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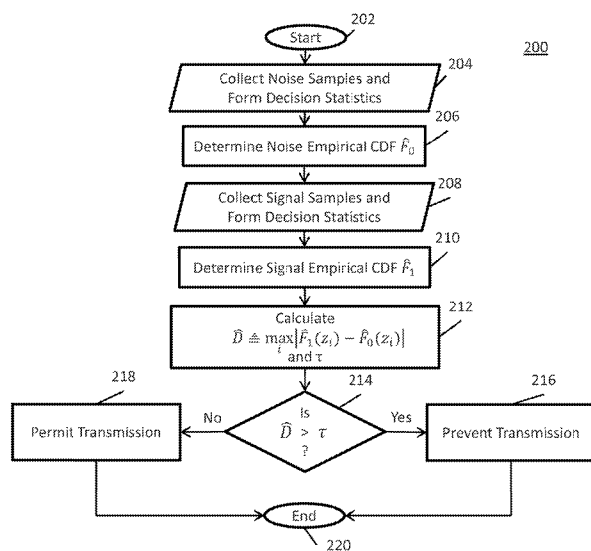


FIG. 2

(57) Abstract: Methods, systems, and media for detecting usage of a radio channel are provided. In some embodiments, methods for detecting usage of a radio channel are provided, the methods comprising: collecting noise samples on the radio channel from a radio receiver; determining a noise empirical cumulative distribution function using a hardware processor; collecting signal samples on the radio channel from the radio receiver; determining a signal empirical cumulative distribution function using a hardware processor; calculating a largest absolute difference between the noise empirical cumulative distribution function and the signal empirical cumulative distribution function using a hardware processor; and determining that the radio channel is being used when the largest absolute difference is greater than a threshold using a hardware processor.

METHODS, SYSTEMS, AND MEDIA FOR DETECTING USAGE OF A RADIO CHANNEL

Cross Reference To Related Application

[0001] This application claims the benefit of United States Provisional Patent Application No. 61/422,114, filed December 10, 2010, which is hereby incorporated by reference herein in its entirety.

Background

[0002] To cope with the recent reality of stringent shortage in frequency spectrum due to the proliferation of wireless services, cognitive radio has been considered as an attractive technique to improve spectrum utilization for future wireless systems. In cognitive radio networks, one important function of secondary transceivers is to determine when primary transceivers are utilizing a channel, and to access the channel in such a way that it causes little performance degradation to the primary transceivers. Previous attempts at detecting the usage of a channel by one or more primary transceivers have had limited performance, especially at low signal-to-noise ratios.

Summary

[0003] In accordance with some embodiments, methods, systems, and media for detecting usage of a radio channel are provided. In some embodiments, methods for detecting usage of a radio channel are provided, the methods comprising: collecting noise samples on the radio channel from a radio receiver; determining a noise empirical cumulative distribution function using a hardware processor; collecting signal samples on the radio channel from the radio receiver; determining a signal empirical cumulative distribution function using a hardware processor; calculating a largest absolute difference between the noise empirical cumulative distribution function and the signal empirical cumulative distribution function using a hardware processor; and determining that the radio channel is being used when the largest absolute difference is greater than a threshold using a hardware processor.

[0004] In some embodiments, systems for detecting usage of a radio channel are provided, the systems comprising: a radio receiver; and at least one hardware processor that: collects noise samples on the radio channel from the radio receiver; determines a noise empirical cumulative distribution function; collects signal samples on the radio channel from the radio receiver; determines a signal empirical cumulative distribution function; calculates a largest absolute difference between the noise empirical cumulative distribution function and the signal empirical cumulative distribution function; and determines that the radio channel is being used when the largest absolute difference is greater than a threshold.

[0005] In some embodiments, non-transitory computer-readable media containing computer-executable instructions that, when executed by a processor, cause the processor to perform a method for detecting usage of a radio channel are provided, the method comprising: collecting noise samples on the radio channel from a radio receiver; determining a noise empirical cumulative distribution function; collecting signal samples on the radio channel from the radio receiver; determining a signal empirical cumulative distribution function; calculating a largest absolute difference between the noise empirical cumulative distribution function and the signal empirical cumulative distribution function; and determining that the radio channel is being used when the largest absolute difference is greater than a threshold.

Brief Description Of The Drawings

[0006] FIG. 1 is a block diagram of a cognitive radio network in accordance with some embodiments.

[0007] FIG. 2 is a flow diagram of an example of a process for detecting usage of a radio channel using a single stage test in accordance with some embodiments.

[0008] FIG. 3 is a flow diagram of an example of a process for detecting usage of a radio channel using a multiple stage test in accordance with some embodiments.

Detailed Description

[0009] In accordance with some embodiments, methods, systems, and media for detecting usage of a radio channel are provided.

[0010] In some embodiments, secondary transceivers can use the Kolmogorov-Smirnov (K-S) test to determine when primary transceivers are using a radio channel. In applying this test, these

secondary transceivers can compute an empirical cumulative distribution function (CDF) of some decision statistic obtained from the received signal, and compare it with the empirical CDF of noise samples from the channel.

[0011] Turning to FIG. 1, an architecture for a cognitive radio system 100 is shown. As illustrated, system 100 may include a plurality of radios 102, 104, and 106. These radios may respectively include transceivers 108, 110, and 112 and antennas 114, 116, and 118. Each transceiver may include both a receiver and a transmitter in some embodiments. As shown, these radios may be multi-input multi-output (MIMO) transceivers where each include multiple antennas (e.g., such as two transmit antennas and four receive antennas (some of which may also be transmit antennas)). In some embodiments, these radios may transmit on any suitable frequencies (e.g., as specified in the IEEE 802.11 standards), may use any suitable modulation (e.g., such as QPSK modulation), etc.

[0012] As shown, transceivers 108 and 110 may be primary transceivers and therefore have priority in using a given radio channel on which the radios operate. When these primary transceivers are using a channel, transceiver 112, which is a secondary transceiver, may determine that it should not use the channel (e.g., not transmit on the channel). In this way, transmission from transceiver 112 will not interfere with the transmission of transceivers 108 or 110.

[0013] As also shown in FIG. 1, transceiver 112 may include MIMO transceiver circuitry 120 and a hardware processor 122. MIMO transceiver circuitry 120 may be any suitable MIMO transceiver circuitry for converting RF signals received by antennas 118 into IQ data 124 and for converting IQ data 126 into RF signals to be transmitted from antennas 118. For example, in some embodiments, MIMO transceiver circuitry 120 may be implemented using a transceiver from Analog Devices, Inc. of Norwood, Massachusetts, or a transceiver from Maxim Integrated Products, Inc. of Sunnyvale, California. Hardware processor 122 may be any suitable hardware processor 122 such as any suitable microprocessor, digital signal processor, a controller, etc.

[0014] Although transceiver 112 is only shown in FIG. 1 as including MIMO transceiver 120 and hardware processor 122 for the sake of clarity, any other suitable components and/or circuitry can be included in transceiver 112. For example, transceiver 112 can include memory, communication interfaces, display controllers, input devices, etc.

[0015] Radios 102, 104, and 106 can be implemented in any suitable devices in some embodiments. For example, radios 102, 104, and/or 106 can be implemented in mobile computers, mobile telephones, mobile access cards, wireless routers, wireless access points, and/or any other suitable wireless device.

[0016] Any suitable approaches can be used by transceiver 112 to determine if a primary transceiver 102 or 104 is using a radio channel. For example, in some embodiments, the presence of one or several primary transceivers transmitting on a given channel can be detected as usage based on signals observed by transceiver 112.

[0017] Whether a transceiver is transmitting on a channel can be determined in any suitable manner. For example, in some embodiments, mathematical models of sampled signals from a channel when a transmitter is present and when a transmitter is not present can be formed, and those models used to perform analysis on a channel under test.

[0018] More particularly, for example, when there are one or more primary transceivers transmitting on a general multiple-input multiple-output (MIMO) frequency-selective fading channel, a sampled signal $y(t)$ received by a secondary transceiver, defined as $y[n] \triangleq y(nT_s)$ with $1/T_s$ being the sampling rate, can be modeled by the following equation (1):

$$y[n] = \sum_{k=1}^K \sum_{l=0}^{L-1} H_k[n, l] s_k[n - l] + v[n]. \quad (1)$$

In equation (1): K is the number of transceivers transmitting (e.g., $K=2$); L is the multipath channel delay spread in terms of the number of symbol intervals (e.g., $L=6$); $s_k[n] \in \mathbb{C}^{N_t}$ is the n -th transmitted symbol vector for the k -th primary transceiver with N_t being the number of transmit antennas on that transceiver (e.g., $N_t = 2$); $y[n] \in \mathbb{C}^{N_r}$ is the n -th received signal vector by the secondary transceiver with N_r being the number of receive antennas on the secondary transceiver (e.g., $N_r = 6$); $H_k[n, l] \in \mathbb{C}^{N_r \times N_t}$ is the time-variant MIMO channel tap matrix of the k -th transceiver; and $v[n] \in \mathbb{C}^{N_r}$ is the noise vector.

[0019] When there are no primary transceivers transmitting over the sensed channel, the sampled signal can be modeled by equation (2) that includes noise only:

$$y[n] = v[n]. \quad (2)$$

[0020] In accordance with some embodiments, if the received signal samples are denoted as $Y \triangleq \{y[n], n = 1, \dots, M\}$, the determination of whether a primary transceiver is transmitting can be performed by testing for the truth of two hypotheses. For example, in such a determination, a hypothesis $\mathcal{H}_0$ can state that no primary transceiver is transmitting and thus that Y follows the

model of equation (2), and a hypothesis $\mathcal{H}_1$ can state that one or more primary transceivers are transmitting and thus that Y follows the model of equation (1).

[0021] In accordance with some embodiments, there can be several special cases of the general signal model in equation (1) that are of interest, as follows: (1) slow-fading, frequency-flat MIMO channels where $L=1$ and $\mathbf{H}_k[n, 0] \equiv H_k, \forall n$; (2) slow-fading frequency-selective MIMO channels where $\mathbf{H}_k[n, l] \equiv H_k[l], \forall n$; and (3) MIMO-OFDM channels where $L=1$, $\mathbf{H}_k[n, 0]$ are obtained by the discrete Fourier transform (DFT) of the time-domain channel coefficients, and n is the subcarrier index.

[0022] The Kolmogorov-Smirnov (K-S) test is a non-parametric test of goodness of fit for a continuous cumulative distribution of data samples. In accordance with some embodiments, it can be used to approve a null hypothesis that two data populations are drawn from the same distribution to a certain required level of significance. On the other hand, failing to approve the null hypothesis can be used to show that the two data populations are from different distributions.

[0023] In accordance with some embodiments a two-sample K-S test can be used to approve or fail to approve the null hypothesis. This test can be referred to as a one dimensional (1D) test. In the two-sample K-S test, a sequence of independent and identically distributed real-valued data samples $z_1, z_2, \dots, z_N$ with the underlying cumulative distribution function (CDF) $F_1(z)$ can be observed when one or more primary transceivers may or may not be transmitting. For example, these data samples can be observed in IQ data 124 by hardware processor 122. Another independent and identically distributed sequence of noise samples $\xi_1, \xi_2, \dots, \xi_{N_0}$ with the underlying CDF $F_0(\xi)$ can also be observed when all transceivers are known to not be transmitting. For example, these data samples can also be observed in IQ data 124 by hardware processor 122. The null hypothesis to be tested is:

$$H_0: F_1 = F_0. \quad (3)$$

[0024] In some embodiments, in performing the K-S test, hardware processor 122 can form the empirical CDF $\hat{F}_1$ from M (e.g., 50) observed signal samples $z_1, z_2, \dots, z_M$ using the following equation (4):

$$\hat{F}_1(z) \triangleq \frac{1}{M} \sum_{n=1}^M \mathbb{I}(z_n \leq z), \quad (4)$$

where $\mathbb{I}(\cdot)$ is the indicator function, which equals one if the input is true (e.g., the amplitude, the quadrature, or any other suitable characteristic of the samples z_n is less than or equal to a certain threshold z) and equals zero otherwise.

[0025] Hardware processor 122 can also form the empirical CDF $\hat{F}_0$ from M_0 (e.g., 100) observed noise samples $\xi_1, \xi_2, \dots, \xi_{N_0}$ using the following equation (5):

$$\hat{F}_0(\xi) \triangleq \frac{1}{M_0} \sum_{n=1}^{M_0} \mathbb{I}(\xi_n \leq \xi). \quad (5)$$

[0026] In some embodiments, the largest absolute difference between the two CDFs can be used as a goodness-of-fit statistic as shown in equation (6):

$$D \triangleq \sup_{w \in \mathbb{R}} |F_1(w) - F_0(w)|. \quad (6)$$

In some embodiments, this difference can be calculated by hardware processor 122 using equation (7):

$$\hat{D} \triangleq \max_i |\hat{F}_1(w_i) - \hat{F}_0(w_i)|, \quad (7)$$

for some uniformly sampled points $\{w_i\}$.

[0027] In some embodiments, the hardware processor 122 can calculate the significance level $\hat{\alpha}$ of the observed value $\hat{D}$ using equation (8):

$$\hat{\alpha} \triangleq P(D > \hat{D}) = Q\left(\left[\sqrt{\tilde{M}} + 0.12 + \frac{0.11}{\sqrt{\tilde{M}}}\right] \hat{D}\right), \quad (8)$$

$$\text{with } Q(x) \triangleq 2 \sum_{m=1}^{\infty} (-1)^{m-1} e^{-2m^2 x^2}, \quad (9)$$

where $\tilde{M}$ is the equivalent sample size, given by:

$$\tilde{M} = \frac{MM_0}{M+M_0}. \quad (10)$$

Note that $Q(\cdot)$ is a monotonically decreasing function with $Q(0) = 1$ and $Q(\infty) = 0$.

[0028] In some embodiments, the hardware processor 122 can reject the hypothesis H_0 at a significance level α if $\hat{\alpha} = P(D > \hat{D}) < \alpha$. The significance level α is an input of the K-S test to specify the false alarm probability under the null hypothesis, i.e.,

$$\alpha \triangleq P(D \geq \tau | H_0), \quad (11)$$

where τ is a threshold value, that can be obtained given a level of significance α by solving equation (8) and (11) for τ .

[0029] Note that the relationship of critical value τ and the significance level α can depend on equivalent sample size $\tilde{M}$.

[0030] Hence given α , H_0 is accepted, i.e., $F_1 = F_0$, if $\hat{D} \leq \tau$; and otherwise H_0 is rejected, i.e., $F_1 \neq F_0$.

[0031] Because the signals in equation (1) are complex-valued, the corresponding distributions are two-dimensional (2D). Accordingly, in accordance with some embodiments, a two-dimensional K-S test can additionally or alternatively be used to approve or fail to approve the null hypothesis.

[0032] Consider a sequence of 2D real-valued data samples $(u_1, v_1), \dots, (u_N, v_N)$. In the 2D K-S test, the CDFs for all four quadrants (I, II, III, and IV) of the 2D plane can be examined by the hardware processor as follows:

$$\begin{aligned} F^I(u, v) &\triangleq P(U < u, V < v); \\ F^{II}(u, v) &\triangleq P(U > u, V < v); \\ F^{III}(u, v) &\triangleq P(U > u, V > v); \text{ and} \\ F^{IV}(u, v) &\triangleq P(U < u, V > v). \end{aligned} \quad (12)$$

[0033] In some embodiments, the hardware processor can calculate the four empirical CDFs for the four quadrants using all possible combinations of the 2D data samples. For example, the first quadrant empirical CDF can be calculated using equations (13):

$$\begin{aligned} \hat{F}_1^I(u, v) &= \frac{1}{M^2} \sum_{(i,j) \in \{1, \dots, M\} \times \{1, \dots, M\}} \mathbb{I}(u_i < u) \mathbb{I}(v_j < v); \\ \hat{F}_1^{II}(u, v) &= \frac{1}{M^2} \sum_{(i,j) \in \{1, \dots, M\} \times \{1, \dots, M\}} \mathbb{I}(u_i > u) \mathbb{I}(v_j < v); \\ \hat{F}_1^{III}(u, v) &= \frac{1}{M^2} \sum_{(i,j) \in \{1, \dots, M\} \times \{1, \dots, M\}} \mathbb{I}(u_i > u) \mathbb{I}(v_j > v); \text{ and} \\ \hat{F}_1^{IV}(u, v) &= \frac{1}{M^2} \sum_{(i,j) \in \{1, \dots, M\} \times \{1, \dots, M\}} \mathbb{I}(u_i < u) \mathbb{I}(v_j > v). \end{aligned} \quad (13)$$

[0034] In some embodiments, the hardware processor can use the 2D samples directly, rather than using all possible combinations, for forming the empirical CDFs as follows using equations (14):

$$\begin{aligned} \hat{F}_1^I(u, v) &= \frac{1}{M} \sum_{n=1}^M \mathbb{I}(u_i < u) \mathbb{I}(v_j < v); \\ \hat{F}_1^{II}(u, v) &= \frac{1}{M} \sum_{n=1}^M \mathbb{I}(u_i > u) \mathbb{I}(v_j < v); \\ \hat{F}_1^{III}(u, v) &= \frac{1}{M} \sum_{n=1}^M \mathbb{I}(u_i > u) \mathbb{I}(v_j > v); \text{ and} \\ \hat{F}_1^{IV}(u, v) &= \frac{1}{M} \sum_{n=1}^M \mathbb{I}(u_i < u) \mathbb{I}(v_j > v). \end{aligned} \quad (14)$$

[0035] In some embodiments, the largest absolute difference between the empirical CDFs among all four quadrants under H_0 and H_1 can be calculated as follows:

$$\hat{D} = \max_{q \in \{I, II, III, IV\}} \max_{1 \leq n \leq N} |\hat{F}_1^q(u_n, v_n) - \hat{F}_0^q(u_n, v_n)| \quad (15)$$

As in the 1D test, for a given significance level α or a threshold value τ , using $\hat{D}$ in equation (15), the hardware processor can then test to approve or disapprove the hypothesis H_0 .

[0036] Turning to FIG. 2, an example process 200 for determining whether a primary transceiver is using a radio channel that can be implemented by hardware processor 122 in accordance with some embodiments is shown.

[0037] As described above, this process uses empirical cumulative distribution function (CDF) calculations based on decision statistics $\{z_n\}$. Any suitable decision statistics can be used to calculate the CDFs. For example, in some embodiments, because the received signals in (1) and (2) are complex-valued, the decision statistics $\{z_n\}$ can be formed based on any of various combinations a signal characteristic (e.g., signal amplitude, signal quadrature, etc.) and a K-S detector dimensionality (e.g., one dimension (1D), two dimensions (2D), etc.). For example, in some embodiments, the decision statistics can be formed based on a magnitude-based, 1D K-S detector from M received signal vectors $\{y[n], n=1, \dots, M\}$, so that $M \cdot N_r$ decision statistics can be obtained as:

$$z_{(n-1)N_r+j} = |y_j[n]|, j=1, \dots, N_r; n=1, \dots, M. \quad (16)$$

As another example, in some embodiments, the decision statistics can be formed based on a quadrature-based, 1D K-S detector from M received signal vectors $\{y[n], n=1, \dots, M\}$, so that $2 \cdot M \cdot N_r$ decision statistics can be obtained as:

$$z_{2[(n-1)N_r+j]} = \Re\{y_j[n]\}, z_{2[(n-1)N_r+j]+1} = \Im\{y_j[n]\}, j=1, \dots, N_r; n=1, \dots, M. \quad (17)$$

As yet another example, in some embodiments, the decision statistics can be formed based on a quadrature-based, 2D K-S detector from M received signal vectors $\{y[n], n=1, \dots, M\}$, so that $M \cdot N_r$ decision statistic pairs can be obtained as:

$$z_{(n-1)N_r+j} = (\Re\{y_j[n]\}, \Im\{y_j[n]\}), j=1, \dots, N_r; n=1, \dots, M. \quad (18)$$

[0038] As illustrated, after process 200 begins at 202, hardware processor 122 can obtain noise statistics by collecting M_0 noise-only sample vectors $\{v[n], n=1, \dots, M_0\}$ and form the corresponding decision statistics (e.g., amplitude or quadrature statistics) $\{\xi_n\}$ at 204. These noise-only samples can be collected in any suitable manner and any suitable number of samples

can be collected. For example, these samples may be collected from IQ data 124 at a time when it is known that no primary transceiver is using the radio channel.

[0039] Then, at 206, the hardware processor can then compute the empirical 1D or 2D noise empirical CDF $\hat{F}_0$, as described above.

[0040] Next, hardware processor 122 can collect M received signal sample vectors $\{y[n], n=1, \dots, M\}$ and form the corresponding decision statistics (e.g., amplitude or quadrature statistics) $\{z_n\}$ at 208. These signal samples can be collected in any suitable manner and any suitable number of samples can be collected. For example, these samples may be collected from IQ data 124 at a time when a primary transceiver may or may not be using the radio channel.

[0041] The hardware processor can then compute the empirical 1D or 2D cdf $\hat{F}_1$, as described above, at 210.

[0042] At 212, hardware processor 122 can next compute the maximum difference $\hat{D}$ in equation (7), and the threshold τ based on the given false alarm rate α using equation (8) and equation (11), as described above. If $\hat{D} > \tau$, then the hardware processor can determine at 214 that a primary transceiver is using the radio channel and prevent secondary transceiver 112 from transmitting on the channel at 216. Otherwise, the hardware processor 122 can determine at 214 that no primary transceiver is using the radio channel and cause the secondary transceiver to transmit on the channel at 218. After 216 or 218, process 200 can terminate at 220.

[0043] It should be understood that some of the above steps of the flow diagram of FIG. 2 can be executed or performed in an order or sequence other than the order and sequence shown and described in the figure. Also, some of the above steps of the flow diagram of FIG. 2 may be executed or performed well in advance of other steps, or may be executed or performed substantially simultaneously or in parallel to reduce latency and processing times.

[0044] In accordance with some embodiments, instead of using a fixed number of samples for each decision, a decision can be made based on a number of samples that varies based on conditions. For example, in some embodiments, with each new detected sample, the empirical CDF $\hat{F}_1$ can be updated and the K-S statistic reevaluated. More particularly, for example, a sequential K-S test can be formed by concatenating P K-S tests, starting with q samples and adding q samples at each subsequent stage up to P stages, where P is the truncation point of the test.

[0045] FIG. 3 illustrates an example process 300 for determining whether a primary transceiver is using a radio channel that can be implemented by hardware processor 122 in accordance with some embodiments.

[0046] As shown, after process 300 begins at 302, hardware processor 122 can obtain noise statistics by collecting M_0 noise-only sample vectors $\{v[n], n=1, \dots, M_0\}$ and form the corresponding decision statistics (e.g., amplitude or quadrature statistics) $\{\xi_n\}$ at 304. These noise-only samples can be collected in any suitable manner and any suitable number of samples can be collected. For example, these samples may be collected from IQ data 124 at a time when it is known that no primary transceiver is using the radio channel.

[0047] Then, at 306, the hardware processor can then compute the empirical 1D or 2D noise empirical CDF $\hat{F}_0$, as described above.

[0048] Next, hardware processor 122 can collect $M=q$ received signal sample vectors $\{y[n], n=1, \dots, M\}$ and form the corresponding decision statistics (e.g., amplitude or quadrature statistics) $\{z_n\}$ at 308. These signal samples can be collected in any suitable manner and any suitable number of samples can be collected. For example, these samples may be collected from IQ data 124 at a time when a primary transceiver may or may not be using the radio channel.

[0049] The hardware processor can then compute the signal empirical 1D or 2D CDF $\hat{F}_1$, as described above, at 310.

[0050] At 312, hardware processor 122 can next compute the maximum difference $\hat{D}$ in equation (7) and the threshold τ using equation (8) and equation (11). However, unlike what is described above wherein τ is calculated based on the false alarm rate α of the overall single stage test, here τ is calculated based on the false alarm probability β of each stage of the P stage test (by substituting α with β in equations (8) and (11)) in order to meet the overall false alarm rate α , where β can be calculated using equation (19):

$$\beta = 1 - \sqrt[P]{1 - \alpha} \quad (19)$$

based on the overall false alarm rate α being represented by the following equation:

$$\alpha = \beta + (1-\beta)\beta + (1-\beta)^2\beta + \dots + (1-\beta)^{P-1}\beta = 1 - (1-\beta)^P. \quad (20)$$

[0051] If $\hat{D} > \tau$, then the hardware processor can determine at 314 that a primary transceiver is using the radio channel and prevent secondary transceiver 112 from transmitting on the channel at 316. Otherwise, hardware processor 122 can branch from 314 to 318 to determine whether to truncate the test. The test may be truncated for any suitable reason. For example, in some

embodiments, the test may be truncated after a certain number of loops, comparisons of the largest absolute difference to the threshold, etc. If so, the processor can determine that no primary transceiver is using the radio channel and cause the secondary transceiver to transmit on the channel at 320. After 316 or 320, process 300 can terminate at 322.

[0052] It should be understood that some of the above steps of the flow diagram of FIG. 3 can be executed or performed in an order or sequence other than the order and sequence shown and described in the figure. Also, some of the above steps of the flow diagram of FIG. 3 may be executed or performed well in advance of other steps, or may be executed or performed substantially simultaneously or in parallel to reduce latency and processing times.

[0053] In some embodiments, any suitable computer readable media can be used for storing instructions for performing the processes described herein, can be used as a content distribution that stores content and a payload, etc. For example, in some embodiments, computer readable media can be transitory or non-transitory. For example, non-transitory computer readable media can include media such as magnetic media (such as hard disks, floppy disks, etc.), optical media (such as compact discs, digital video discs, Blu-ray discs, etc.), semiconductor media (such as flash memory, electrically programmable read only memory (EPROM), electrically erasable programmable read only memory (EEPROM), etc.), any suitable media that is not fleeting or devoid of any semblance of permanence during transmission, and/or any suitable tangible media. As another example, transitory computer readable media can include signals on networks, in wires, conductors, optical fibers, circuits, any suitable media that is fleeting and devoid of any semblance of permanence during transmission, and/or any suitable intangible media.

[0054] Although the invention has been described and illustrated in the foregoing illustrative embodiments, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the details of implementation of the invention can be made without departing from the spirit and scope of the invention, which is only limited by the claims which follow. Features of the disclosed embodiments can be combined and rearranged in various ways.

What Is Claimed Is:

1. A method for detecting usage of a radio channel comprising:
 - (a) collecting noise samples on the radio channel from a radio receiver;
 - (b) determining a noise empirical cumulative distribution function using a hardware processor;
 - (c) collecting signal samples on the radio channel from the radio receiver;
 - (d) determining a signal empirical cumulative distribution function using a hardware processor;
 - (e) calculating a largest absolute difference between the noise empirical cumulative distribution function and the signal empirical cumulative distribution function using a hardware processor; and
 - (f) determining that the radio channel is being used when the largest absolute difference is greater than a threshold using a hardware processor.
2. The method of claim 1, wherein the radio receiver is part of a transceiver.
3. The method of claim 1, wherein the radio channel is a MIMO channel.
4. The method of claim 1, further comprising forming decision statistics for the noise samples and the signal samples based on amplitude characteristics.
5. The method of claim 1, further comprising forming decision statistics for the noise samples and the signal samples based on quadrature characteristics.
6. The method of claim 1, further comprising repeating (c), (d), (e), and (f) when the largest absolute difference is not greater than a threshold using a hardware processor.
7. The method of claim 6, further comprising determining whether a given number of comparisons of a largest absolute difference value to the threshold has been performed before repeating (c), (d), (e), and (f).

8. A system for detecting usage of a radio channel comprising:
a radio receiver; and
at least one hardware processor that:
 - (a) collects noise samples on the radio channel from the radio receiver;
 - (b) determines a noise empirical cumulative distribution function;
 - (c) collects signal samples on the radio channel from the radio receiver;
 - (d) determines a signal empirical cumulative distribution function;
 - (e) calculates a largest absolute difference between the noise empirical cumulative distribution function and the signal empirical cumulative distribution function; and
 - (f) determines that the radio channel is being used when the largest absolute difference is greater than a threshold.
9. The system of claim 8, wherein the radio receiver is part of a transceiver.
10. The system of claim 8, wherein the radio channel is a MIMO channel.
11. The system of claim 8, wherein the at least one hardware processor also forms decision statistics for the noise samples and the signal samples based on amplitude characteristics.
12. The system of claim 8, wherein the at least one hardware processor also forms decision statistics for the noise samples and the signal samples based on quadrature characteristics.
13. The system of claim 8, wherein the at least one hardware processor also repeats (c), (d), (e), and (f) when the largest absolute difference is not greater than a threshold.
14. The system of claim 13, wherein the at least one hardware processor also determines whether a given number of comparisons of a largest absolute difference value to the threshold has been performed before repeating (c), (d), (e), and (f).

15. A non-transitory computer-readable medium containing computer-executable instructions that, when executed by a processor, cause the processor to perform a method for detecting usage of a radio channel, the method comprising:

- (a) collecting noise samples on the radio channel from a radio receiver;
- (b) determining a noise empirical cumulative distribution function;
- (c) collecting signal samples on the radio channel from the radio receiver;
- (d) determining a signal empirical cumulative distribution function;
- (e) calculating a largest absolute difference between the noise empirical cumulative distribution function and the signal empirical cumulative distribution function; and
- (f) determining that the radio channel is being used when the largest absolute difference is greater than a threshold.

16. The non-transitory computer-readable medium of claim 15, wherein the radio receiver is part of a transceiver.

17. The non-transitory computer-readable medium of claim 15, wherein the radio channel is a MIMO channel.

18. The non-transitory computer-readable medium of claim 15, wherein the method further comprises forming decision statistics for the noise samples and the signal samples based on amplitude characteristics.

19. The non-transitory computer-readable medium of claim 15, wherein the method further comprises forming decision statistics for the noise samples and the signal samples based on quadrature characteristics.

20. The non-transitory computer-readable medium of claim 15, wherein the method further comprises repeating (c), (d), (e), and (f) when the largest absolute difference is not greater than a threshold.

21. The non-transitory computer-readable medium of claim 20, wherein the method further comprises determining whether a given number of comparisons of a largest absolute difference value to the threshold has been performed before repeating (c), (d), (e), and (f).

100

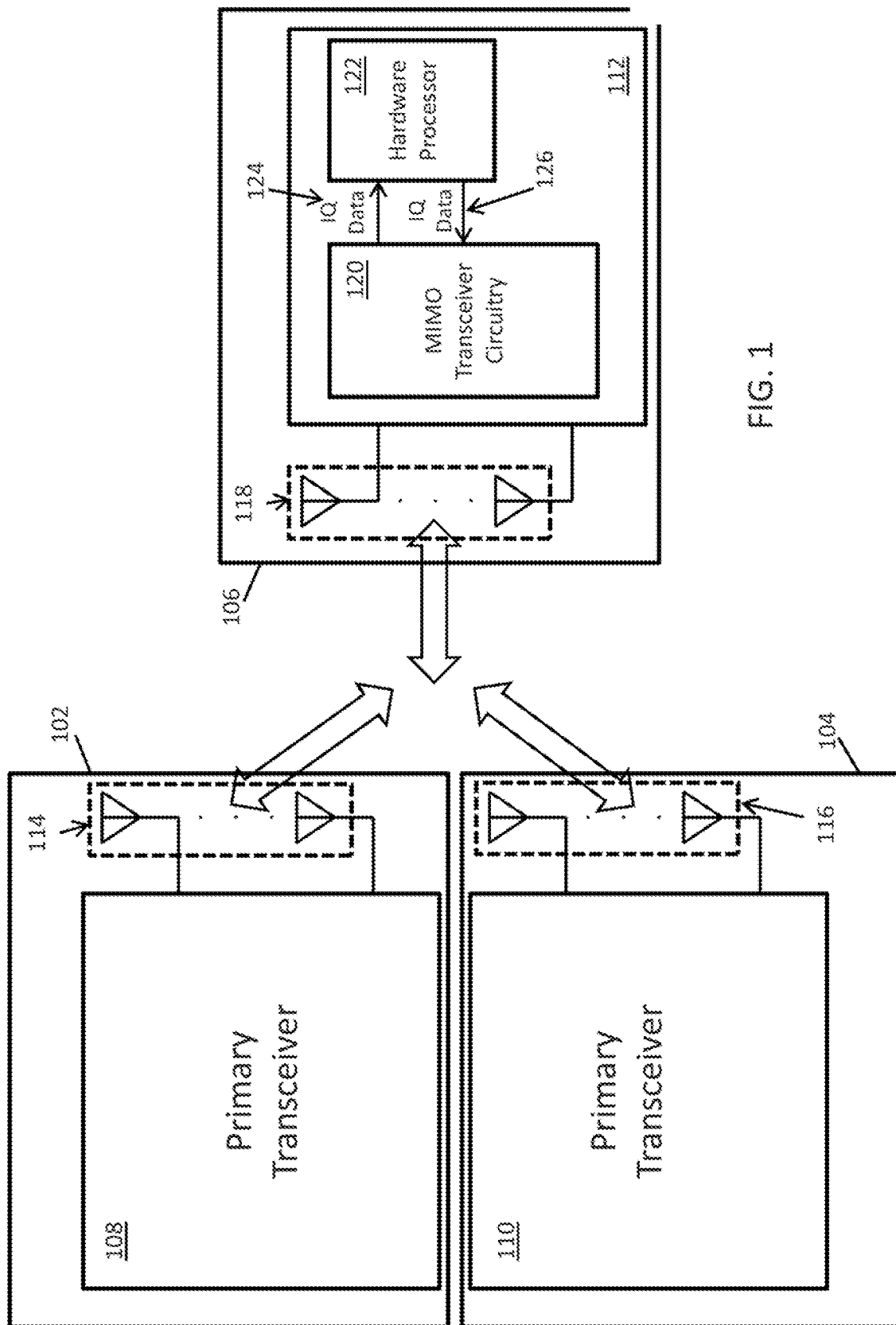


FIG. 1

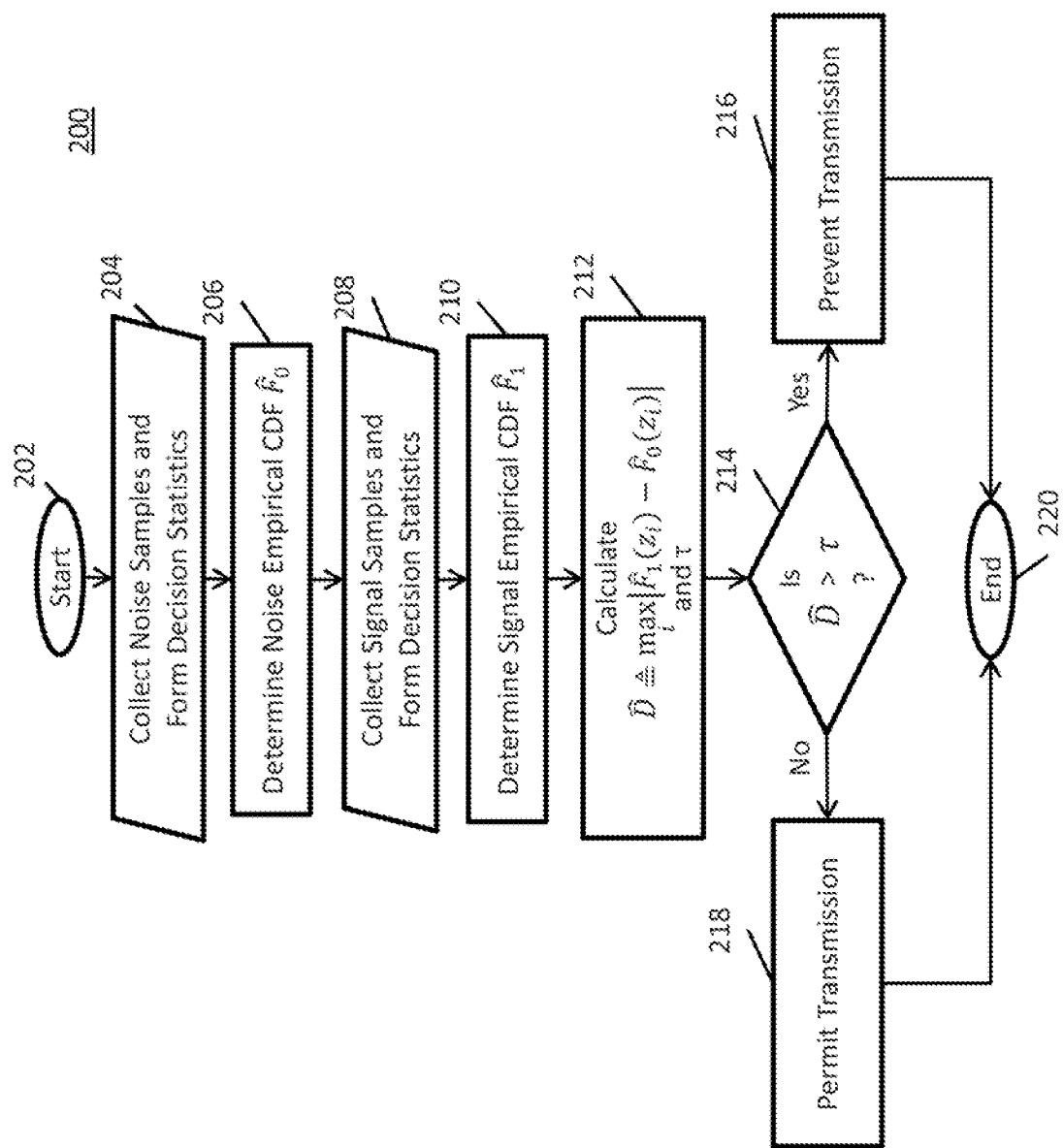


FIG. 2

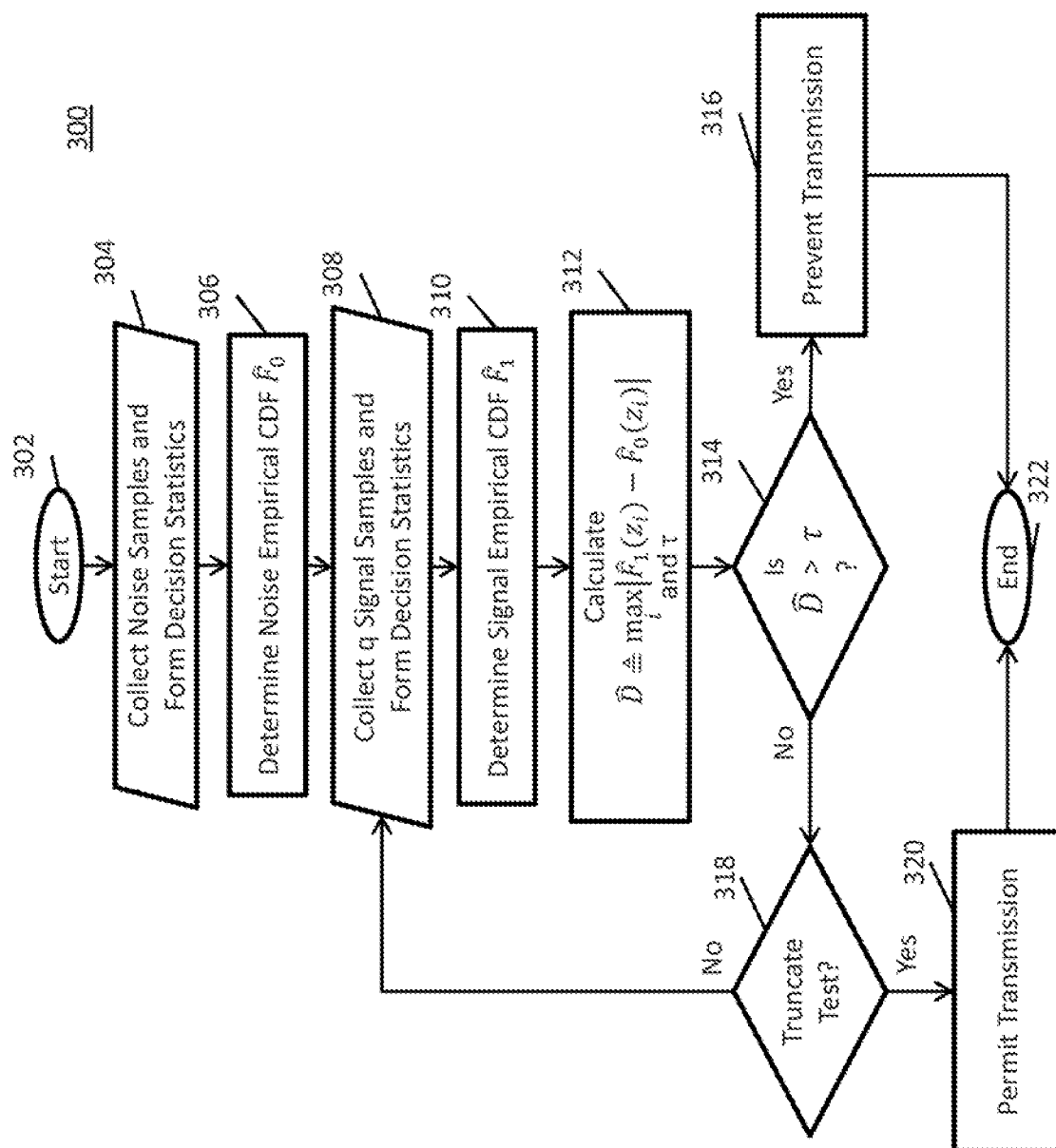


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2011/064434

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H04W 72/04 (2012.01)

USPC - 370/229

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) - H04W 72/00, 72/04, 72/12; 74/00 (2012.01)

USPC - 370/229, 230, 232, 329, 338

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)

PatBase, Google Patent Search, Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2007/0066229 A1 (ZHANG et al) 22 March 2007 (22.03.2007) entire document	1-21
Y	US 2010/0135226 A1 (CHANDRAMOULI et al) 03 June 2010 (03.06.2010) entire document	1-21
Y	US 2008/0181252 A1 (ROFOUGARAN) 31 July 2008 (31.07.2008) entire document	4, 5, 11, 12, 18, 19
A	US 2007/0230335 A1 (SANG et al) 04 October 2007 (04.10.2007) entire document	1-21

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

* Special categories of cited documents:

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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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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

15 February 2012

Date of mailing of the international search report

01 MAR 2012

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