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(71) Applicant *(for all designated States except US)*: **NAVINI NETWORKS, INC.** [US/US]; 2240 Campbell Creek Blvd., Suite 110, Richardson, TX 75082 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **LIU, Qingwen** [—/US]; 1000 W. Spring Valley Road, #215, Richardson, TX 75080 (US). **JIN, Hang** [CA/US]; 3708 Stoneway Drive, Plano, TX 75025 (US). **XIE, Weiguo** [CN/US]; 3524 Bonita Drive, Plano, TX 75025 (US). **GRABNER, John** [US/US]; 817 Shannon, Plano, TX 75025 (US).

(74) Agents: **CHEN, Howard** et al.; Kirkpatrick & Lockhart Preston Gates Ellis, LLP, 55 Second Street, Suite 1700, San Francisco, CA 94105 (US).

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(54) Title: SYSTEM AND METHOD FOR DETECTING LOCATIONS OF A CUSTOMER PREMISES EQUIPMENT

(57) Abstract: The present invention discloses a system for detecting locations of a customer premises equipment in a wireless communication system with one or more base transceiver stations and one is efficient. A plurality of antennas in a base transceiver station receives signals transmitted from a customer premises equipment. A timing detection module extracts the timing offset from the receiving signals and a first calculation module calculates the distance between the BTS and the CPE based on the timing offset. A signal detection module detects magnitudes and phases of the receiving signals and a second calculation module determines a dominant beam according to the antenna pattern and calculates the direction of arrival of the dominant beam. A third calculation module calculates the location of the CPE relative to the base transceiver station based on the distance and the direction of arrival.

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SYSTEM AND METHOD FOR DETECTING LOCATIONS OF A CUSTOMER PREMISES EQUIPMENT

CROSS REFERENCE

[0001] The present application claims the benefit of U.S. Provisional Application Serial No. 60/801,936, which was filed on May 19, 2006, and entitled "Location via Antenna Array" and U.S. Patent Application Serial No. 11/734,670, which was filed on April 12, 2007 and entitled "System and Method for Detecting Locations of a Customer Premises Equipment."

BACKGROUND

[0002] One of the value-added services supplied by wireless network service providers is to provide personalized services based on the location of a subscriber. The coordinates for a mobile customer premises equipment (CPE), obtained by using the Global Positioning System (GPS), are often shown in a latitude and longitude. This location information is valuable to network service providers. By gathering the location information about a CPE, network service providers can manage network resources more efficiently, support traffic monitoring more effectively, and develop a more economic frequency reuse plan. Furthermore, network service providers can deploy location-based applications, such as navigation services, E911 services, and real-time advertisement, based on the geographic location of a CPE.

[0003] A session in the subscription-based wireless network defines a communication task between a base station (BTS) and a CPE. A session profile contains all but location information related to the session between the BTS and the CPE. The session profile includes information such as the power level of the physical layer, the frequency allocation of the medium access control layer, the provisioning parameters of quality of service, and accounting information. The CPE may support multiple sessions simultaneously.

[0004] Other statistics, such as the duration of the session, the bandwidth consumed by the session, the speed of the movement of the CPE, also provide important information about the CPE. The GPS coordinates for a location, the session profile, and the statistics information about the CPE facilitate the creation of new services, which, in turn, generate more revenues for network service providers.

[0005] A conventional wireless communication system that provides location-based services requires multiple BTSs to gather information about a CPE and it also requires a back-end server to collect information about the CPE from all participating BTSs and determine the GPS location of the CPE. There are many ways to determine the location of a CPE, based on the information collected by multiple BTSs.

[0006] In a wireless communication system with BTSs that have multiple antennas, it could take only one BTS to monitor and track the movement of a CPE. This BTS gathers the information from all receiving antennas and then retrieves helpful information. It is thus an objective of the invention to develop a system and method to process the information to determine the GPS coordinates for a CPE and create innovative services.

[0007] An advantage of the invention is that it improves the prior art solutions by offering a better way to determine the GPS location of a CPE while the system only requires one BTS.

SUMMARY

[0008] The present invention discloses a system for detecting locations of a customer premises equipment in a wireless communication system with one or more base transceiver stations and one is sufficient. A plurality of antennas in a base transceiver station receives signals transmitted from a customer premises equipment. A timing detection module extracts the timing offset from the receiving signals and a first calculation module calculates the distance between the BTS and the CPE based on the timing offset. A signal detection module detects magnitudes and phases of the receiving signals and a second calculation module determines a dominant beam according to the antenna pattern and calculates the direction of arrival of the dominant beam. A third calculation module calculates the location of the CPE relative to the BTS based on the distance and the direction of arrival.

[0009] 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.

BRIEF DESCRIPTION OF THE DRAWING

[0010] The drawings accompanying and forming part of this specification are included to depict certain aspects of the invention. A clearer conception of the invention and of operation of system provided with the invention will become more readily apparent by referring to the exemplary, and therefore non-limiting, embodiments illustrated in the drawings, wherein like reference numbers (if they occur in more than one view) designate the same elements. 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] FIG. 1 is a block diagram illustrating a system for detecting locations of a CPE.

[0012] FIG. 2 illustrates a system for determining the GPS coordinates for a CPE.

[0013] FIG. 3 illustrates a close-loop transmission timing adjustment.

[0014] FIG. 4 is a diagram of the antenna pattern of a BTS with respect to a CPE.

[0015] FIG. 5 shows a method for obtaining the distance of a CPE.

DESCRIPTION

[0016] 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.

[0017] The present invention discloses a system for detecting locations of a CPE in a wireless communication system with one or more BTSs and one is sufficient. The present invention also discloses a method to more accurately determine the GPS coordinates for a CPE using one BTS equipped with an array of antennas.

[0018] One of the embodiments of the present invention is a location-based service system adopting the disclosed method. The location-based service system utilizes the GPS location information about a CPE to provide better services and operate more efficiently.

[0019] The method disclosed in the present invention determines the GPS coordinates for a CPE by deriving the DOA from the antenna beam pattern of a BTS and mapping the absolute Cartesian coordinates to the GPS coordinates for the CPE. The absolute Cartesian coordinates are determined by the following parameters: the distance between the BTS and the CPE, the DOA of the antenna beam, and the Cartesian coordinates for the BTS.

[0020] The location-based service system described in the present invention only requires a single BTS to determine the GPS location of a CPE, facilitates the extracting of the data from the location information based on the GPS, and generates innovative applications to better serve the subscribers of the wireless network. The accuracy of the estimated GPS location will be improved with more BTSs participating in the process, but unlike a conventional system, the system disclosed in the invention does not require additional BTS.

[0021] FIG. 1 is a block diagram illustrating a system for detecting locations of a CPE. Block 110 is a plurality of antennas on a BTS. The plurality of antennas on the BTS receives signals transmitted from the CPE.

[0022] Block 120 is a timing detection module that extracts a timing offset from receiving signals. Block 125 is a distance calculator that calculates the distance between the BTS and the CPE based on timing offset information. Block 130 is a signal detection module that detects magnitudes and phases of the antenna pattern of the receiving signals. Block 135 is a DOA calculator that determines a dominant beam of the antenna pattern and calculates the direction of arrival (DOA) of the signal from the dominant beam. Block 140 is a location server that calculates the location of the CPE relative to the BTS based on the data produced by blocks 125 and 135.

[0023] FIG. 2 is a flow diagram illustrating the determination of the GPS coordinates for a CPE by a location server. There are four steps in the flow diagram. In step 210, the CPE calculates a timing offset adjustment, which represents the sum of an open-loop timing adjustment and a close-loop timing adjustment, and subsequently reports it to the BTS. FIG. 3 further describes a method to calculate the timing offset of the CPE.

[0024] In step 220, the BTS collects magnitude and phase information about the receiving signal, transmitted from an array of antennas by the CPE. The BTS determines the DOA of the receiving signal based on the magnitude and phase information about the antenna beam pattern. The beam with the largest amplitude in the antenna beam pattern is designated as the dominant beam, the direction of which determines the DOA. FIG. 4 is a diagram of an antenna beam pattern.

[0025] In step 230, the BTS sends to a location server (LS) the timing offset, DOA, and session profile information about the CPE. The LS calculates the two dimensional Cartesian coordinates for the CPE based on the timing offset and DOA information. FIG. 5 further describes the procedure to calculate the two dimensional Cartesian coordinates for the CPE.

[0026] In step 240, the location server maps the two dimensional Cartesian coordinates to the GPS coordinates; namely, latitude and longitude, for the CPE. The mapping involves geographic mathematics. Because the shape of the earth is slightly oblate, many approximation methods can be used to map the two dimensional Cartesian coordinates to the GPS coordinates for a location. One embodiment of the approximation is to let the longitude of the CPE equal to X_CPE_absolute and the latitude of the CPE equal to Y_CPE_absolute.

[0027] The accuracy of the GPS coordinates for the CPE depends on the accuracy of the estimation of the distance between the BTS and the CPE and DOA. Several postprocessing procedures can be adopted to remove the erroneous information that is less accurate. There are three filter modules that facilitate postprocessing, and they are the signal-to-noise-ratio (SNR) filtering module, the beamforming filtering module, and the speed filtering module.

[0028] The SNR filtering module eliminates the calculated DOA and distance information if the corresponding SNR is less than a given threshold. The beamforming filtering module eliminates the calculated DOA and distance information if the ratio of the amplitude of the dominant beam to the average amplitude of the rest of the beams is less than a given threshold. As to the speed filtering module, it eliminates the calculated DOA and distance information if the speed of the CPE derived from the consecutive records is lager than a given threshold. The three filtering modules can be used individually or consecutively in a predetermined order.

[0029] FIG. 3 is a flow diagram of a close-loop adjustment. In step 310, after receiving the signals sent by a BTS, a CPE transmits a signal to the BTS at a scheduled time. In Step 320, the BTS determines the timing offset of the CPE. In Step 330, the BTS sends a timing offset adjustment message to the CPE. In Step 340, the CPE makes a timing correction by adjusting its transmission timing according to the received adjustment message when sending signals to the BTS afterwards.

[0030] In an open-loop adjustment, the CPE adjusts the timing offset according to some internal references. For example, if the downlink timing of the receiving signal is advanced by Δt, the CPE will delay the uplink timing by the same amount Δt. The CPE sums up the open-loop and close-loop timing offset adjustments and reports the result to the BTS.

[0031] A conventional method to obtain DOA information is to apply the eigenvalue decomposition method to an antenna input correlation matrix. There are several eigenvalue decomposition methods, such as the Min-Norm method, the Multiple Signal Classification (MUSIC), and the Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT). The method in the present invention obtains DOA information using the signals received by multiple antennas on a BTS.

[0032] FIG. 4 is a diagram illustrating an antenna beam pattern of a BTS with respect to a CPE. The diagram shows the magnitude and direction of the detected beams. The beam with the largest amplitude is designated as the dominant beam whose direction is DOA. In FIG. 4, the DOA is 250 degrees.

[0033] FIG. 5 is a supplementary diagram to explain how a location server calculates the two dimensional Cartesian coordinates for a CPE.

[0034] Let D_EST 520 denote the line-of-sight distance between a BTS and a CPE and be represented by the following equation: D_EST = c * timing_offset, where c is the speed of light, which is roughly equal to 3*10^8 (meters/second), and timing_offset is the timing offset of the CPE. Let H_BTS 510 denote the height of a BTS tower. The distance between the BTS and the CPE is calculated based on the following equation: Distance_BTS_CPE 530 = $sqrt(D\_EST^2 - H\_BTS^2)$.

[0035] The relative Cartesian coordinates for the CPE are determined by two values, and they are the distance between the BTS and the CPE and DOA. The relative Cartesian coordinates for the CPE are calculated according to the following equations: X_CPE_relative = Distance_BTS_CPE * cos(DOA) and Y_CPE_relative = Distance_BTS_CPE * sin(DOA).

[0036] The absolute Cartesian coordinates for the CPE are calculated according to the following equations: X_CPE_absolute = X_BTS_absolute + X_CPE_relative and Y_CPE_absolute = Y_BTS_absolute + Y_CPE_relative.

[0037] In a wireless network with multiple BTSs, the accuracy of the estimation of a CPE location can be further improved by reporting the CPE location collaboratively by multiple BTSs. The BTSs in such a system could establish communication channels among themselves to exchange the location information about the CPE. The CPE communicates with one or more BTSs simultaneously. The geographic mathematics can also be applied to the estimation process to improve the accuracy of the estimation of the CPE location.

[0038] The system disclosed in the invention comprises of multiple CPEs and one or more BTSs, one or more servers. The BTS gathers the distance and DOA information about the CPE and the associated session profile and send them to a server, for example a location server, to determine the CPE location. The server, in turn, calculates the GPS coordinates for the CPE and modify the associated session profile and sends them to a server with development tools, for example an application server.

[0039] The development tools in the server use the updated session profile and the GPS location information about the CPE to extract data that facilitates the creation of new services.

[0040] One example of the data extracted from the session profile and the GPS location information is the moving-path of the CPE. An application can generate a plot to display the estimated and actual moving-paths of the CPE. The moving-path plot can help wireless network service providers to improve network resource planning.

[0041] Wireless network service providers can develop numerous applications to exploit the data embedded in the GPS location information. For example, the space division multiple access (SDMA), the drop call analysis, the SNR/traffic density geographic analysis, the geographic-information based power/bandwidth allocation, and the handoff assistance.

[0042] New businesses can also be developed based on the information about the movement of CPEs to benefit the subscribers of the wireless network. These new businesses include, but not limited to, the CPE location-based Google map, the local business search, the advertisement, the E911, the navigation, and the real-time highway traffic report.

[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 wireless communication system comprising:

a plurality of antennas on a base transceiver station (BTS) each receiving one of a plurality of beams of a signal transmitted from a customer premises equipment (CPE);

a timing detection module configured to extract at least one timing offset from at least one of the plurality of beams;

a first calculation module configured to calculate a distance between the BTS and the CPE based on the timing offset;

a signal detection module configured to detect magnitudes and phases of the plurality of beams;

a second calculation module configured to determine a dominant beam among the plurality of beams and calculate a direction of arrival (DOA) of the signal from the dominant beam; and

a third calculation module configured to calculate a location of the CPE relative to the BTS based on the distance and the DOA.

2. The wireless communication system of claim 1, wherein the timing offset information is produced by exchanging timing information between the BTS and CPE.

3. The wireless communication system of claim 1, wherein the timing detection module extracts the timing offset by using open-loop and close-loop timing adjustment information.

4. The wireless communication system of claim 1, wherein the second calculation module selects a beam with the largest amplitude to be the dominant beam.

5. The wireless communication system of claim 1 further comprising a fourth calculation module configured to convert the relative location of the CPE to a set of global positioning system (GPS) coordinates based on a location of the BTS.

6. The wireless communication system of claim 5, wherein the conversion comprises:

calculating the absolute Cartesian coordinates for the CPE; and

mapping the absolute Cartesian coordinates to the GPS coordinates.

7. A wireless communication system comprising:

a plurality of antennas serving a base transceiver station (BTS) each receiving one of a plurality of beams of a signal transmitted from a customer premises equipment (CPE);

a timing detection module configured to extract at least one timing offset from at least one of the plurality of beams;

a first calculation module configured to calculate a distance between the BTS and the CPE based on the timing offset;

a signal detection module configured to detect magnitudes and phases of the plurality of beams;

a second calculation module configured to determine a dominant beam among the plurality of beams and calculate a direction of arrival (DOA) of the signal from the dominant beam;

a third calculation module configured to calculate a location of the CPE relative to the BTS based on the distance and the DOA; and

a fourth calculation module configured to convert the relative location of the CPE to a set of global positioning system (GPS) coordinates based on a GPS location of the BTS.

8. The wireless communication system of claim 7, wherein the timing offset information is produced by exchanging timing information between the BTS and CPE.

9. The wireless communication system of claim 7, wherein the timing detection module extracts the timing offset by using open-loop and close-loop timing adjustment information.

10. The wireless communication system of claim 7, wherein the second calculation module selects a beam with the largest amplitude to be the dominant beam.

11. The wireless communication system of claim 7, wherein the conversion comprises:

calculating the absolute Cartesian coordinates for the CPE; and

mapping the absolute Cartesian coordinates to the GPS coordinates.

12. A method for detecting a location of a customer premises equipment (CPE) in a wireless communication network, the method comprising:

determining a direction of arrival from the dominant beam in the antenna pattern;

determining timing offset data for the customer premises equipment;

calculating a distance between a base transceiver station (BTS) and the customer premises equipment based on the timing offset data; and

obtaining the location of the customer premises equipment relative to the base transceiver station based on the direction of arrival and the distance information.

13. The method of claim 12, wherein the dominant beam is a beam with the largest amplitude.

14. The method of claim 12, wherein the timing offset information is produced by exchanging timing offset information between the BTS and the CPE.

15. The method of claim 14, wherein the timing offset information about the CPE further includes open-loop and close-loop timing estimations.

16. The method of claim 12, wherein the direction or arrival information is determined by the dominant beam in the antenna pattern.

17. The method of claim 12 further comprising:

calculating the absolute Cartesian coordinates for the CPE; and

mapping the absolute Cartesian coordinates to the GPS coordinates.

18. The method of claim 17, wherein the calculating of the absolute Cartesian coordinates are based on distance and the direction of arrival information.

19. The method of claim 17, wherein the mapping of the absolute Cartesian coordinates to the GPS coordinates further includes geographic calculation.

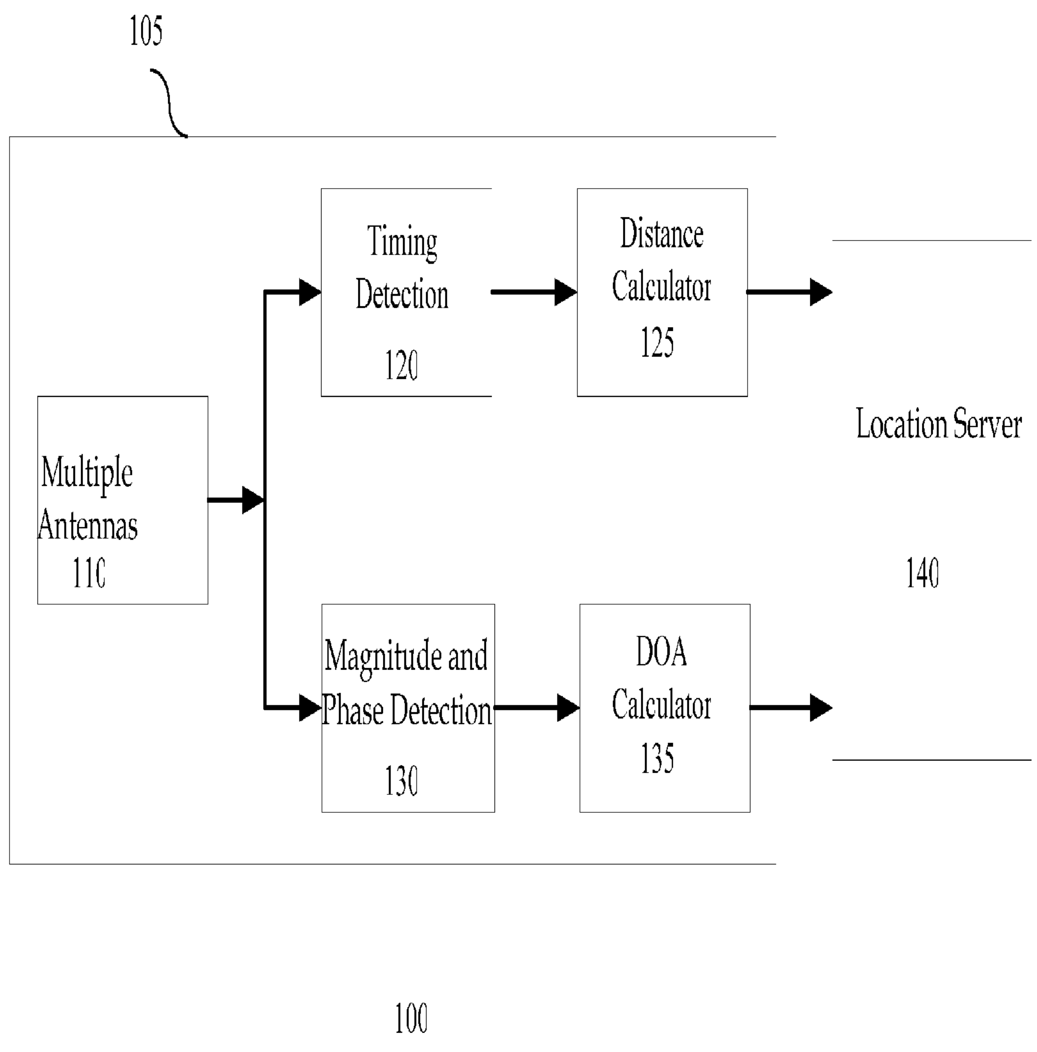
105
Timing Detection 120
Distance Calculator 125
Location Server 140
Multiple Antennas 110
Magnitude and Phase Detection 130
DOA Calculator 135
100

FIG. 1

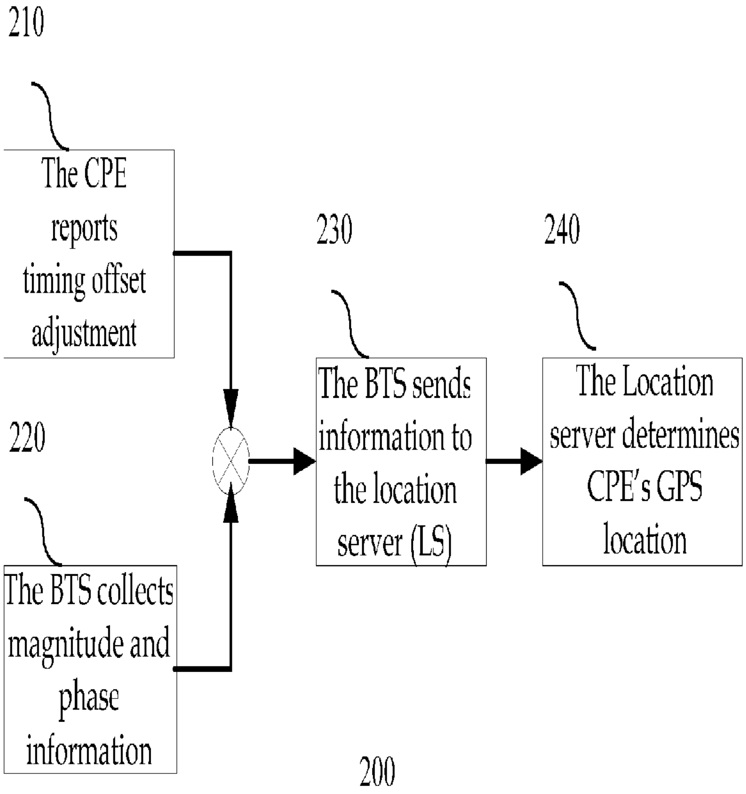
210
The CPE reports timing offset adjustment
220
The BTS collects magnitude and phase information
230
The BTS sends information to the location server (LS)
240
The Location server determines CPE's GPS location
200

FIG. 2

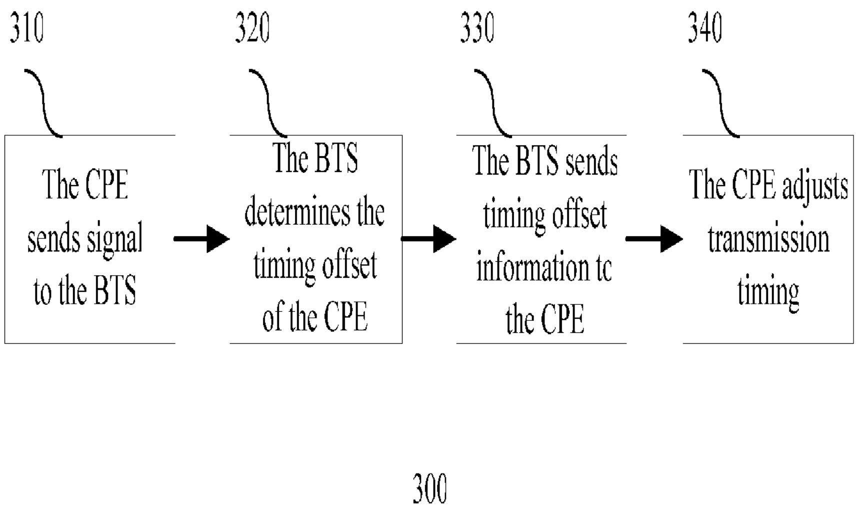
310
320
330
340
The CPE sends signal to the BTS
The BTS determines the timing offset of the CPE
The BTS sends timing offset information tc the CPE
The CPE adjusts transmission timing
300

FIG. 3

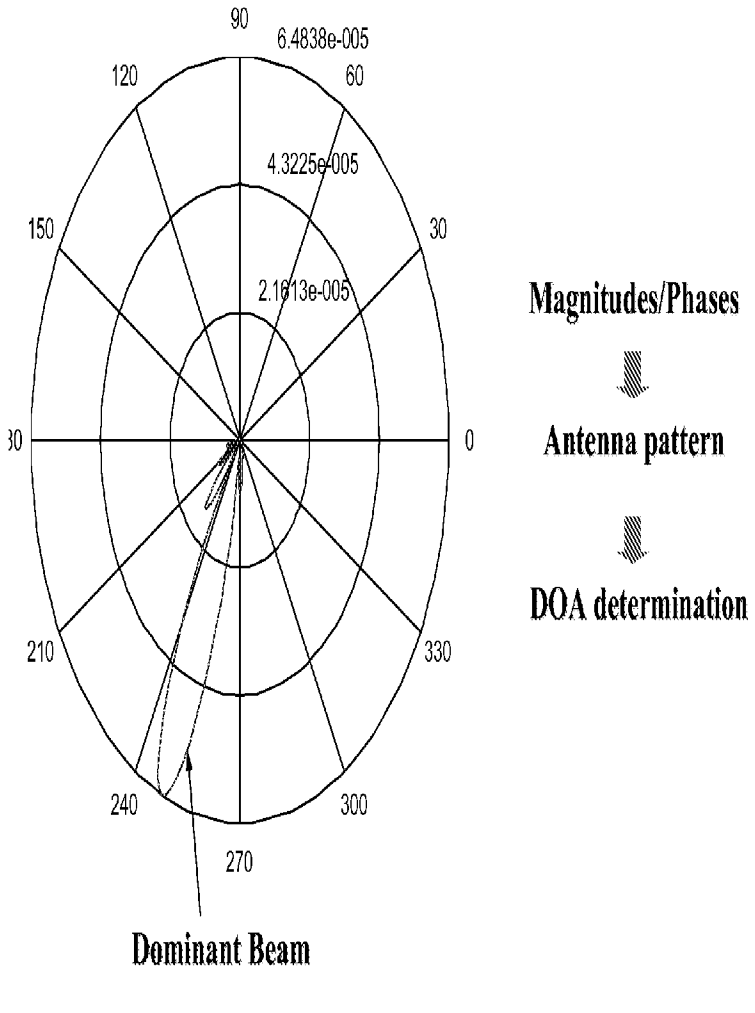

FIG. 4 (supplementary)

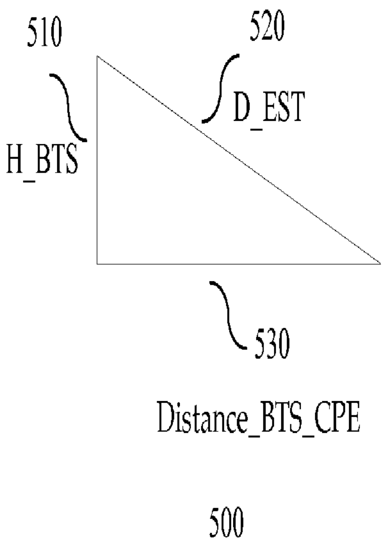

FIG. 5 (supplementary)