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(54) Title: METHOD AND SYSTEM FOR DETECTING PREAMBLES IN A MULTI-CELL SYSTEM

(57) Abstract: The present invention discloses a method and system for detecting preambles in a multi-cell communication system. The method detects preambles reliably even in the presence of interference caused by multiple cells reusing the same frequency in the multi-cell communication system. After receiving a signal in the receiving period, the time domain signal is sampled and transformed into the frequency domain vector. The correlation vector is calculated with the frequency domain vector and pseudonoise code of the wireless station according to the method disclosed in this invention. The presence of a preamble is verified if the value in the correlation vector exceeds a predetermined threshold.



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METHOD AND SYSTEM FOR DETECTING PREAMBLES IN A MULTI-CELL SYSTEM

CROSS REFERENCE

[0001] The present application claims the benefit of U.S. Provisional Application Serial Number 60/815,661, which was filed on June 22, 2006, and U.S. Patent Application Serial Number 11/605,600 filed November 28, 2006.

BACKGROUND

[0002] In wireless communications, a preamble is a signal that is broadcasted by a base transceiver station (BTS) to all mobile stations (MSs) for facilitating carrier and timing acquisitions. A preamble consists of a bit-sequence called the pseudonoise (PN) code. The PN code is a pseudo-random sequence of 1's and 0's. The cross-correlation and the autocorrelation of the PN codes are similar to those of white noise. Preamble detection is an essential function of a wireless station for detecting incoming signals, as the presence of a preamble with a unique sequence is indicative of an incoming signal. Here, it is generally understood that a wireless station refers to either a mobile terminal or a fixed terminal such as a BTS.

[0003] A receiver chain of a wireless station employs a preamble detection module, e.g., a correlator, to detect preamble. If there is a preamble in a receiving signal, the correlator will produce an output the magnitude of which is larger than a predetermined threshold.

[0004] In a multi-cell wireless communication system, for example, a cellular system, it is desirable to use the same frequencies repeatedly across the cellular

system. The reuse of frequencies enables the wireless communication system with a limited number of radio channels to accommodate a large number of subscribers.

[0005] In such a multi-cell wireless communication system, the tolerance to interference determines the frequency reuse factor, defined as the number of distinctive frequencies per cluster of cells adjacent to each other. Subsequently, the frequency reuse factor determines the efficiency of spectrum usage. The frequency reuse factor is positively related to the carrier to interference ratio (C/I) and negatively related to the spectrum utilization rate.

[0006] For example, if the frequency reuse factor is 3, the efficiency of spectrum usage is reduced by a factor of 3. Ideally, if all cells in a cluster use the same frequency, the frequency reuse factor would be 1. Increasing the utilization rate of the spectrum comes with a price. If the frequency reuse factor is 1, the signals from one or more BTSs or customer premise equipment (CPEs) in one cell could spill over to the adjacent cells and cause interference.

[0007] The multi-cell interference caused by frequency reuse is one of the major factors that impair the performance of a wireless communication system. The effect of multi-cell interference can be reduced by employing the beamforming method in a unicast communication, but not in broadcast or multicast communications. Preambles are broadcasted by a BTS to all the MS in a wireless communication system. Therefore, a need has arisen for an improved method and system for detecting preambles in the multi-cell communication system.

SUMMARY

[0008] The construction and method of operation of the invention, however, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

[0009] The present invention discloses a method and system for detecting preambles in a multi-cell communication system. The method detects preambles reliably even in the presence of interference caused by multiple cells reusing the same frequency in the multi-cell communication system. After receiving a signal in the receiving period, the time domain signal is sampled and transformed into the frequency domain vector. The correlation vector is calculated with the frequency domain vector and pseudonoise code of the wireless station according to the method disclosed in this invention. The presence of a preamble is verified if the value in the correlation vector exceeds a predetermined threshold.

BRIEF DESCRIPTION OF THE DRAWING

[0010] The drawings accompanying and forming part of this specification are included to depict certain aspects of the invention. The invention may be better understood by reference to one or more of these drawings in combination with the description presented herein. It should be noted that the features illustrated in the drawings are not necessarily drawn to scale.

[0011] FIGs. 1A and 1B are exemplary cell configurations in spatial and frequency domains, respectively, in a multi-cell wireless communication system.

[0012] FIGs. 2A and 2B are examples of grouping sampling points into sampling windows.

[0013] FIG. 3 is a flow diagram illustrating a preamble detection method according to an embodiment of the present invention.

[0014] FIG. 4 is a diagram shows a correlation results for the preamble detection.

DESCRIPTION

[0015] The following detailed description of the invention refers to the accompanying drawings. The description includes exemplary embodiments, not excluding other embodiments, and changes may be made to the embodiments described without departing from the spirit and scope of the invention. The following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims.

[0016] The present invention discloses a novel method for detecting a preamble of an incoming signal in a multi-cell wireless communication system. The method and system determine the integer part of carrier frequency offset and coarse timing position of the preamble. One embodiment of the present invention is an Orthogonal Frequency Division Multiplex Access system with a frequency reuse factor of 1.

[0017] An effective reuse pattern W refers to a situation in which all the W cells in a multi-cell communication system have the same center frequency but each cell uses a non-overlapping segment of the frequency band when transmitting the preambles. In other words, an effective reuse pattern W is virtually the same as having W different frequency bands.

[0018] In a conventional multi-cell system, each cell is configured as a hexagon. i.e, there are six cells adjacent to the center cell. FIG. 1 is an exemplary cell configuration in a multi-cell communication system with a frequency reuse

factor equal to 1 and a reuse pattern equal to three. The BTSs in the three adjacent cells have the same center frequency but each of them uses a non-overlapping segment of the frequency band when a preamble is transmitted.

[0019] FIG. 1A is a cell configuration in spatial domain. FIG. 1B shows a narrow band assignment for preamble transmission in frequency domain corresponding to a drawing 110 in FIG. 1A. In FIG. 1B, a drawing 120 depicts a spectrum divided into narrow bands with reuse pattern 3 when a preamble is transmitted. The narrow bands are arranged into groups and each group has three non-overlapping narrow bands. The preamble signals sent by the BTS at the center cell, cell 0, occupy all the narrow bands marked with 0, denoted as segment 0. The preamble signals sent by the BTS in one of the three adjacent cells, cell 1, occupy all the narrow bands marked with 1, denoted as segment 1. This is also true for cell 2. In this case, a receiver module in the wireless station tuned to the center frequency can receive the signals from all BTS in the three adjacent cells.

[0020] In a multi-cell wireless communication system, the preambles broadcasted by the BTS in each cell carry a unique PN sequence. By calculating autocorrelation of the receiving signal, a wireless station can reliably detect the presence of a preamble when there is little interference with the receiving signal. However, if the receiving signal of the wireless station is impaired by interference, the autocorrelation method is no longer a reliable way to detect preambles.

[0021] The time domain signal in the receiving period is sampled by the sampler module in the receiver chain. The sampling points in the receiving period are further subdivided into subgroups, each of which is defined as a sampling window with L sampling points. The sampling windows can be

overlapped with each other. FIGs. 2A and 2B show examples of the grouping of the sampling points into sampling windows. Each vertical line 210 represents a sampling point. FIG. 2A shows non-overlapping sampling windows 220, 222, and 224. FIG. 2B shows overlapping sampling windows 230, 232, 234, 236 and 238.

[0022] FIG. 3 is a flow diagram of the disclosed preamble detection method. The following procedure is applicable to every sampling window shown in FIGs. 2A and 2B.

[0023] In step 310, a receiver module of a wireless station first detects the carrier frequency of a receiving signal. If the carrier frequency offsets of the receiving signal is within a predetermined range, for example, 16 ppm (part per million), the preamble detection module is activated.

[0024] In step 320, an L-Point Fast Fourier Transform operation is used to transform the L sampling points in the sampling window into a frequency domain vector with L elements. Each element in the frequency domain vector represents a narrow band in the frequency domain.

[0025] The frequency domain vector R with L elements is represented by the following: $R = FFT(r) = [R(1), R(2), \dots, R(L)]$, where r is the vector of L sampling points in the sampling window. The frequency domain vector covers the radio spectrum, allocated to the wireless communication system, which is shared by three adjacent cells. During the period of preamble transmission, each element in the frequency domain vector represents one narrow band and is allocated to cell 0, cell 1, and cell 2 in sequence. In other words, every third element of the frequency domain vector is allocated to the preamble of one specific cell. However, during data transmission, the data traffic occupies the whole bandwidth.

[0026] In step 330, the energy in the sampling window of each segment is calculated as follows: $E^{(j)} = \sum_{n=0}^{\lfloor (L-j-1)/3 \rfloor} |R(3n+j+1)|^2$, where j is the segment number and $j \in \{0,1,2\}$, $E^{(j)}$ is the total energy in segment j , and $\lfloor \dots \rfloor$ denotes the floor operation of the enclosed value.

[0027] Let N_{sg} be the segment number that has the highest energy, ie. $E^{(N_{sg})} \geq E^{(j)}$, where $j \in \{0,1,2\}$ and $j \neq N_{sg}$.

[0028] The frequency domain vector of the segment with the highest energy is then denoted as $R_{sg} = [R(i+1), R(3+i+1), \dots, R(3 \times \lfloor (L-i-1)/3 \rfloor + i+1)]$, where $i = N_{sg}$ and R_{sg} is a subset of vector R .

[0029] In step 340, a new vector Q is generated to reduce the channel effect on the detected signal by the following equation,

[0030] $Q = [R^*(i+1)R(3+i+1), R^*(3+i+1)R(6+i+1), \dots, R^*(3 \times \lfloor (L-i-1)/3 \rfloor - 1 + i+1)R(3 \times \lfloor (L-i-1)/3 \rfloor + i+1)]$, where operator $(.)^*$ denotes conjugate transpose of the enclosed vector. Q is the dot product of the conjugate of the vector R_{sg} and the shifted vector of R_{sg} .

[0031] Assuming that the wireless communication system defines a set of M pre-determined PN codes with the same length, denoted as N_{PN} , the wireless station in the wireless communication system creates a list of M pre-generated modified PN codes of length $N_{PN}-1$. The modified PN code is defined as the dot product of the predetermined PN code with the shifted version of the same predetermined PN code.

[0032] For example, if the PN code is $c = [c(1), c(2), \dots, c(N_{PN})]$, then the modified predetermined PN code is $\hat{c} = [c(1)c(2), c(2)c(3), \dots, c(N_{PN} - 1)c(N_{PN})]$, where N_{PN} , the length, is the number of the binary bits (1 or -1), in the predetermined PN code.

[0033] In step 350, in order to calculate the correlation between the frequency domain vector and the modified PN code, a bit mask is further applied to the Q vector to produce a vector with the same length as the modified predetermined PN code. The bit mask has the same length as vector Q, and it consists of a sequence of 0's followed by $N_{PN} - 1$ 1s and then followed by a sequence of 0's. The default bit mask has $N_{PN} - 1$ 1s in the middle of the bit mask.

[0034] A new vector $\hat{Q}$ is obtained after the completion of the following two operations: Taking Boolean AND operation between the bit mask and the vector Q and removing a predetermined number of elements, also known as guard bands, from both ends of the vector generated by the AND operation.

[0035] In order to take into account all possible carrier frequency offsets, a set of bit masks is generated to create a set of vectors $\hat{Q}$, with each vector $\hat{Q}$ corresponding to one carrier frequency offset value. Each bit mask is the result of shifting the default bit mask by a certain number of units of sub-carrier spacing. If the carrier frequency offset of the receiving signal is in the range of $[-a, a]$ sub-carrier spacing, where a is an integer, the bit mask is shifted in the range of $[-b, +b]$ sub-carrier spacing, where b is an integer and $b = \lceil a/3 \rceil$, where $\lceil \dots \rceil$ denotes the ceiling operation of the enclosed value. In other words, the default bit mask is shifted to the left or right by at most b position. As a result, $2b+1$ $\hat{Q}$ vectors are generated and each is associated with one carrier frequency offset value.

[0036] In step 360, a correlation vector S is obtained by calculating the correlation between each pair of the vectors $\hat{Q}$ and $\hat{c}$, shown in the following equation: $S^{(k)} = \hat{Q}(\hat{c})^T$, where operator $(.)^T$ denotes conjugate transpose of the enclosed vector. Each element $S^{(k)}$ in the correlation vector is a scalar and $k \in \{0, 1, \dots, (2b+1) \times M - 1\}$.

[0037] Whether a preamble is present in the receiving signal can be determined by comparing the highest value of the correlation result $S^{(k)}$ with the predetermined threshold, such as the average of the correlation values. If there exists an $S^{(k)}$ that exceeds the predetermined threshold, a preamble is present in the sampling window and thus the preamble is detected and the integer part of the carrier frequency offset is identified. FIG. 4 is a diagram illustrating the correlation results. The peak 410 in the diagram is the indication of the presence of a preamble.

[0038] The integer part of the carrier frequency offset is determined by the following equation: carrier frequency offset = $3N_{offset} + N_{sg} - N_{sg}^{(c)}$, where N_{offset} is the number of units of sub-carrier spacing; N_{sg} is the segment number; $N_{sg}^{(c)}$ is the segment number that the BTS of the cell sends the PN code c , with $N_{sg}^{(c)} \in \{0, 1, 2\}$. If the carrier frequency offsets are in $[-6, 6]$ sub-carrier spacing, $N_{offset} \in \{-2, -1, 0, 1, 2\}$.

[0039] In step 370, the preamble detection module continues to exam every sampling window and identifies the highest $S^{(k)}$ among sampling windows. The sampling window with the highest $S^{(k)}$ is identified as the coarse timing position of the preamble.

[0040] The present invention discloses a method and system for detecting a preamble reliably in the presence of interference caused by multiple cells reusing the same frequency in a multi-cell communication system.

[0041] After receiving a signal in the receiving period, the method first identifies the segment with the highest energy, among the cells sharing the same center frequency, and generates a frequency domain vector for the segment. It then takes the dot operation on the frequency domain vector to reduce the channel effect. Subsequently, the correlation between the frequency domain vector and the modified PN code is calculated.

[0042] By examining the outcome of correlation operation, the numerical operations of the method conclude whether a preamble is presents in the receiving signals of the receiving period. The numerical operations of the method also determine the integer part of the frequency offset and coarse timing position of the preamble if it is present in the receiving signal. Since the present method includes shift, product and correlation operations, the method is also known as Shift-Product-Correlation (SPC).

[0043] The above illustration provides many different embodiments or embodiments for implementing different features of the invention. Specific embodiments of components and processes are described to help clarify the invention. These are, of course, merely embodiments and are not intended to limit the invention from that described in the claims.

[0044] Although the invention is illustrated and described herein as embodied in one or more specific examples, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims. Accordingly, it is appropriate that

the appended claims be construed broadly and in a manner consistent with the scope of the invention, as set forth in the following claims.

WHAT IS CLAIMED IS:

1. A method for detecting a preamble in a multi-cell communication system, the method comprising:

obtaining a first frequency domain vector representing a plurality of cells from a receiving signal through applying a Fast Fourier Transform analysis on a time-domain vector sampled from the receiving signal;

identifying a first segment with the highest energy among the plurality of cells through analyzing the first frequency domain vector;

generating a second frequency domain vector from the first frequency domain vector by applying vector operations to the first frequency domain vector;

generating one or more third frequency domain vectors corresponding to the first segment from the second frequency domain vector by applying one or more bit masks to the second frequency domain vector;

calculating a correlation vector of one or more predetermined codes with the one or more third frequency domain vectors; and

comparing one or more elements in the correlation vector with a predetermined threshold,

wherein a preamble is present in the receiving signal if at least one element in the correlation vector exceeds the predetermined threshold.

2. The method of claim 1, wherein the obtaining comprises detecting the presence of the receiving signal, checking if the carrier frequency offset is within a predetermined range.

3. The method of claim 1, wherein the time-domain vector of receiving signal is further divided into one or more subgroups of sampling windows.

4. The method of claim 1, wherein the vector operations applied to the first frequency domain vector further comprising:

taking conjugate-transpose of the first frequency domain vector;

shifting the first frequency domain vector by predetermined amount; and

taking the dot product of the conjugate-transpose and the shifted first frequency domain vectors.

5. The method of claim 1, wherein the bit mask has the same length as the second frequency domain vector and consists of a sequence of 0's of a predetermined length, followed by a sequence of 1's of a predetermined length and then followed by a sequence of 0's of a predetermined length.

6. The method of claim 5, wherein the bit mask has a sequence of 1's of a predetermined length in the middle of the bit mask by default.

7. The method of claim 6, wherein one or more bit masks are generated by shifting the default bit mask by a certain number of units of sub-carrier spacing.

8. The method of claim 1, wherein the generating one or more third frequency domain vectors includes taking Boolean AND operation between the one or more bit masks and the second frequency domain vector.

9. The method of claim 8, wherein generating one or more third frequency domain vectors further includes removing a predetermined number of elements, also known as guard bands, from both ends of the vector generated by the

Boolean AND operation between the bit mask and the second frequency domain vector.

10. The method of claim 1, wherein the plurality of predetermined codes are predetermined numbers of modified pseudonoise codes.

11. A method for detecting a preamble in a multi-cell communication system, the method comprising:

obtaining a first frequency domain vector representing a plurality of cells from a receiving signal through applying a Fast Fourier Transform analysis on a time-domain vector sampled from the receiving signal, wherein the obtaining further comprising:

detecting the presence of the receiving signal;

checking if the carrier frequency offset is within a predetermined range;

identifying a first segment with the highest energy among the plurality of cells through analyzing the first frequency domain vector;

generating a second frequency domain vector from the first frequency domain vector by applying vector operations to the first frequency domain vector, and the vector operations further includes taking conjugate-transpose of the first frequency domain vector, shifting the first frequency domain vector by predetermined amount, and taking the dot product of the conjugate-transpose and the shifted first frequency domain vectors;

generating one or more third frequency domain vectors corresponding to the first segment from the second frequency domain vector by applying one or more bit masks to the second frequency domain vector, wherein the bit mask has

the same length as the second frequency domain vector and consists of a sequence of 0's of a predetermined length, followed by a sequence of 1's of a predetermined length and then followed by a sequence of 0's of a predetermined length;

calculating a correlation vector of one or more predetermined codes with the one or more third frequency domain vectors; and

comparing one or more elements in the correlation vector with a predetermined threshold,

wherein a preamble is present in the receiving signal if at least one element in the correlation vector exceeds the predetermined threshold.

12. The method of claim 11, wherein the time-domain vector of receiving signal is further divided into one or more subgroups of sampling windows.

13. The method of claim 11, wherein the bit mask has a sequence of 1's of a predetermined length in the middle of the bit mask by default.

14. The method of claim 13, wherein one or more bit masks are generated by shifting the default bit mask by a certain number of units of sub-carrier spacing.

15. The method of claim 11, wherein the generating one or more third frequency domain vectors includes taking Boolean AND operation between the one or more bit masks and the second frequency domain vector.

16. The method of claim 15, wherein generating one or more third frequency domain vectors further includes removing a predetermined number of elements, also known as guard bands, from both ends of the vector generated by the Boolean AND operation between the bit mask and the second frequency domain vector.

17. The method of claim 11, wherein the plurality of predetermined codes are predetermined numbers of modified pseudonoise codes.

18. A system for detecting a preamble in a multi-cell wireless communication system, the system comprising:

a sampling module configured to create time-domain vector of receiving signal;

a Fast Fourier Transform module configured to transforms the time-domain vector to the frequency domain vector;

a summing and comparing module configured to identify the segment with the highest energy and generating first frequency domain vector of the segment.;

a shifting and multiply module configured to generate second frequency domain vector of the segment;

a correlation module configured to pre-calculate one or more modified pseudonoise codes, generate one or more third frequency domain vectors, and calculate a correlation vector between the one or more modified pseudonoise codes and one or more third frequency domain vectors of the segment; and

a comparing module configured to compare one or more elements in the correlation vector with a predetermined threshold,

wherein a preamble is present in the receiving signal if at least one element in the correlation vector exceeds the predetermined threshold.

19. The system of claim 18, wherein the sampling module samples the incoming signals when the carrier frequency offset is within a pre-determined range.
20. The system of claim 18, wherein the correlation module applies one or more bit masks to the second frequency domain vector and generates one or more third frequency domain vectors.
21. The system of claim 20, wherein the bit mask has the same length as the second frequency domain vector and consists of a sequence of 0's of a predetermined length followed by a sequence of 1's of a predetermined length, and then followed by a sequence of 0's of a predetermined length.
22. The system of claim 21, wherein the bit mask has a sequence of 1's of a predetermined length in the middle of the bit mask by default.
23. The system of claim 18, wherein the correlation module generates the third frequency domain vectors further comprising:
- taking Boolean AND operation between the bit masks and the second frequency domain vector; and
 - removing a predetermined number of elements, also known as guard bands, from both ends of the vector generated by the Boolean AND operation.
24. The system of claim 18, wherein the system identifies the presences of the preamble is at least one of the element is the correlation vector exceeds the predetermined threshold.

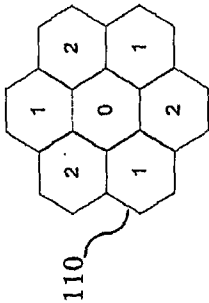


FIG. 1A

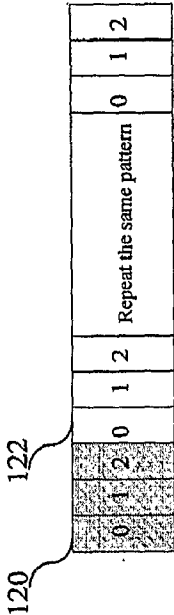


FIG. 1B

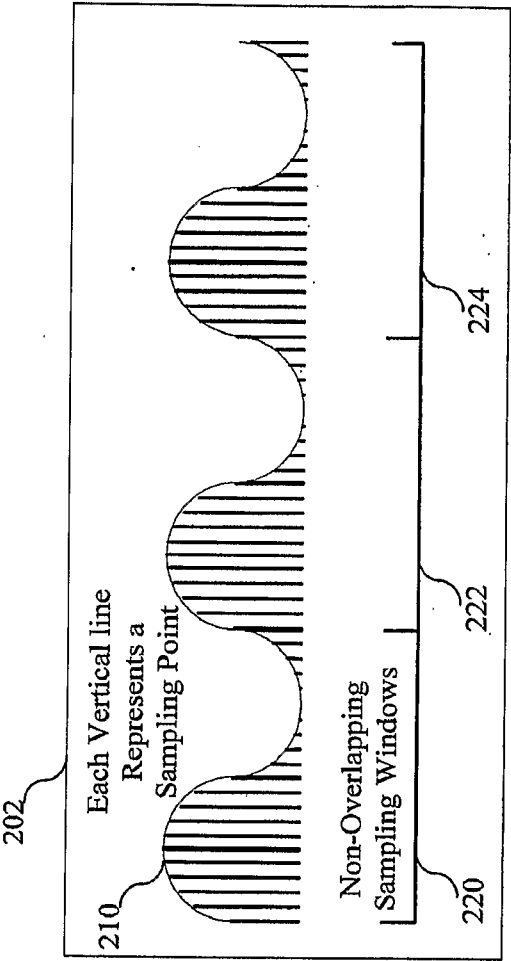


FIG. 2A

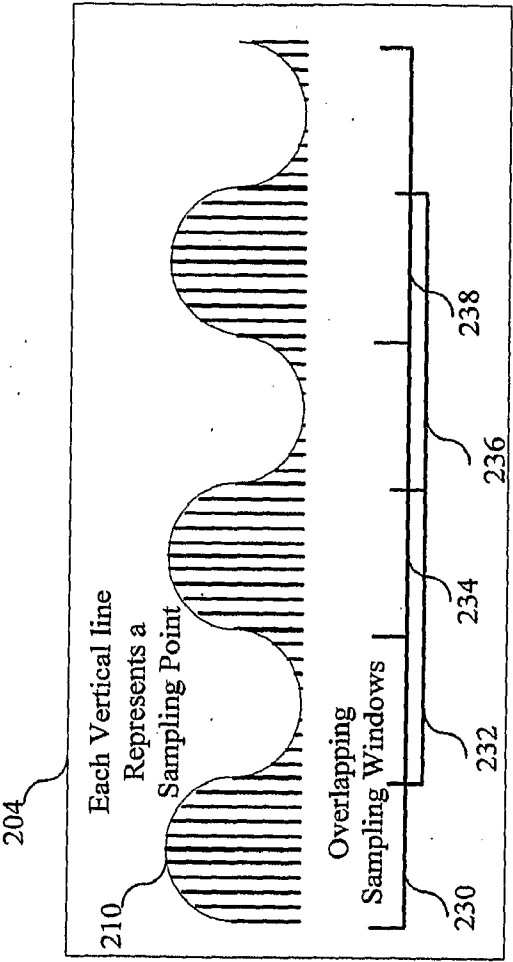


FIG. 2B

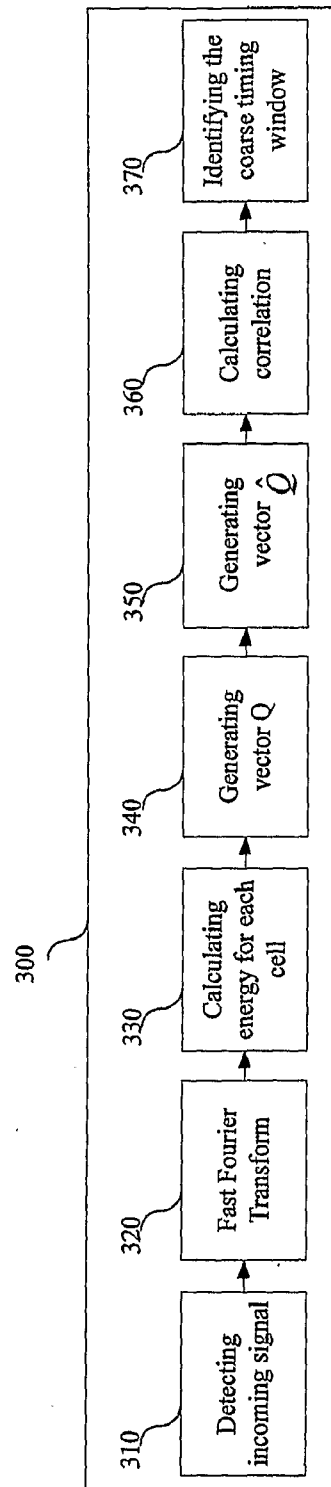


FIG. 3

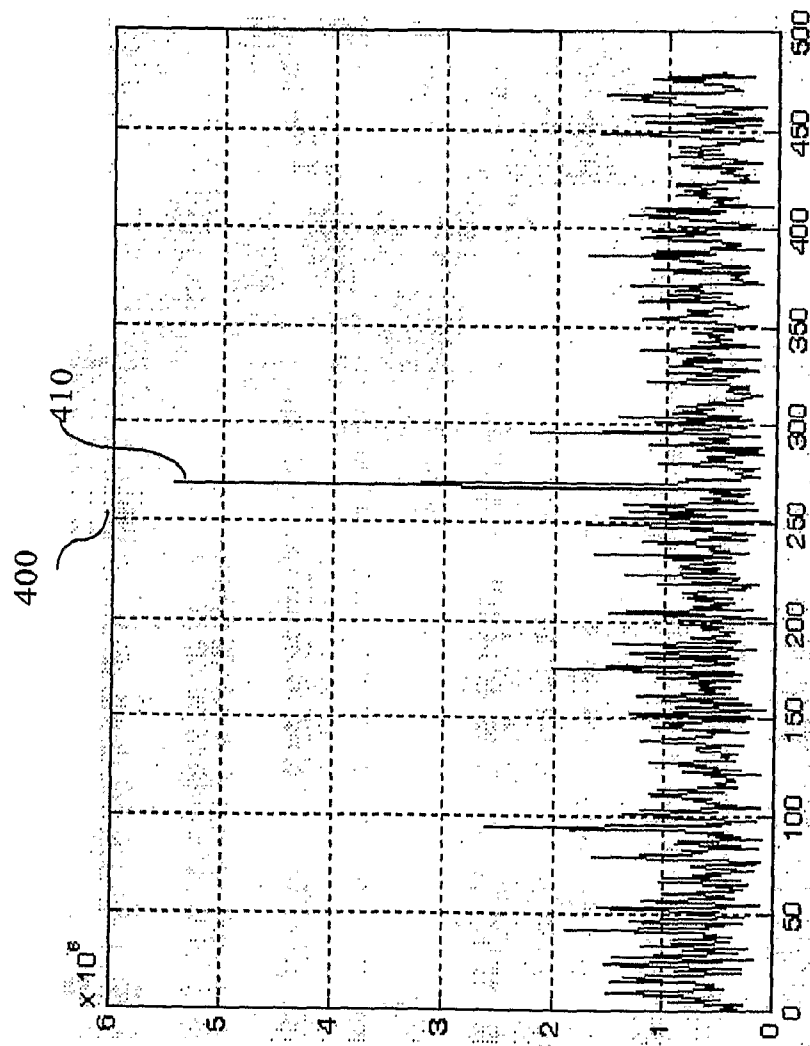


FIG. 4