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(54) Title: DETECT-AND-MULTIPLEX TECHNIQUE FOR SPECTRUM SHARING

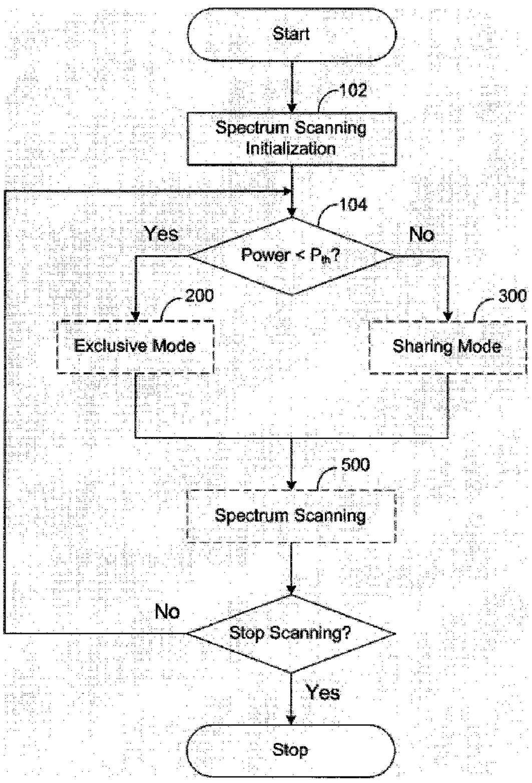

FIG 1: The flowchart of the DAM technique.

(57) Abstract: A wireless communication system and a detect-and-multiplex (DAM) spectrum sharing technique eliminate contention by secondary spectrum users by multiplexing multiple access methods. Suitable multiple access methods include time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), space division multiple access (SDMA), orthogonal frequency division multiple access (OFDMA), spectral nulling (SN) or a hybrid scheme (HS) based on a combination of two or more of the above techniques. Unlike, detect-and-avoid (DAA) multiple access methods, the DAM method increases spectrum usage efficiency, and allows more users to share the same region of the spectrum.

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Detect-and-Multiplex Technique for Spectrum Sharing

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CROSS-REFERENCE TO RELATED APPLICATIONS

The present application relates to and claims priority of (a) U.S. provisional patent application no. 60/887,529, filed on January 31, 2007; and (b) U.S. patent application no. 12/019,547, filed January 24, 2008, both of which are incorporated herein by reference. For the US designation, the present application is a continuation of the aforementioned U.S. patent application no. 12/019,547.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to wireless communication. In particular, the present invention relates to sharing a spectrum among many wireless users to improve efficiency.

2. Discussion of the Related Art

Various spectrum-sharing methods exist for increasing the efficiency or flexibility of spectrum usage, while decreasing the impact of interference. These methods are described, for example, in:

(a) U.S. Patent 5,907,812, entitled "Method and Arrangement for Spectrum Sharing in a Radio Communication Environment," to P. H. G. Van de Berg, issued on May. 25, 1999, discloses a method for flexible coexistence of several radio systems based on spectrum sensing. The method does not use a multiplexing method, but avoids channels that are being used.

(b) U.S. Patent 5,412,658, entitled "Beacon Detection Method and Apparatus for Sharing Spectrum Between Wireless Communications Systems and Fixed Microwave Systems," to H. W. Arnold, D. M. Devasirvathan, N. R. Sollenberger, L. G. Sutliff, and V. K. Varma, issued on May. 2, 1995, discloses a spectrum sharing method for point-to-point and time division multiple access (TDMA) systems that is based on beacon detection.

(c) European Patent Application Publication, EP1220557A1, entitled "Communication

System and Method of Sharing a Communication Resource," by C. Faure, D. Calin, and T. L. Lee, filed on December 29, 2000, discloses a method for dynamically sharing frequencies, both proprietary and shared, that is based on a detect-and-avoid (DAA) mechanism.

(d) U.S. Patent Application Publication, 2005/0095986, entitled "Spectrum Sharing in the Unlicensed Band," by A. Hassan, P. Bahl, J. P. de Vries, filed on October 30, 2003 and published on May. 5, 2005, discloses a method for autonomous interferer detection and adaptation.

(e) U.S. Patent 5,448,754, entitled "Radio Frequency Sharing Personal Communications System," to C. M. P. Ho, and J. D. Lockton, filed January 6, 1994, and issued on Sep. 5, 1995, discloses a frequency allocation scheme that is based on real-time interference sensing.

(f) U.S. Patent 5,548,809, entitled "Spectrum Sharing Communication System and System for Monitoring Available Spectrum," to P. H. Lemson, issued on Aug. 20, 1996, discloses a dynamic frequency allocation technique that is based on a deployed signal-level monitoring system.

(g) U.S. Patent 5,497,503, entitled "Method for Assigning Frequency Channels in a Cellular Communication System and for Identifying Critical Existing Fixed Microwave Receivers that Restrict Operation of Such a System," to J. T. Rydberg, and K. B. Hallman issued on Mar. 5, 1996, discloses a method for assigning frequency channels to base stations in a cellular communication system that is based on receiver clustering.

(h) U.S. Patent 5,805,633, entitled "Method and Apparatus for Frequency Planning in a Multi-system Cellular Communication Network," to J. Uddenfeldt, issued on Sep. 8, 1998, discloses an apparatus for frequency planning in a multi-system network, in which a number of systems operate in multiple frequency bands.

(i) U.S. Patent 7,177,647, entitled "Spectrum Sharing Between Wireless Systems," by M. Goldhammer, issued on Feb. 13, 2007, discloses a method for spectrum sharing that is based on time-frame allocation.

(j) U.S. Patent Application Publication 2006/0286934 A1, entitled "Method and Apparatus for Dynamic Spectrum Sharing," by S. L. Kuffner, R. L. Peterson, and E. Visotsky, published on Dec. 21, 2006, discloses a technique for dynamic spectrum sharing that is based on node identification and measurement of local signal value.

The following references analyze DAA mechanisms for ultrawideband (UWB) interference mitigation, but do not disclose multiplexing alternatives for spectrum sharing: (k)

"Detect and Avoid (DAA) Mechanisms for UWB Interference Mitigation," by V. Somayazulu, J. Foerster, and R. Roberts, published in *IEEE 2006 International Conference on Ultra-Wideband*, pp. 513 – 518, Sept. 2006; (l) "Performance of UWB Systems using a Temporal Detect-and-Avoid Mechanism," by T. Zasowski, and A. Wittneben, published in *IEEE 2006 International Conference on Ultra-Wideband*, pp. 495 – 500, Sept. 2006; (m) "Performance Evaluation of Detect and Avoid Procedures for Improving UWB Coexistence with UMTS and WiMAX systems," A. Durantini, R. Giuliano, F. Mazzenga, and F. Vatalaro, published in *IEEE 2006 International Conference on Ultra-Wideband*, pp. 501 – 506, Sept. 2006; (n) "Interference Mitigation for Coexistence of Heterogeneous Ultra-Wideband Systems", Y. Zhang, H. Wu, Q. Zhang, and P. Zhang, published in *EURASIP Journal on Wireless Communications and Networking*, vol. 2006; (o) "Study of Coexistence between UWB and Narrowband Cellular Systems" M. Mittelbach, C. Muller, D. Ferger, A. Finger, published in *Joint International Workshop on Ultra Wideband Systems and International Conference on Ultrawideband Systems and Technologies*, pp. 40 – 44, May 2004.

(p) "Spectrum Pooling: An Inovative Strategy for the Enhancement of Spectrum Efficiency", by T. A. Weiss, and F. K. Jondral, published in *IEEE Communications Magazine*, pp. 8-14, March 2004, discloses a concept of spectrum pooling which allows secondary utilization of already licensed frequency bands.

(q) "OverDRiVE - Spectrum Efficient Multicast Services to Vehicles", R. Tönjes, K. Mößner, T. Lohmar, and M. Wolf, published in *IST Mobile Summit*, Thessaloniki, Greece, June 2002, discloses a hybrid network that ensures spectrum efficient provision of mobile multimedia services and enables interworking of cellular and broadcast networks in a common frequency range with dynamic spectrum allocation.

The prior art methods require that the secondary spectrum users contend for the spectrum when the primary owner of the spectrum is transmitting, and thus do not result in optimal spectrum usage. These methods do not use a multiplexing method to increase the spectral efficiency and thus, reduce the network capacity as less users can be supported by the fixed amount of spectrum. The methods are not flexible, requiring modification of the existing networks or special accommodation by the existing networks.

SUMMARY

A wireless communication system and a detect-and-multiplex (DAM) spectrum sharing technique eliminate contention by secondary spectrum users by multiplexing multiple access methods. Suitable multiple access methods include time division multiple access (TDMA), frequency division multiple access (FDMA), code division multiple access (CDMA), space division multiple access (SDMA), orthogonal frequency division multiple access (OFDMA),

spectral nulling (SN) or a hybrid scheme (HS) based on a combination of two or more of the above techniques. Unlike, DAA methods, the DAM method increases spectrum usage efficiency, and allows more users to share the same region of the spectrum.

According to one embodiment of the present invention, a method assigns, initially, a portion of a spectrum for exclusive use by a first user. The first user may then determine if a condition in the portion of the spectrum is favorable to allow one or more other users to communicate over the same portion of the spectrum using a multi-access method. To determine the channel condition, the first user detects the interference-plus-noise power in the portion of the spectrum, and enabling the other users when the interference-plus-noise power exceeds a predetermined threshold. The interference-plus-noise power may be detected using an adaptive scanning method selected from adaptive scanning methods having different update schedules.

The present invention is better understood upon consideration of the detailed description below in the conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a detect-and-multiplex (DAM) technique according to one embodiment of the present invention.

FIG. 2 illustrates in further detail exclusive operation mode **200**, in accordance with one embodiment of the present invention.

FIG. 3 illustrates in further detail sharing operating mode **300**, in accordance with one embodiment of the present invention.

FIG. 4 illustrates multiplexing multiple access schemes to allow spectrum sharing, according to one embodiment of the present invention.

FIG. 5 illustrates a spectrum scanning method, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a DAM technique according to one embodiment of the present invention. As shown in **FIG. 1**, the method includes (a) exclusive operating mode **200** and (b) sharing operating mode **300**. After spectrum scanning initialization step **102**, the interference-plus-noise power level is tested against a predefined threshold **104** to determine which of the operating modes should be used by the wireless system.

FIG. 2 illustrates in further detail exclusive operation mode **200**, in accordance with one embodiment of the present invention. As shown in **FIG. 2**, when the previous operating mode is sharing operating mode **300**, an initialization step is performed. Thereafter, the primary user is granted transmit and receive accesses to the given spectrum channel exclusively. Returning to **FIG. 1**, at spectrum scanning step **500**, the exclusive primary user measures the interference-plus-noise power in its spectral band over a measure period T_m. When the power exceeds the predefined threshold P_{th}, the method switches to sharing operating mode **300**.

FIG. 3 illustrates in further detail sharing operating mode **300**, in accordance with one embodiment of the present invention. As shown in **FIG. 3**, when the previous operating mode is exclusive operating mode **200**, an initialization step is performed. Thereafter, multiple users i.e., both primary and secondary users are granted transmit and receive accesses to the given spectrum channel. In sharing operating mode **300**, multiple users share the given spectrum channel using a predefined multiplexing strategy **400** (see, further detail in **FIG. 4**). Returning to **FIG. 1**, at spectrum scanning step **500**, the interference-plus-noise power is monitored over measure period T_m. When the power falls below the threshold P_{th}, the method switches to exclusive operating mode **200**.

The power threshold P_{th} is a system parameter that is determined at design time, and depends on the power transmitted by each mobile node, the thermal noise power, and the maximum allowable distance between two mobile nodes.

During the spectrum scanning process **500** (see **FIG. 5**), the measure period T_m is a system parameter which can be dynamically modified while the system is in operation. As shown in **FIG. 5**, spectrum scanning process **500** may be implemented by different measuring modes according to the duration of measure period T_m. If measure period T_m is selected to be shorter than a predefined threshold time T_{th}, fast update mode **502** measures interference-plus-noise power more frequently than under slow update mode **504**. Fast update mode **502** ensures accurate and fast interferer detection, but requires more complex mobile node hardware and higher power consumption. The predefined threshold time T_{th} is selected based on channel conditions (e.g., fading, shadowing and Doppler effects), the mobility of the mobile nodes, and the session times of the mobile nodes.

Alternatively, under slow update mode **504**, measure period T_m is longer than the predefined threshold time T_{th}, and the interference-plus-noise power is measured and updated only intermittently. Slow update mode **504** ensures simpler mobile node hardware and reduced power consumption, at the expense of accuracy and speed in the interferer detection.

In contrast to conventional DAA methods, a DAM method of the present invention does not require that the secondary spectrum users contend for the spectrum channel when the primary user is transmitting. As shown in **FIG. 4**, simultaneous medium access may be achieved through multiplexing the use of the spectrum using the following methods:

(a) Time Division Multiple Access (TDMA) **402**. Under TDMA, users transmit in non-overlapping time slots. Time slots may be assigned to users dynamically or statically, and may be assigned deterministically or stochastically.

(b) Frequency Division Multiple Access (FDMA) **404**. Under FDMA, users transmit in non-overlapping frequency slots. Frequency slots may be assigned to users dynamically or statically, and can be assigned deterministically or stochastically.

(c) Code Division Multiple Access (CDMA) **406**. Under CDMA, users transmit using orthogonal codes, which may be dynamically or statically assigned to users.

(d) Space Division Multiple Access (SDMA) **408**. Under SDMA, the physical locations of the transmitters (hence, their respective interference powers) is used to coordinate medium access.

(e) Orthogonal Frequency Division Multiple Access (OFDMA) **410**. Under OFDMA, users are assigned subsets of sub-carriers, which allow simultaneous lower data rate transmissions from several users.

(f) Spectral Nulling (SN) **412**. Under SN, each user monitors the spectrum to shape its transmitting signal. Specifically, the user introduces spectral nulls, as necessary, to minimize interference with the primary spectrum owner and secondary users.

(g) Hybrid Scheme (HS) **414**. Under a hybrid scheme, users transmit using a combination of any of the six previous methods described in (a) to (f).

(h) Miscellaneous Scheme **416**, representing new and future multiple access schemes.

A method of the present invention has the advantage that the secondary spectrum users need not contend for the spectrum while the primary user of the spectrum is transmitting. Relative to prior art DAA techniques, a DAM technique of the present invention increases spectrum usage efficiency, allowing more users to share a common region of the spectrum.

The detailed description above is provided to illustrate specific embodiments of the present invention and is not intended to be limiting. Numerous modifications and variations within the scope of the present invention are possible. The present invention is set forth in the following claims.

CLAIMS

We claim:

1. A method for spectrum sharing comprising:

assigning a portion of the spectrum for use by a first user to communicate; and

based on a measurement of interference-plus-noise power in the portion of the spectrum, assigning the portion of the spectrum to a second user for a second user to communicate using a multi-access method.

2. A system for spectrum sharing comprising:

a first user assigned to communicate over a portion of the spectrum; and

a second user assigned, upon a favorable measurement of a interference-plus noise power, to communicate over the portion of the spectrum using a multi-access method.

3. A method carried out by a first user which is assigned a portion of a spectrum, comprising:

communicating over the portion of the spectrum exclusively;

determining a condition in the portion of the spectrum; and

enabling one or more other users to communicate over the portion of the spectrum using a multiple-access method.

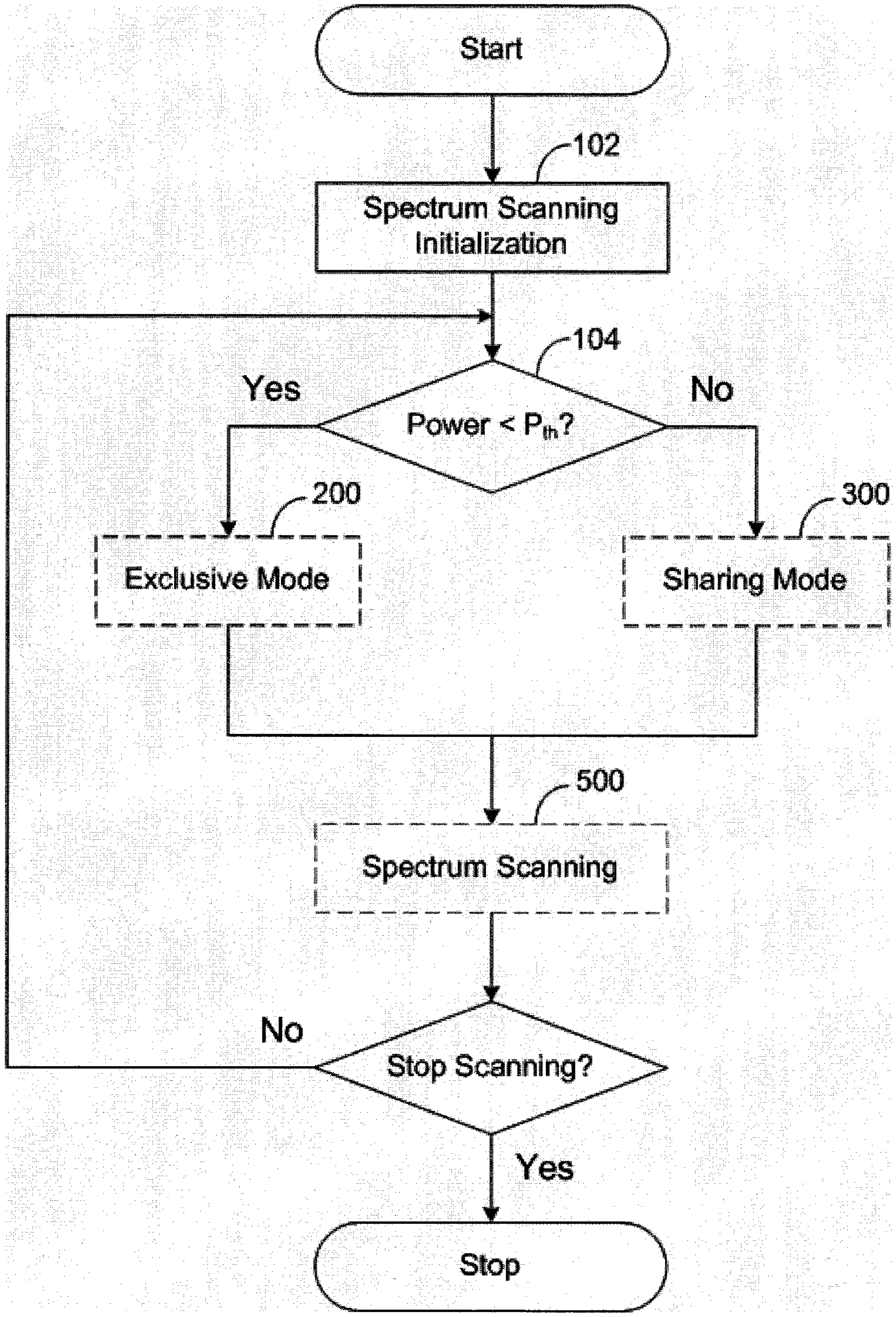

FIG 1: The flowchart of the DAM technique.

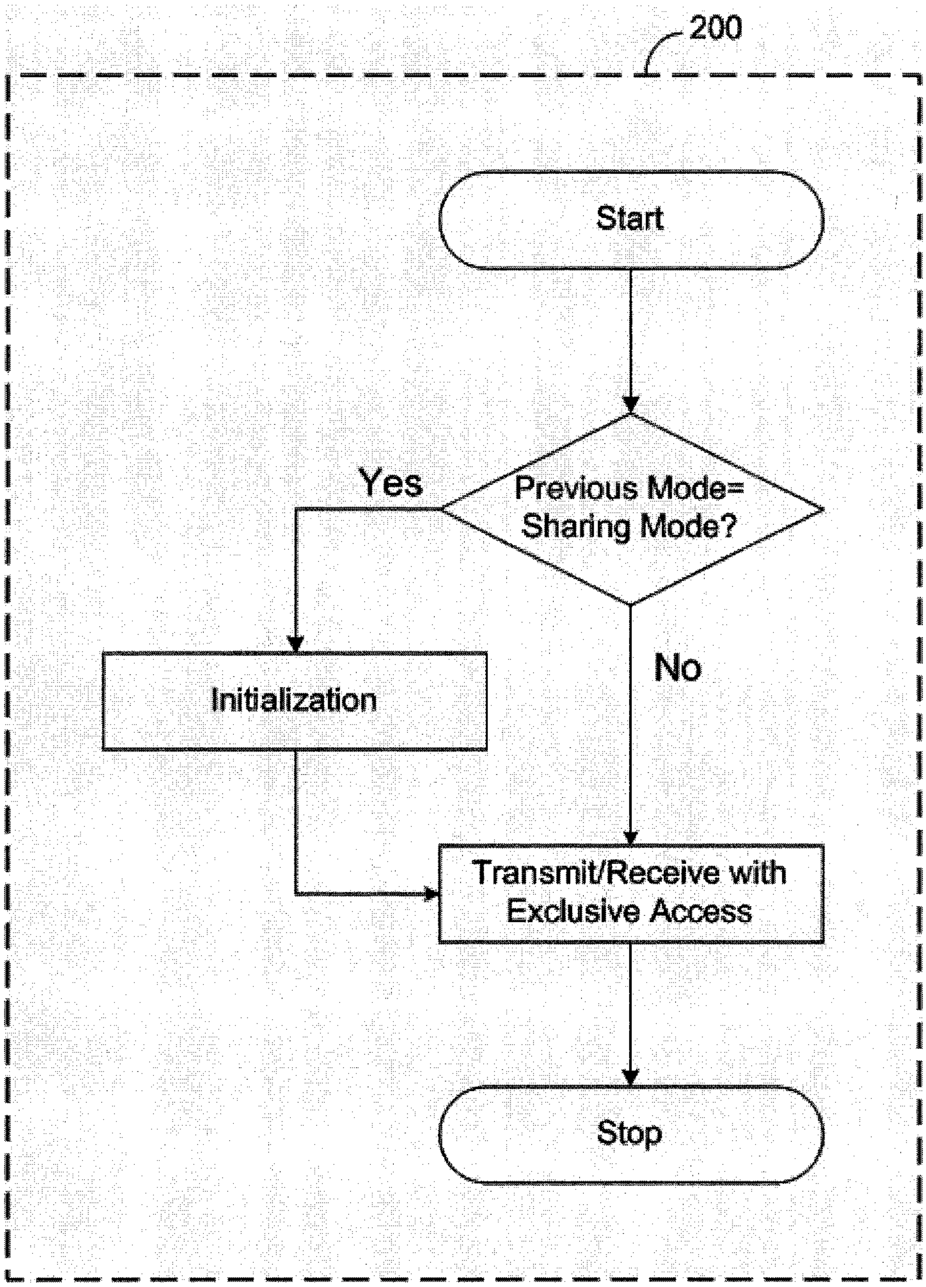

FIG 2: The "Exclusive Mode" subsystem.

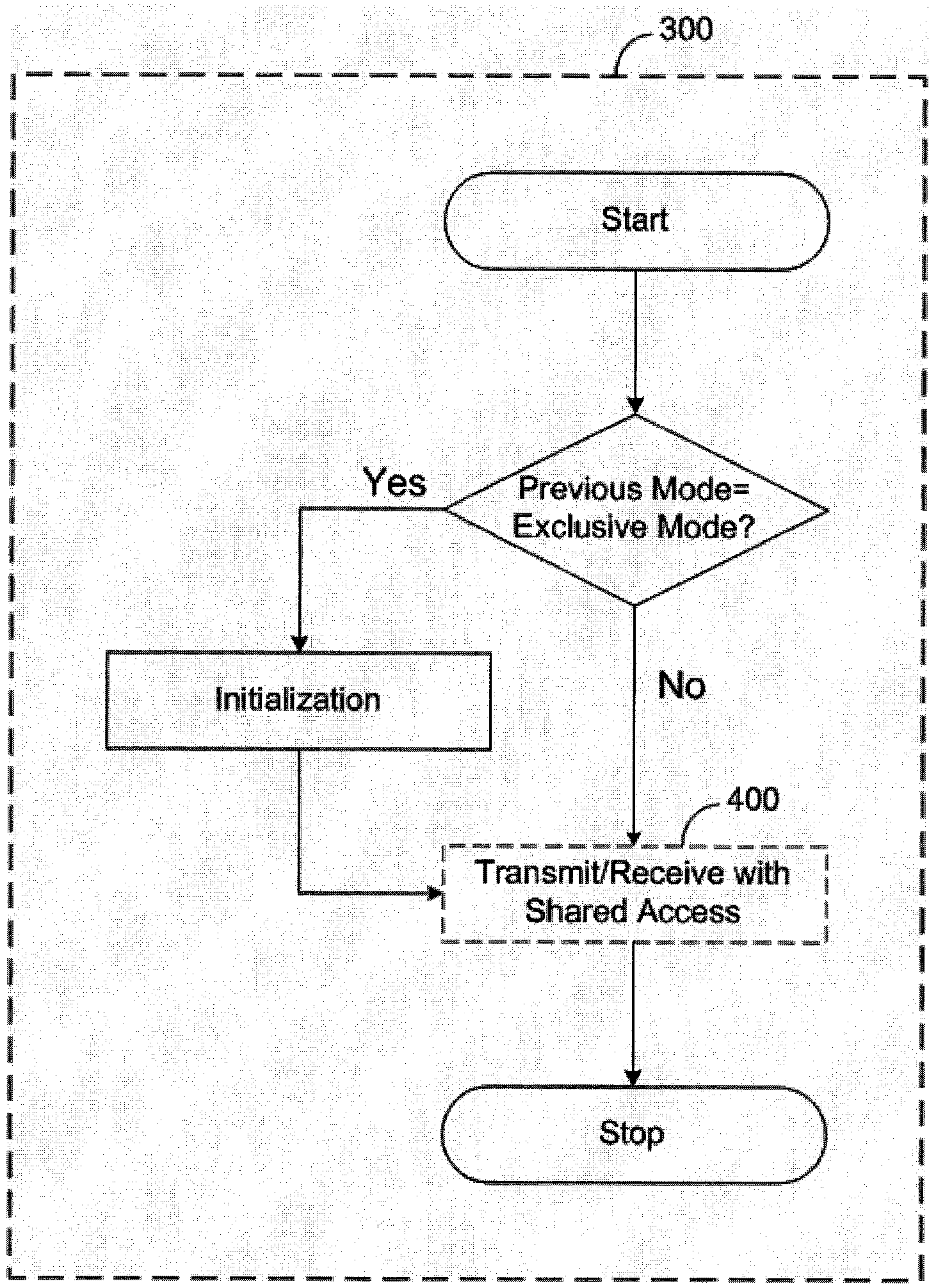

FIG 3: The "Sharing Mode" subsystem.

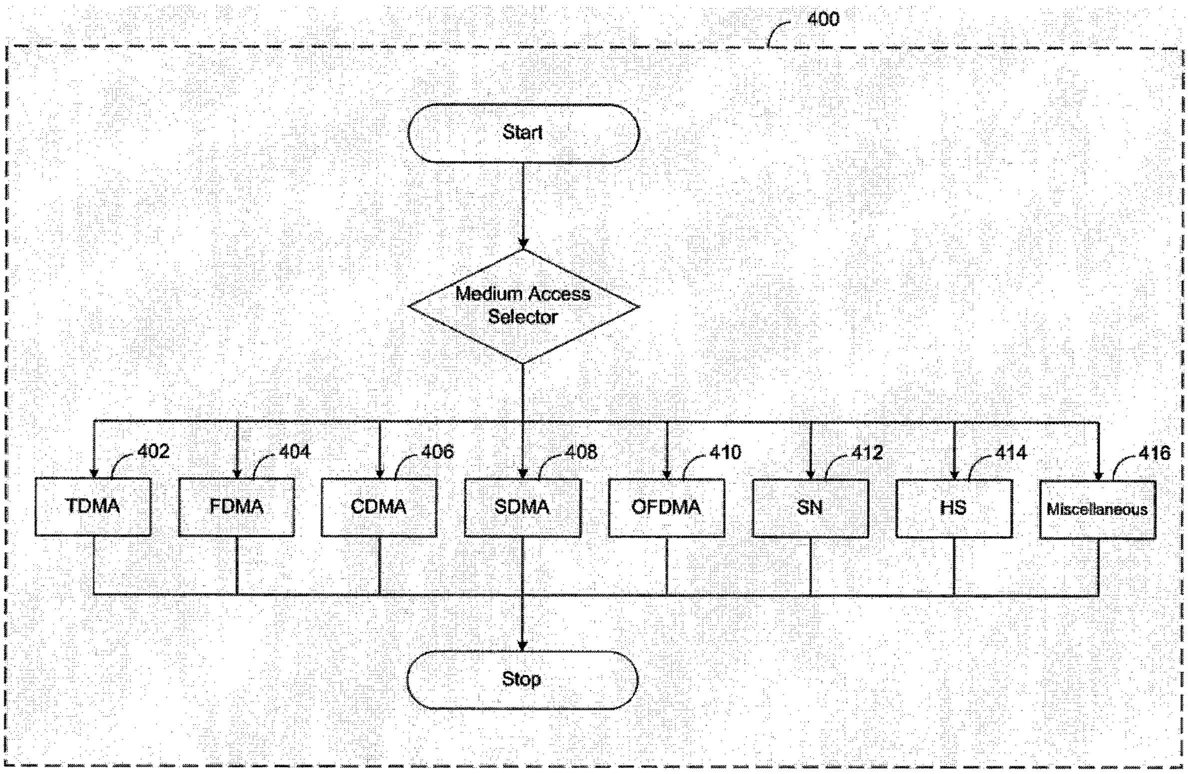

FIG 4: The "Transmit/Receive with Shared Access" subsystem.

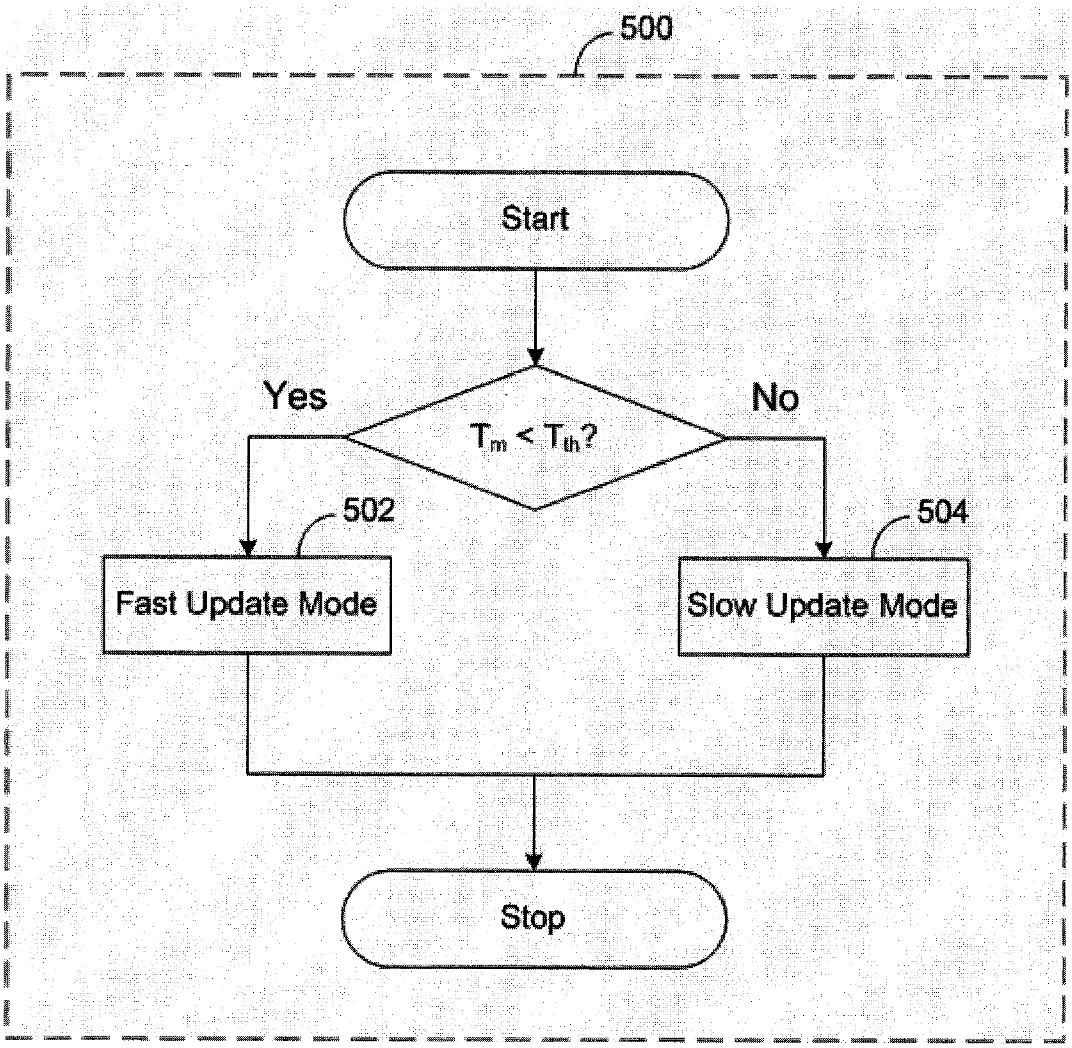

FIG 5: The "Spectrum Scanning" process subsystem.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US08/52183

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H04B 1/00 (2008.04)
USPC - 375/146
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - H04B 1/00; H04B 7/00; H04B 15/00; G01R 31/08; G06F 11/00; G08C 15/00; H04J 1/16; H04J 3/14; H04L 1/00; H04L 12/26; H04B 7/212; H04J 3/00; H04B 7/216; H04B 7/208; H04B 7/212; H04B 7/204 (2008.04)
USPC - 370/252, 337, 335, 342, 344, 347, 319, 320, 321; 455/69, 68, 63.1; 375/146, 147

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Database: PatBase

Search Terms: spectrum sharing, detect, multiplex, interference plus noise power, assign, spectrum

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/0086027 A1 (SHATTIL) 06 May 2004 (06.05.2004) entire document	1-3
A	US 5,648,955 A (JENSEN et al) 15 July 1997 (15.07.1997) entire document	1-3

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
06 May 2008	23 MAY 2008

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