and CR **9** even though a primary user **114** and/or a plurality of cooperative CRs CR**1** to CR**5** are also using the spectrum. According to one embodiment, the present disclosure improves spectrum utilization by this coexistence of cooperative and non-cooperative CRs' transmissions.

CR **6** may suffer from intermittent failure due to hardware or software temporal failure, or also because of a temporal obstacle. As a result, switching CR **6** immediately to non-cooperative sensing after any spectrum sensing observation, which mismatches with the voting result, should be avoided. Hence, referring to FIG. **1**, the present disclosure uses a memory, for example shift register **830** at CR **6** and memories for every CR to record if the sensing results of local spectrum observation and the voting result of fusion center **214** in FIG. **2** match or not. The elements of memory or shift register **830** are explained in detail, later in this disclosure, when referring to FIG. **8**. If the memory of a CR**6** indicates that the CR**6**'s spectrum observations are not matching the voting results for a certain number of times or a threshold value, for example 5, then the CR should switch to non-cooperative sensing. In one embodiment, the present disclosure continues comparing the local observation of the user with the voting result even while the CR user is operating under non-cooperative sensing. Once the number of local observations in the shift register matching the voting results reaches a certain threshold, the CR switches back to cooperative sensing to increase the robustness of the voting process.

Non-limiting examples of a primary user or primary system in this disclosure may be a base station, and Television white spaces. Since a non-cooperative CR may suffer from shadowing or fading, it is important to protect a primary user and cooperative cognitive CRs from the interference that may be caused by the non-cooperative CR. Hence, a non-cooperative CR must make sure that its transmission does not affect the primary user or cooperative CRs at a harmful level. To accomplish that, the present disclosure provides the following steps for a non-cooperative CR. In one embodiment, the present disclosure directs a non-cooperative CR to first sense the spectrum to find whether it is available or not. Once it finds that the spectrum is available, according to one embodiment, the present disclosure directs the CR to send a broadcast message to all its neighboring CRs to inform them about its intention to access the spectrum and to enquire if that is possible. According to one embodiment, the present disclosure maintains that each neighbor receiving the message will reply with a message indicating its expectation about whether the transmission from the non-cooperative CR will cause harmful interference to the neighbor node or primary user or not. If all neighbors indicate that no harmful interference will be caused by the non-cooperative CR to them or to the primary user, then the present disclosure, directs the non-cooperative CR to use the spectrum.

Referring now to FIG. **6**, FIG. **6** illustrates a non-limiting example of a primary user and cooperative CRs being protected from interference from a non-cooperative CR. In FIG. **6**, CR **6** checks a condition **604** on whether the CR **6** is suffering shadowing or fading. If condition **604** is not met, no action is taken. If condition **604** is true then condition **606** checks if the CR **6** senses that the spectrum is available. If condition **606** is false, then no action is taken. If condition **606** is true, then, in step **608**, CR **6** sends a broadcast message to CR **1** to CR **5**. In step **608**, CR **6** receives reply messages from CR **1** to CR **5** and checks condition **612** to find out whether reply messages indicate no interference. If condition **612** is false, CR **6** does not transmit. If condition **612** is true, CR **6** uses the spectrum. This happens because the primary user and the neighboring CRs may be idle or far away from the effects caused by the non-cooperative CR**6**'s transmission.

Referring now to FIG. **7**, FIG. **7** illustrates a non-limiting example of a flowchart using a shift register and a threshold at a CR **6** to determine when the CR **6** should switch to the non-cooperative mode, according to certain embodiments.

In FIG. **7** in module **704** a CR **6** senses the spectrum and also receives the decision made by fusion center **214** in FIG. **2**. Then condition **706** is checked to find out whether the sensing result of the CR **6** matches the decision of the fusion center. If the sensing result of CR **6** is different from the fusion center decision, then a 1 is entered into shift register of CR **6** in module **708**. If condition **706** is met, in step **714** a 0 is entered into shift register of CR **6**. In condition **710** of FIG. **7** it is checked if the value of the shift register of CR **6** is below a predefined threshold, for example 5. If condition **710** is met, the process returns to step **704**. If condition **710** is not true, CR **6** switches to non-cooperative mode.

Referring now to FIG. **8**, FIG. **8** illustrates a non-limiting example of a how the shift register of CR **6** is used in the flow chart of FIG. **7**, according to certain embodiments.

In FIG. **8** a sensing result of CR **6** **802** and a voting result of fusion center or **804** are inputs to comparator **806**. The output **816** of comparator **806** is input to a shift register **830** as an input to flip flop **816**. The shift register **830** comprises three flip flops **808**, **810**, and **812**. The flip flops **818**, **810**, and **812** are connected to clock **814** signal. The clock **814** signal connected to flip flop **808** is denoted by **818**. The clock **814** signal connected to flip flop **810** is denoted by **8120**. The clock **814** signal connected to flip flop **812** is denoted by **822**. The clock **814** operates at 33 MHz. The purpose of the shift register **830** is to count the number of mismatches within a number of sensing samples. The shift register **830** is initially is set to zero. Each time the comparator output **816** is a one, a 1 is entered into the shift register **830** to keep record of the number of times the sensing result of CR **6** is different from the voting result of the fusion center. Each time the comparator output **816** is a 0, a 0 is entered into the shift register **830**. Processing circuitry, such as that described in FIG. **9** may be used as an alternative to the shift register and discrete logic that performs the comparison. For example, if shift register **830** has 10 bits instead of 3 bits, and if the mismatch threshold is 6, then CR **6** switches to non-cooperative mode if there are 6 bits with value 1 in the shift register **830** and the CR **6** switches back to cooperative mode, if there are 5 bits with value **0**. This makes this method invulnerable to intermittent failure, because according to one embodiment of this disclosure, the CR **6** switches to the non-cooperative mode only if the local sensing result of CR **6** mismatches the voting result within a certain number of sensing samples, and compared to a certain value of mismatch threshold.

In one embodiment, the present disclosure improves spectrum utilization by letting CRs which are blocked from using the spectrum, due to cooperative sensing mode, utilize the available resources without causing interference to a primary user or other CRs.

In another embodiment, the present disclosure is a hybrid or a combination of cooperative and non-cooperative spectrum sensing.

In another embodiment, the present disclosure mitigates the drawbacks of cooperative sensing in some cases.

Next, a hardware description of a device according to exemplary embodiments is described with reference to FIG. **9**. In FIG. **9**, the device includes a CPU **900** which performs the processes described above. The process data and instructions may be stored in memory **902**. These processes and instructions may also be stored on a storage medium disk **904** such as a hard drive (HDD) or portable storage medium or may be stored remotely. Further, the claimed advancements are not limited by the form of the computer-readable media on which the instructions of the inventive process are stored. For example, the instructions may be stored on CDs, DVDs, in FLASH memory, RAM, ROM, PROM, EPROM, EEPROM, hard disk or any other information processing device with which the device communicates, such as a server or computer.

Further, the claimed advancements may be provided as a utility application, background daemon, or component of an operating system, or combination thereof, executing in conjunction with CPU **900** and an operating system such as Microsoft Windows 7, UNIX, Solaris, LINUX, Apple MAC-OS and other systems known to those skilled in the art.

CPU **900** may be a Xenon or Core processor from Intel of America or an Opteron processor from AMD of America, or may be other processor types that would be recognized by one of ordinary skill in the art. Alternatively, the CPU **900** may be implemented on an FPGA, ASIC, PLD or using discrete logic circuits, as one of ordinary skill in the art would recognize. Further, CPU **900** may be implemented as multiple processors cooperatively working in parallel to perform the instructions of the inventive processes described above.

The device in FIG. **9** also includes a network controller **906**, such as an Intel Ethernet PRO network interface card from Intel Corporation of America, for interfacing with network **77**. As can be appreciated, the network **77** can be a public network, such as the Internet, or a private network such as an LAN or WAN network, or any combination thereof and can also include PSTN or ISDN sub-networks. The network **77** can also be wired, such as an Ethernet network, or can be wireless such as a cellular network including EDGE, 3G and 4G wireless cellular systems. The wireless network can also be WiFi, Bluetooth, or any other wireless form of communication that is known.

The device further includes a display controller **908**, such as a NVIDIA GeForce GTX or Quadro graphics adaptor from NVIDIA Corporation of America for interfacing with display **910**, such as a Hewlett Packard HPL2445w LCD monitor. A general purpose I/O interface **912** interfaces with a keyboard and/or mouse **914** as well as a touch screen panel **916** on or separate from display **910**. General purpose I/O interface also connects to a variety of peripherals **918** including printers and scanners, such as an OfficeJet or DeskJet from Hewlett Packard.

A sound controller **920** is also provided in the device, such as Sound Blaster X-Fi Titanium from Creative, to interface with speakers/microphone **922** thereby providing sounds and/or music.

The general purpose storage controller **924** connects the storage medium disk **904** with communication bus **926**, which may be an ISA, EISA, VESA, PCI, or similar, for interconnecting all of the components of the device. A description of the general features and functionality of the display **910**, keyboard and/or mouse **914**, as well as the display controller **908**, storage controller **924**, network controller **906**, sound controller **920**, and general purpose I/O interface **912** is omitted herein for brevity as these features are known.

Although the description and discussion were in reference to certain exemplary embodiments of the present disclosure, numerous additions, modifications and variations will be readily apparent to those skilled in the art. The scope of the invention is given by the following claims, rather then the preceding description, and all additions, modifications, variations and equivalents that fall within the range of the stated claims are intended to be embraced therein.

The invention claimed is:

**1**. A spectrum sensing method in a communication system comprising:

sensing a shared spectrum with a cognitive radio that is one of a plurality of cognitive radios;

switching the cognitive radio, non interfering cognitive radios of the plurality of cognitive radios and cooperative secondary users to a non-cooperative mode;

keeping a record of a number of times a result of spectrum sensing of the cognitive radio of the plurality of cognitive radios matches a result of cooperative sensing;

setting a threshold in a shift register value to determine when to switch between cooperative and non-cooperative sensing modes based on comparing the shift register value to the threshold; and

sending a control message to provide the non-cooperative cognitive radios of the plurality of cognitive radios access to the spectrum.

**2**. The method of claim **1** wherein the spectrum is a wireless radio frequency spectrum.

**3**. The method of claim **1**, wherein the switching is performed, regardless of a cooperative sensing result.

**4**. The method of claim **1**, wherein the keeping includes keeping a record in a shift register.

**5**. The method of claim **1**, wherein the plurality of cognitive radios include cooperative and non-cooperative cognitive radios in a same network.

**6**. The method of claim **1** further comprising avoiding interference from a non-cooperative cognitive radio to a primary system and cooperative cognitive radios by sending a broadcast message.

**7**. The method of claim **1** further comprising:

avoiding interference from a non-cooperative cognitive radio to a primary system and cooperative cognitive radios by sending a broadcast message from the non-cooperative cognitive radio to neighboring cognitive radios whenever the non-cooperative cognitive radio senses that the spectrum is available.

**8**. The method of claim **7** further comprising:

sending reply messages from neighboring cognitive radios to the non-cooperative cognitive radio in response to the broadcast message.

**9**. The method of claim **7** further comprising:

sending reply messages from neighboring cognitive radios to the non-cooperative cognitive radio in response to the broadcast message, wherein respective reply messages contain information on whether transmission from the non-cooperative cognitive radio causes harmful interference.

**10**. The method of claim **1** further comprising:

avoiding interference to a primary user or cooperative cognitive radios by using two antennas for each cognitive radio, wherein one antenna is for transmission over a certain channel and the other antenna is for sending a control message.

**11**. The method of claim **10**, wherein control messages comprise broadcast messages and reply messages.

**12**. A spectrum sensing apparatus in a communication system comprising:

a cognitive radio that includes a sensor to sense a shared spectrum, the cognitive radio being one of a plurality of cognitive radios in the communication system;

a switch configured to change an operational mode to a non-cooperative mode of the cognitive radio and a portion of the plurality of cognitive radios that are not interfering with a primary system and cooperative cognitive radios;

a shift register disposed in the cognitive radio to keep record of a number of times a result of spectrum sensing of the cognitive radio matches a result of cooperative sensing;

comparator circuity configures to compare the shift register value to a threshold to determine if the switch should change the mode between cooperative and a non-cooperative sensing; and

a plurality of transmitter antennas configured to send a control message to provide a non-cooperative cognitive radio access to the shared spectrum.

**13**. The apparatus of claim **12**, wherein the plurality of tramitter antennas include two antennas that respectively send broadcast messages and reply messages.

**14**. The apparatus of claim **12**, wherein the spectrum is a wireless radio frequency spectrum.

**15**. A non-transitory computer-readable storage medium including computer executable instructions, wherein the instructions, when executed by a computer, cause the computer to perform a method of sensing, the method comprising:

sensing a shared spectrum with a cognitive radio that is one of a plurality of cognitive radios;

switching the cognitive radio,non interfering cognitive radios of the plurality of cognitive radios, and cooperative secondary users to a non-cooperative mode;

keeping a record of a number of times a result of spectrum sensing of the cognitive radio of the plurality of cognitive radios matches a result of cooperative sensing; setting a threshold in a shift register value to determine when to switch between cooperative and non-cooperative sensing modes based on comparing the shift register value to the threshold; and

sending a control message to provide the non-cooperative cognitive radios of the plurality of cognitive radios access to the shared spectrum.

**16**. The method of claim **15**, wherein the switching is performed, regardless of a cooperative sensing result.

**17**. The method of claim **15**, wherein the keeping includes keeping a record in a shift register.

**18**. The methods of claim **15** further comprising:

avoiding interference to a primary user or cooperative cognitive radios by using two antennas for each cognitive radio, wherein one antenna is for transmission over a predetermined channel and the other antenna is for sending control messages, wherein the control messages include broadcast messages and reply messages.

**19**. The method of claim **15** further comprising:

avoiding interference from a non-cooperative cognitive radio to a primary system and cooperative cognitive radios by sending a broadcast message from the non-cooperative cognitive radio to neighboring cognitive radios whenever the non-cooperative cognitive radio senses that the spectrum is available.

**20**. The method of claim **15** further comprising:

sending reply messages from neighboring cognitive radios to the non-cooperative cognitive radio in response to the broadcast message, wherein respective reply messages contain information on whether transmission from a non-cooperative cognitive radio causes harmful interference.

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