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(54) Title: METHOD OF SYSTEM FOR INCREASING THE RELIABILITY AND ACCURACY OF LOCATION ESTIMATION IN A HYBRID POSITIONING SYSTEM

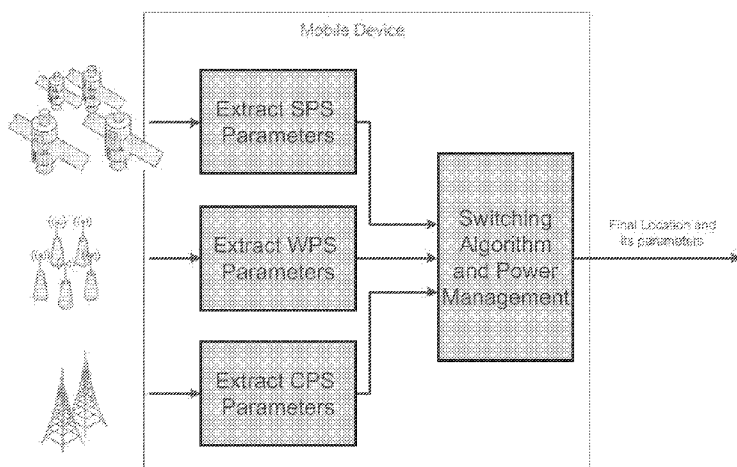


Fig. 2

(57) Abstract: Methods and systems of hybrid positioning are provided for increasing the reliability and accuracy of location estimation. According to embodiments of the invention, the quality of reported locations from specific sources of location is assessed. Satellite and non-satellite positioning systems provide initial positioning estimates. For each positioning system relevant information is collected and based on the collected information each system is assigned appropriate weight.

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METHOD OF AND SYSTEM FOR INCREASING THE RELIABILITY AND ACCURACY OF LOCATION ESTIMATION IN A HYBRID POSITIONING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Application No. 61/409,643 filed November 3, 2010, entitled “Method Of And System For Increasing The Reliability And Accuracy Of Location Estimation In A Hybrid Positioning System,” incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The invention generally relates to hybrid positioning and more specifically, describes new methods to assess the quality of a reported location from specific source of location to be used for hybrid positioning.

Description of the Related Art

[0003] In recent years the number of mobile computing devices has increased dramatically, creating the need for more advanced mobile and wireless services. Mobile email, walkie-talkie services, multi-player gaming and call-following are examples of how new applications are emerging for mobile devices. In addition, users are beginning to demand/seek applications that not only utilize their current location but also share that location information with others. Parents wish to keep track of their children, supervisors need to track the locations of the company's delivery vehicles, and a business traveler looks to find the nearest pharmacy to pick up a prescription. All of these examples require an individual to know his own current location or the location of someone else. To date, we all rely on asking for directions, calling someone to ask their whereabouts or having workers check-in from time to time to report their positions.

[0004] Location-based services are an emerging area of mobile applications that leverage the ability of new devices to calculate their current geographic positions and report them to a user or to a service. Examples of these services range from obtaining local weather, traffic updates and driving directions to child trackers, buddy finders and urban concierge services. These new location-sensitive devices rely on a variety of technologies that all use the same general concept. By measuring radio signals originating from known reference points, these

devices can mathematically calculate the user's position relative to these reference points. Each of these approaches has its strengths and weaknesses depending upon the nature of the signals and measurements, and the positioning algorithms employed.

[0005] The Navstar Global Positioning System ("GPS") operated by the US Government leverages about two-dozen orbiting satellites in medium-earth orbits as reference points. A user equipped with a GPS receiver can estimate his three-dimensional position (latitude, longitude, and altitude) anywhere at any time within several meters of the true location as long as the receiver can see enough of the sky to have four or more satellites "in view." Cellular carriers have used signals originating from and received at cell towers to determine a user's or a mobile device's location. Assisted GPS ("AGPS") is another model that combines both GPS and cellular tower techniques to estimate the locations of mobile users who may be indoors and must cope with attenuation of GPS signals on account of sky blockage. In this model, the cellular network attempts to help a GPS receiver improve its signal reception by transmitting information about the satellite positions, their clock offsets, a precise estimate of the current time, and a rough location of the user based on the location of cell towers. No distinction is made in what follows between GPS and AGPS.

[0006] All positioning systems using satellites as reference points are referred to herein as Satellite-based Positioning System ("SPS"). While GPS is the only operational SPS at this writing, other systems are under development or in planning. A Russian system called GLONASS and a European system called Galileo may become operational in the next few years. All such systems are referred to herein as SPS. GPS, GLONASS and Galileo are all based on the same basic idea of trilateration, i.e., estimating a position on the basis of measurements of ranges to the satellites whose positions are known. In each case, the satellites transmit the values of certain parameters which allow the receiver to compute the satellite position at a specific instant. The ranges to satellites from a receiver are measured in terms of the transit times of the signals. These range measurements can contain a common bias due to the lack of synchronization between the satellite and receiver (user device) clocks, and are referred to as pseudoranges. The lack of synchronization between the satellite clock and the receiver (user device) clock can result in a difference between the receiver clock and the satellite clock, which is referred to as internal SPS receiver clock bias or receiver clock bias, here. In order to estimate a three dimensional position there is a need for four satellites to estimate receiver clock bias along with three dimensional measurements. Additional measurements from each satellite correspond to pseudorange rates in the form of Doppler frequency. References below to raw SPS measurements are intended generally to mean

pseudoranges and Doppler frequency measurements. References to SPS data are intended generally to mean data broadcast by the satellites. References to an SPS equation are intended to mean a mathematical equation relating the measurements and data from a satellite to the position and velocity of an SPS receiver.

[0007] WLAN-based positioning is a technology which uses WLAN access points to determine the location of mobile users. Metro-wide WLAN-based positioning systems have been explored by several research labs. The most important research efforts in this area have been conducted by the PlaceLab (www.placelab.com, a project sponsored by Microsoft and Intel); the University of California, San Diego ActiveCampus project (ActiveCampus – Sustaining Educational Communities through Mobile Technology, technical report #CS2002-0714); and the MIT campus-wide location system. One example of a commercial metropolitan WLAN-based positioning system in the market at the time of this writing, is referred to herein as a WiFi Positioning System (“WPS”) and is a product of Skyhook Wireless, Inc.

SUMMARY

[0008] Under one aspect of the invention, a method includes determining initial position estimates of a device using a satellite positioning system and also non-satellite positioning systems. The method, then, collects relevant information regarding each source of location and assigns weights for each source of location.

[0009] Under another aspect of the invention, a method for determining the position of a device in a hybrid positioning system is provided. The method comprises analyzing signals from at least two of a satellite positioning system (“SPS”), a Wi-Fi positioning system, and a cell positioning system (“CPS”), determining for each of the at least two of the SPS, Wi-Fi positioning system, and CPS, a corresponding initial position estimate of the device and at least one corresponding parameter, and selecting one of the corresponding initial position estimates as a final position estimate of the device based on at least one of a history of previously reported positions, the at least one corresponding SPS parameter, the at least one corresponding Wi-Fi positioning system parameter, and the at least one corresponding CPS parameter.

[0010] Under aspects of the invention, signals from a satellite positioning system, a Wi-Fi positioning system, and a cell positioning system are analyzed by the device. For each positioning system the device determines a corresponding initial position estimate and corresponding parameters and selects one of the corresponding initial position estimates as the final position of the device based the history of previously positions or the corresponding parameters.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0011] Fig. 1 illustrates a mobile device receiving signals from SPS satellites, WPS beacons, and CPS towers.

[0012] Fig. 2 illustrates a process for collecting relevant parameters of each location system (SPS, WPS, and CPS) and use of an algorithm implemented in a mobile device for switching.

[0013] Fig. 3 illustrates a process for collecting relevant parameters of each location system (SPS, WPS, and CPS) and use of an algorithm implemented in a mobile device for switching and a reference database.

[0014] Fig. 4 illustrates a method of location estimation according to aspects of the present invention.

[0015] Fig. 5 illustrates a method of determining the type of environment and the quality of the location estimate for a satellite position system.

DETAILED DESCRIPTION

[0016] Embodiments of a hybrid positioning system are disclosed herein. A hybrid positioning system refers to a positioning system for device location, which itself consists of more than one individual positioning system (or “source of location”). The hybrid positioning system can be defined as a system using final positions of different sources of locations as initial positions. The hybrid positioning system can select or combine the initial locations and generates a position estimate based on observations by more than one source of location. The hybrid system combines observations from several separate positioning systems and provides one position estimate of the device. Each individual positioning system is able to detect a set of signal information from each of the system’s signal sources, herein called “observables”. Based on the possible observables of each reported location from different sources of location (*i.e.*, different individual systems), the hybrid positioning system selects a source of location or a combination of different sources of locations and reports its final location to the user. In order to do so, embodiments of the invention use different observables at the receiver side to assess the quality of different sources of locations. This disclosure discusses methods to be used to select the best location. It also discusses methods to select the best location while reducing power consumption of a device. This can be achieved, for example, by changing the scanning rate of the device. Embodiments of the invention achieve better accuracy, better availability, faster time to fix (which includes time to first fix), and less power consumption for a device relative to known methods.

[0017] As mentioned above, implementations of the hybrid positioning system include more than one positioning system or generates position estimates based on more than one source of location. The individual positioning systems can use a method particular to that system to estimate a position of a device. In some implementations, a hybrid positioning system includes, or receives information from, at least two of the following three positioning systems: (1) a satellite positioning system, which uses signals transmitted by satellites to locate the device, (2) a WiFi positioning system, which uses signals transmitted by WiFi access points to locate the device, and/or (3) a cell positioning system, which uses signals transmitted by cell towers to locate the device.

[0018] Fig. 1 illustrates a scenario in which a mobile device receives signals from SPS satellites, WPS beacons, and CPS towers. The individual positioning systems within an embodiment of the hybrid positioning system are used in the hybrid decision-making when they satisfy certain performance criteria enforced by the hybrid positioning system. The hybrid positioning system can enforce the individual positioning systems criteria to require accuracy better than a given threshold value in order to consider positioning estimates from the individual positioning systems in the switching algorithm. For example, the hybrid positioning system may decide to only use satellite locations when the number of satellites in view exceeding a certain threshold and reject otherwise.

[0019] Embodiments of the invention enable a hybrid positioning system to select a reported location from a specific positioning system. The hybrid positioning system analyzes different observable parameters obtained by individual positioning systems and selects one of the estimated positions provided by the individual positioning systems. The hybrid positioning system also analyzes different observable parameters by individual positioning systems to make a decision regarding enabling or disabling one or more available positioning systems and/or disabling corresponding devices in order to reduce the overall system power consumption. The hybrid positioning system then decides on which positioning system to use and how to report the final location of the device. One goal of certain implementations of the invention is to increase performance of a hybrid positioning system. Better performance can mean better accuracy, better availability, faster time to fix, or better power consumption. Performance can also be referred to as a combination of two or more of the accuracy, availability, accuracy, time to fix, power consumption as well.

[0020] In one embodiment, the outcome of each source of location in certain circumstances is combined and the calculated location is reported to the user. Under certain implementations, the quality of reported location for each source of location in hybrid positioning system is

evaluated. The quality of each source of location and its reported location is evaluated by analyzing the observable parameters at the receiver. In certain circumstances, a high quality source of location is the one that shows strong signals and good positioning accuracy. On the other hand, a bad quality source of location is the one that shows weak signals and poor positioning accuracy. It should be noted that for each source of location, the parameters to indicate the quality of positioning accuracy is different from other sources of location.

[0021] As mentioned above, a hybrid positioning system can include two or more of an SPS, WPS, and/or CPS. Each of these sources of locations might provide user locations independent of other sources of locations. For example, at one instance of time, the hybrid positioning system might have access to locations obtained from all three sources, i.e. SPS, WPS, and CPS. The hybrid positioning system can then analyze each source of location for the accuracy of its reported location. After assessing the quality of each source of location, the hybrid positioning system can select the best and most accurate location and report that to user as final location estimate. Fig. 2 illustrates the process of collecting relevant parameters of each location system (SPS, WPS, and CPS) and sending the parameters to an algorithm implemented in a mobile device.

[0022] In the above mentioned process, either source of reported location or the hybrid positioning system are enabled to cache the previous reported location for some interval of time. For example, a hybrid system might report a cached SPS location for 10 seconds before reporting no location or before switching to WPS location. If hybrid system decides that WPS location accuracy is much worse than SPS location, it can report the old SPS location for an extended interval of time, then start reporting WPS location.

[0023] Generally, the accuracy of the reported location deteriorates from SPS to WPS to CPS. One technique for the selection of sources of location estimates based on availability of better-known sources of location is known by those having ordinary skill in the art as a waterfall switching algorithm. Embodiments of the invention select between different sources of location estimates and report the best location according to a performance criterion rather than a predetermined preference. Thus, for example, a decision can be made to select and/or report position location estimate from a WPS even though an estimate from an SPS location is available when the hybrid positioning system determined that the quality of the position estimate from the SPS is lower than that of the WPS.

[0024] Herein, are disclosed for each source of location (*i.e.*, individual positioning system) parameters that are relevant to a switching algorithm that allows the hybrid positioning system to evaluate the quality of the reported location. The first source of location discussed herein is

SPS, which relies on receiving satellite and measurement information from satellites at the receiver side. When started, an SPS listens for satellite signals, receives, and processes them. The received signals, along with some other information passed to the SPS (*e.g.*, via a network) could enable the receiver to calculate its location. The principle used here is to know the exact location of the satellite and measure the distance of the satellite to the receiver. The receiver then solves a set of equations and calculates the location of the receiver. The quality of the reported location in SPS is usually assessed through Horizontal Dilution of Precision (HDOP.) The smaller the HDOP value, the better the positioning accuracy. Examples of SPS are GPS (Global Positioning System), Galileo, GLONASS, or Compass.

[0025] In one implementation, the elapsed time to obtain the fix (which is called time to fix or TTF) is used as an indicator of the quality of an estimated location. Specifically, in open environments and areas with good visibility to SPS satellites, fix comes quickly. On the other hand, in challenging environments for SPS devices, *e.g.*, in a location with a limited view of the sky, fix might take some time to arrive. The hybrid position system can take advantage of this difference in TTF and assign a quality factor to SPS location. In addition, elapsed time after fix (TAF) can also be used as an indicator of the quality of an SPS estimated location. Time after fix (TAF) refers to the duration of time that a fix has been continuously provided without a gap in time. In general, in open environments and areas with good visibility to SPS satellites, an SPS device can maintain its fix. However, in challenging environments for SPS devices, the device might not be able to maintain the fix. This results in small TAF values and indicates that device is in challenging environment for SPS.

[0026] Furthermore, implementations of the invention combine the above metrics and use the result as an indicator of the quality of an SPS estimated location. The combination of TTF and TAF can be considered as another metric. The proposed metric looks for “gaps” in time for consecutive fixes. So if SPS fixes are obtained and lost frequently, system decides that the SPS device is in challenging environment for SPS. For example, if SPS fix is lost for 5 seconds and a fix is provided after five seconds, then TTF for the new fix is 5s. If we get subsequent fixes for the next 120s, then TAF is 120s. The combination of TTF and TAF, 5s to get the fix and continuous fixes for 120s, would indicate that there is no gap in acquiring SPS fixes and the quality of SPS location is likely to be very good.

[0027] Secondary measures are also employed to estimate the quality of an SPS location estimate, as follows. The hybrid positioning system can use number of satellites used to calculate the SPS location as an indicator of type of environment. In open environments, the number of satellites used in a fix is generally large. On the other hand, in challenging

environments for SPS, fixes are obtained with very few satellites, and fixes are maintained with few satellites. Also, the velocity of the device as determined by SPS can be used as a secondary measure of quality. In general, when the SPS velocity is relatively large, the SPS receiver is considered to be located in an open sky environment and its location is considered to be very accurate. For example, having SPS locations with reported velocity of 60mph would indicate that the device is in driving mode and hence likely to be outdoors and not indoors. This would indicate that the quality of SPS-provided location is good. Finally, the number of satellites currently in view can be used as an indicator of the type of environment. In open sky environments, generally, an SPS can receive signals from different satellites, and the number of satellites in view is large. On the other hand, in challenging environments for SPS, the number of satellites in view is low. Note that number of satellites in view refers to number of satellites from which the SPS receiver receives signal. The velocity in this discussion can come from SPS or other sources of location such as Wi-Fi positioning system. It can also come from other sensors on the device or working with the device. For example, the velocity can come from speedometer of a car which is connected to the device. Same discussion applies to bearing.

[0028] There also exist another measure to estimate the quality of the provided SPS location. The hybrid positioning system can use the variations in positions provided by SPS in specified time interval to measure the quality of SPS location. For example, variations measures such as variance, standard deviation, range, interquartile range, etc. might be used to gauge the variation of SPS position for 30 seconds of reporting location. In addition, the hybrid positioning system can use variations of other parameters related to SPS position in order to assess the quality of SPS reported location. The changes should follow a logical order of changes for a device. For example, the hybrid positioning system can use variations in velocity, bearing, and number of satellites used to derive the SPS location which all are reported by SPS. In such cases, huge jumps and variations in velocity or bearing of the device would indicate that SPS-provided locations might be of lower quality and/or the environment has changed.

[0029] The hybrid positioning system can also use the variation of combination of all the above parameters in order to assess the quality of the SPS location. In open and non-challenging environments to SPS, usually SPS provided location moves slowly from one point to the other point. In mobile devices that are within such environments, these changes can also be correlated with velocity of the vehicle and the integrity of the provided solution can be checked. The displacements in subsequent locations are according to the signals received from satellites and they follow the physical rules governing the device. For example, for a device moving with 10 m/s velocity, the location of the device from one point in time to a second after

that time should only change 10 m. Changes much larger than 10 m would indicate that either the location or the velocity reported by SPS and other positioning systems were not correct and should raise a flag for the hybrid positioning system. For such quality checks, the hybrid positioning system, based on realistic values for velocity and bearing and previous SPS location, can reject a new reported SPS location, if the new location is much further than anticipated location. This can provide integrity on the reported location and avoid large jumps in location which are not feasible.

[0030] For another example, in open environments, the SPS location rarely has huge jumps in velocity and bearing as they should continuously change. Also, the number of satellites used to derive SPS location does not exhibit large jumps. This results in small variations in velocity, bearing, and number of satellites. On the other hand, in challenging environments, we frequently observe jumps in number of satellites reported by SPS. Velocity and bearing also show large variations. These changes are also not in line with change of velocity of the device. Therefore, the variations in the reported positions by SPS are significantly higher compared to open sky environments. Another specific variation can be defined as the jumps in reported location. This “jumpiness” behavior is usually not observed in open sky and non-challenging environment to SPS. On the other hand, in challenging environment for SPS, the location might frequently and unusually jump from a place to another place.

[0031] The next source of location examined here is a WiFi positioning system (WPS). WiFi positioning generally relies on received signals from different WiFi beacon devices. After receiving the signals from a wireless beacon or WiFi access point (AP) device, it might calculate the received power for all visible devices. WiFi Positioning then compares this information against a database of known AP devices and decides on the location of the user. WiFi Positioning is generally less accurate than SPS, but it has been shown that in challenging environments for SPS, WiFi Positioning can be more accurate. Such challenging environments might include urban canyons (a canyon-like effect created by surrounding buildings) and indoor environments. This disclosure discusses the possibility of detecting such cases and the type of environment. Based on such a conclusion, the hybrid positioning system selects the best possible location when both SPS and WiFi positioning are available.

[0032] In one implementation, the number of observed wireless beacons (i.e. wireless access points) can be used as an indicator of type of environment. In general, a large number of wireless devices can indicate a challenging environment for SPS, such as indoors or in a dense urban environment. If an environment is challenging for SPS, it might take longer to acquire a fix, and the accuracy of the fix might be lower. This might indicate that although both WiFi

Positioning and SPS locations are available, the WiFi Positioning location might be more accurate. For example, in dense urban environments, the number of observed wireless devices typically follows a distribution where its mean is much larger than distribution of number of APs in open sky environments. This observation could indicate that the device is located in a dense urban environment, and its SPS location might not be as accurate as a WPS location, or SPS takes longer than normal to acquire a fix.

[0033] In addition, the quality of the location estimate returned from a WPS can be used as an indicator of the quality of WiFi Positioning location relative to other individual systems. The relative quality of reported locations from a WPS and an SPS enables the hybrid system to make a better decision in reporting the final location. For example, a very good location obtained from WiFi Positioning could be more accurate than a location obtained from SPS with few satellites and poor quality of location.

[0034] Some implementations can use the maximum observed power from observed wireless devices as an indicator of the type of the environment that the device is working and relate it to the relative quality of SPS and the quality of WiFi Positioning location. Generally, when a wireless device is observed with high power, it could indicate that the receiver is located in indoor environments. Hence, it could be difficult to obtain a high quality SPS location, which translates to higher time to fix and lower accuracy. This could indicate that any SPS provided location does not represent the true location and suffers from large inaccuracies in the provided location.

[0035] Further still, the distance between an SPS-provided location and a WiFi Positioning-provided location can be used as a metric to select between two reported locations. Generally, when the two locations are very far from one another, it is assumed that the SPS location is more accurate due to the nature of SPS. Hence, the hybrid positioning system should report the SPS location as its final location.

[0036] In further embodiments of the invention, an aggregate of different parameters, namely, number of satellites used in a fix, number of parameters in view, horizontal dilution of precision "HDOP," quality value of positioning in WiFi Positioning, inferred type of the environment the device is working in, number of WLAN devices used in WiFi Positioning, association information to an WLAN device, etc. are used to select the most accurate source of location. The aggregate parameters can indicate the type of environment in which the receiver resides. Thus, the system can use the aggregate information to select the best source among several location estimates.

[0037] Also disclosed herein are techniques to use the aforementioned information to reduce the power consumption of a mobile device, and, thereby, increase battery life. In certain implementations, several parameters, namely, the number of WLAN devices used in WiFi Positioning and the maximum power observed from WLAN devices, are used to infer that the mobile device is in a challenging environment for SPS. Thus, an SPS present in the mobile device is instructed to remain off or the powering-on of the SPS is delayed. Furthermore, the SPS can be powered-down if it does not acquire a fix within a designated period of time.

[0038] Such a technique can be employed when the mobile device starts a search for location. In traditional methods, the mobile device turns all devices on to find a location and presents the location result according to the waterfall switching algorithm. The techniques disclosed herein propose to use the above parameters to delay turning-on the SPS hardware, or avoid powering-on the SPS all together in certain situations, in order to reduce power consumption by the mobile device. Moreover, if powered on, the SPS hardware would be turned off if they do not acquire a fix within a predetermined period of time.

[0039] Similarly, other device and network information can be used to power-up or power-down portions of hardware or separate devices. Implementations of the invention propose to use association information between a WLAN AP and a mobile device, or any communication between a WiFi enabled device and a WLAN AP, as an indication of a high likelihood that the mobile device is indoor and/or is stationary. Such a determination can be used to delay powering-on SPS hardware in situations where it could not be completely confirmed that the device is indoors and/or is stationary. In the alternative, the SPS hardware can be left off or turned off if no location is acquired.

[0040] Further still, the techniques disclosed herein can be used to power-off SPS hardware within a mobile device when indications are detected that the mobile device is indoors or in a challenging environment for SPS. Similarly, the determination that the mobile device is indoors can be combined with the detection that the mobile device is not moving (or moving very slowly) to result in powering-off the SPS hardware. Therefore, when WPS hardware in the mobile device detects a low velocity, or that the user is stationary, the mobile device can power-off the SPS hardware to reduce power consumption. On the other hand, when the WPS hardware detects a moderate or higher velocity, the SPS hardware can be kept on.

[0041] The techniques disclosed herein also enable different methods to reduce the power consumption of mobile devices by dynamically changing the scan rate of the WiFi positioning system. In certain operating scenarios, increased scan rates do not improve the accuracy of position estimates of the system and only consume more power. Thus, some implementations

determine if a scanning strategy is not optimized and adjust the scanning rate of the positioning engine to optimize the power consumption. In addition, some embodiments optimize the trade-off between positioning accuracy and power. Parameters such as association to a WLAN device, velocity of the mobile unit estimated from different sources of location, number of WLAN devices used in WiFi Positioning, maximum power observed from any WLAN device in range, and number of satellites in view can be used to change the scanning rate of the positioning algorithm.

[0042] Other parameters can also be used to optimize the scanning rate. Scanning rate is defined as the rate of scanning the surrounding environment and searching for related signals for each positioning system. Scanning rate is applicable to Wi-Fi Positioning Systems and CPS. SPS typically continuously search for signals from satellites and updates location estimate every second. However, Wi-Fi Positioning Systems can have different scanning rates, therefore the rate of turning on the wireless device and scanning the environment for near by wireless APs can be different from SPS. The scanning rate of the Wi-Fi Positioning System or CPS can be adjusted dynamically when the positioning algorithm switches from initial location state (one-shot location – for applications without a need to track the device) to tracking state (in which location is updated periodically). For example, in such scenarios, the scanning rate for initial location state is lowered for power saving, while in tracking mode, because the user is concerned about receiving the best possible location, the scanning rate is increased to improve the accuracy. In another implementation, the time during which a location request is active is used to optimize the scanning rate. For example, if a particular application calls for a location request at a known frequency (e.g., every 10 seconds), then the scanning rate of the positioning algorithm can be adjusted to scan and/or power-on particular location system only when a location estimate must be provided.

[0043] In certain implementations, the techniques for reducing power consumption to increase battery life are disabled when the mobile device detects that it is connected to an external power source.

[0044] According to alternative embodiments, Fig. 3 illustrates the process of collecting relevant parameters of each location system (SPS, WPS, and CPS), using a reference database that may perform the initial position determination, and sending different parameters and the initial positions returned from the database to an algorithm implemented in a mobile device.

[0045] Fig. 4 illustrates a flow chart of a method for position estimation of a mobile device according to aspects of the present disclosure. Signals from at least two positioning systems are analyzed in step 410. In the example illustrated in Fig. 4, signals from a satellite

positioning system (“SPS”), a Wi-Fi positioning system, and a cell positioning system (“CPS”) are analyzed. The method determines a corresponding initial position estimate for the SPS (420), for the Wi-Fi positioning system (430), and/or for the CPS (440), based on the analyzed signals. The method in step 450 selects an initial position estimate as the final position estimate 460.

[0046] Fig. 5 illustrates a method for determining the type of environment using SPS parameters. When the device is in an open sky environment, there are no gaps between SPS fixes. For example, as seen at the top part of the figure, the TTF is between $t=0$ and $t=5$, and then the TAF is between $t=5$ and $t=120$. At the bottom part of the figure, there is an example of a challenging environment where there are a lot of instances where there is a fix and shortly after the fix is lost.

Example 1

[0047] The following discussion is one example of a method for switching between different sources of locations (individual positioning systems). In this example, the hybrid positioning system is assumed to have access to both an SPS and a WPS. During certain periods of time, each source of location is capable of providing a location estimate. However, at times, due to blockage of signals, for example, one or both systems are unable to provide a location estimate.

[0048] In such an operating scenario, the hybrid positioning system assesses the quality of the location estimates from each source of location. If location estimates from the SPS and the WPS are both available, the hybrid positioning system evaluates the accuracy of the location estimate provided by the SPS. For example, this can include analyzing the SPS parameters described above. If the quality of the location estimate provided by the SPS is high, the hybrid positioning system reports the SPS location immediately and does not evaluate the quality of the location estimate of the WPS. Otherwise, if the quality of the location estimate from the SPS is low, the hybrid positioning system analyzes the parameters of the WPS and compares the quality determinations. If the WPS accuracy is above a given threshold while the accuracy of the SPS location estimate has fallen below a certain threshold, the hybrid positioning system reports the location provided by the WPS. In cases where the position estimates from both the SPS and the WPS, the hybrid positioning system reports the SPS provided location. Finally, if only one source of location is able to provide an estimated location, then the hybrid positioning system reports the location from the only available system.

Example 2

[0049] In another illustrative implementation, a neural network can be used to select between the sources of location. This approach can be generalized when more sources are available. In the training phase of this approach, the hybrid positioning system is trained with a comprehensive set of data. Each data set includes an SPS location estimate and its associated parameters, a WPS location estimate and its associated parameters, a CPS location estimate and its associated parameters, and the best final decision that could be made for that case. In the training phase, the best final decision can be based on the known locations of the device when the training data set is assembled. The parameters associated with SPS and WPS sources of location are those described above. Parameters associated with CPS as a source of location include number of towers used for positioning, the relative power of the signals from the towers, the statistics of the signal power (e.g., variability, type of noise, etc.), and an error estimation associated with the towers, if available. After training the neural network with this dataset until it converges, the neural network determines a set of coefficients to be arithmetically added or multiplied to the inputs of the neural network. These coefficients can then be used in a receiver program to select between all possible options.

[0050] Another technique for deciding which source(s) of location to use in a particular situation includes considering the history of previous location estimates. For example, assuming that both WPS and SPS estimates are available at the present moment and both have been available for a certain period of time, the hybrid positioning system can elect to use the SPS locations estimate as the present location. This is so because long-acquired SPS location estimates are believed to have more accurate locations than recent obtained location estimates. In other words, the time after obtaining a first location estimate in a current run of a hybrid positioning system can directly affect the decision as to which source of location is the most reliable and/or accurate. If a receiver is able to track SPS location estimates for more than several minutes, the location accuracy of that source is deemed to increase as time passes.

[0051] As discussed in more detail above, there are several implementations of the techniques disclosed herein for determining the most reliable and/or most accurate source of location in a particular situation. In some embodiments of the invention, the hybrid positioning system can use different algorithms to select between different sources of location depending on how long the hybrid positioning system has been operational after initialization. For example, upon initialization and for a predetermined time thereafter, the system can employ the switching technique set forth above in Example 1, and at operational times greater than the predetermined time employ the switching technique set forth above in Example 2.

[0052] The techniques and systems disclosed herein may be implemented as a computer program product for use with a computer system or computerized electronic device. Such implementations may include a series of computer instructions, or logic, fixed either on a tangible medium, such as a computer readable medium (e.g., a diskette, CD-ROM, ROM, flash memory or other memory or fixed disk) or transmittable to a computer system or a device, via a modem or other interface device, such as a communications adapter connected to a network over a medium.

[0053] The medium may be either a tangible medium (e.g., optical or analog communications lines) or a medium implemented with wireless techniques (e.g., Wi-Fi, cellular, microwave, infrared or other transmission techniques). The series of computer instructions embodies at least part of the functionality described herein with respect to the system. Those skilled in the art should appreciate that such computer instructions can be written in a number of programming languages for use with many computer architectures or operating systems and under different platforms.

[0054] Furthermore, such instructions may be stored in any tangible memory device, such as semiconductor, magnetic, optical or other memory devices, and may be transmitted using any communications technology, such as optical, infrared, microwave, or other transmission technologies.

[0055] It is expected that such a computer program product may be distributed as a removable medium with accompanying printed or electronic documentation (e.g., shrink wrapped software), preloaded with a computer system (e.g., on system ROM or fixed disk), or distributed from a server or electronic bulletin board over the network (e.g., the Internet or World Wide Web). Of course, some embodiments of the invention may be implemented as a combination of both software (e.g., a computer program product) and hardware. Still other embodiments of the invention are implemented as entirely hardware, or entirely software (e.g., a computer program product).

[0056] Moreover, the techniques and systems disclosed herein can be used with a variety of mobile devices. For example, mobile telephones, smart phones, personal digital assistants, satellite positioning units (e.g., GPS devices), and/or mobile computing devices capable of receiving the signals discussed herein can be used in implementations of the invention. The location estimate, expected error of the position estimate, and/or the probability values can be displayed on the mobile device and/or transmitted to other devices and/or computer systems. Further, it will be appreciated that the scope of the present invention is not limited to the above-

described embodiments, but rather is defined by the appended claims; and that these claims will encompass modifications of and improvements to what has been described.

[0057] What is claimed is:

CLAIMS

1. A method for determining a position of a device using signals from multiple positioning systems, the method comprising:

analyzing signals from at least two of a satellite positioning system (“SPS”), a Wi-Fi positioning system, and a cell positioning system (“CPS”);

determining for each of the at least two of the SPS, the Wi-Fi positioning system, and the CPS, a corresponding initial position estimate of the device and at least one corresponding parameter; and

selecting one of the corresponding initial position estimates as a final position estimate of the device based on at least one of a history of previously reported positions, the at least one corresponding SPS parameter, the at least one corresponding Wi-Fi positioning system parameter, and the at least one corresponding CPS parameter.

2. The method according to claim 1, wherein each initial position estimate is determined solely from the signals of the corresponding positioning system.

3. A method for determining a position of a device using signals from multiple positioning systems, the method comprising:

analyzing signals from at least two of a satellite positioning system (“SPS”), a Wi-Fi positioning system, and a cell positioning system (“CPS”);

determining for each of the at least two of the SPS, the Wi-Fi positioning system, and the CPS, a corresponding initial position estimate of the device and corresponding parameters;

selecting one of the corresponding initial position estimates as a final position estimate of the device based on at least one of a history of previously reported positions, the at least one corresponding SPS parameter, the at least one corresponding Wi-Fi positioning system parameter, and the at least one corresponding CPS parameter; and

switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on the at least one of the history of the previously reported positions, the at least one corresponding SPS parameter, the at least one corresponding Wi-Fi positioning system parameter, and the at least one corresponding CPS parameter.

4. The method according to claim 3, wherein the SPS initial position is cached for a period of time.
5. A method for determining a position of a device using signals from multiple positioning systems, the method comprising:
 - analyzing signals from at least two of a satellite positioning system (“SPS”), a Wi-Fi positioning system, and a cell positioning system (“CPS”);
 - determining for each of the at least two of the SPS, the Wi-Fi positioning system, and the CPS, a corresponding initial position estimate of the device and corresponding parameters;
 - assessing for each of the corresponding initial position estimates a quality of the initial position estimate; and
 - selecting one of the corresponding initial position estimates as a final position estimate of the device based on the assessed qualities of the initial position estimates.
6. The method according to claim 5, wherein an elapsed time to obtain a fix (TTF) is used as an indicator of the quality of the initial position estimate of the SPS.
7. The method according to claim 6, further comprising
 - switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
 - wherein the indicator of the type of environment is based on the TTF.
8. The method according to claim 5, wherein an elapsed time after a fix (TAF) is used as an indicator of the quality of the initial position estimate of the SPS.
9. The method according to claim 8, further comprising
 - switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
 - wherein the indicator of the type of environment is based on the TAF.
10. The method according to claim 5, wherein a combination of a TTF and a TAF is used as an indicator of the quality of the initial position estimate of the SPS.

11. The method according to claim 10, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
wherein the indicator of the type of environment is based on the combination of a TTF and a TAF.
12. The method according to claim 5, wherein a number of satellites in fix or in view is used as an indicator of the quality of the initial position estimate of the SPS.
13. The method according to claim 12, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
wherein the indicator of the type of environment is based on the number of satellites in fix or in view.
14. The method according to claim 5, wherein a velocity of the device is used as an indicator of the quality of the initial position estimate of the SPS.
15. The method according to claim 14, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
wherein the indicator of the type of environment is based on the velocity of the device.
16. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the SPS is based on a combination of at least two of a TTF, a TAF, a number of satellites in fix or in view, and a velocity of the device.
17. The method according to claim 16, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
wherein the indicator of the type of environment is based on the combination of at least two of the TTF, the TAF, the number of satellites in fix or in view, and the velocity of the device.

18. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the SPS is based on variations in position estimates provided by the SPS.
19. The method according to claim 18, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
wherein the indicator of the type of environment is based on the variations in position estimates provided by the SPS.
20. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the SPS is based on variations in velocity of the device.
21. The method according to claim 20, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
wherein the indicator of the type of environment is based on the variations in velocity of the device.
22. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the SPS is based on variations in bearing.
23. The method according to claim 22, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;
wherein the indicator of the type of environment is based on the variations in bearing.
24. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the SPS is based on jumpiness of reported positions by the SPS.
25. The method according to claim 24, further comprising
switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;

wherein the indicator of the type of environment is based on the jumpiness of reported positions by the SPS.

26. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the Wi-Fi positioning system is based on a number of Wi-Fi access points in range of the device.

27. The method according to claim 26, further comprising

switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;

wherein the indicator of the type of environment is based on the number of Wi-Fi access points in range of the device.

28. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the Wi-Fi positioning system is based on a maximum observed power from Wi-Fi access points in range of the device.

29. The method according to claim 28, further comprising

switching to another one of the corresponding initial position estimates as a second final position estimate of the device based on an indicator of a type of environment;

wherein the indicator of the type of environment is based on the maximum observed power from Wi-Fi access points in range of the device.

30. The method according to claim 1, wherein selecting one of the corresponding initial position estimates of the device as a final position estimate of the device is according to the distance between the SPS-provided initial position estimate and the Wi-Fi positioning system initial position estimate.

31. The method according to claim 1, wherein selecting one of the corresponding initial position estimates of the device as a final position estimate of the device is according to at least one of a number of satellites used in a fix, a horizontal dilution of precision, a number of Wi-Fi access points used in Wi-Fi positioning, association information to a Wi-Fi access point, and history of previous location estimates.

32. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the SPS is based on SPS parameters including at least one of a TTF, a TAF, a number of satellites in fix or in view, a velocity of the vehicle, a HDOP, variations of the TTF, variations of the TAF, variations of the number of satellites in fix or in view, variations of the velocity of the vehicle, and variations of the HDOP.
33. The method according to claim 32, further comprising
- turning on or off logic in the device that determines initial position estimates based on an indicator of a type of environment;
 - changing the scanning rate of the Wi-Fi positioning system and/or the CPS based on an indicator of a type of environment;
 - wherein the indicator of the type of environment is based on the SPS parameters.
34. The method according to claim 5, wherein an indicator of the quality of the initial position estimate of the Wi-Fi positioning system is based on Wi-Fi parameters including at least one of a number of access points in range of the device, a maximum power, statistics of power, quality of Wi-Fi positioning systems, variations of the number of access points in range of the device, variations of the maximum power, variations of the statistics of power, variations of the quality of the initial position estimate of the Wi-Fi positioning systems.
35. The method according to claim 34, further comprising
- turning on or off logic in the device that determines initial position estimates based on an indicator of a type of environment;
 - changing the scanning rate of the Wi-Fi positioning system and/or the CPS based on an indicator of a type of environment;
 - wherein the indicator of the type of environment is based on the Wi-Fi positioning system parameters.
36. The method according to claim 1, wherein a scanning rate of each of the at least two of a SPS, a Wi-Fi positioning system, and a CPS is individually optimized according to at least one of an association information to a Wi-Fi access point, a velocity of the device, a number of Wi-Fi access points used in Wi-Fi positioning, and a number of satellites used in view

37. The method according to claim 1, further comprising changing the scanning rate for the Wi-Fi positioning system or the CPS if the device is in one-shot or tracking mode.

38. The method according to claim 1, further comprising turning on or off the device based on the device being in one-shot or tracking mode.

39. The method according to claim 1, further comprising changing the scanning rate for the Wi-Fi positioning system or the CPS if the device is connected to an external power supply

40. The method according to claim 1, further comprising:

evaluating the quality of the corresponding initial position estimate of a first positioning system of the at least two of a SPS, a Wi-Fi positioning system, and a CPS; and

selecting the corresponding initial position estimate of the first positioning system as the final position estimate of the device without evaluating the quality of the initial position estimate of a second positioning system of the at least two of a SPS), a Wi-Fi positioning system, and a CPS.

41. A method for determining a position of a device using signals from multiple positioning systems, the method comprising:

analyzing signals from at least two of a satellite positioning system ("SPS"), a Wi-Fi positioning system, and a cell positioning system ("CPS");

determining for each of the at least two of a SPS, Wi-Fi positioning system, and CPS, a corresponding initial position estimate of the device based on the analyzed signals;

combining the corresponding initial position estimates to determine a combined initial position estimate; and

selecting either one of the corresponding initial position estimates of the device or the combined initial position estimate as a final position estimate of the device.

42. A computer-readable storage device containing a set of instructions that causes a mobile device to:

analyze signals from at least two of a satellite positioning system ("SPS"), a Wi-Fi positioning system, and a cell positioning system ("CPS");

determine for each of the at least two of a SPS, Wi-Fi positioning system, and CPS, a corresponding initial position estimate of the device based on the analyzed signals; and

select one of the corresponding initial position estimates of the device as a final position estimate of the device.

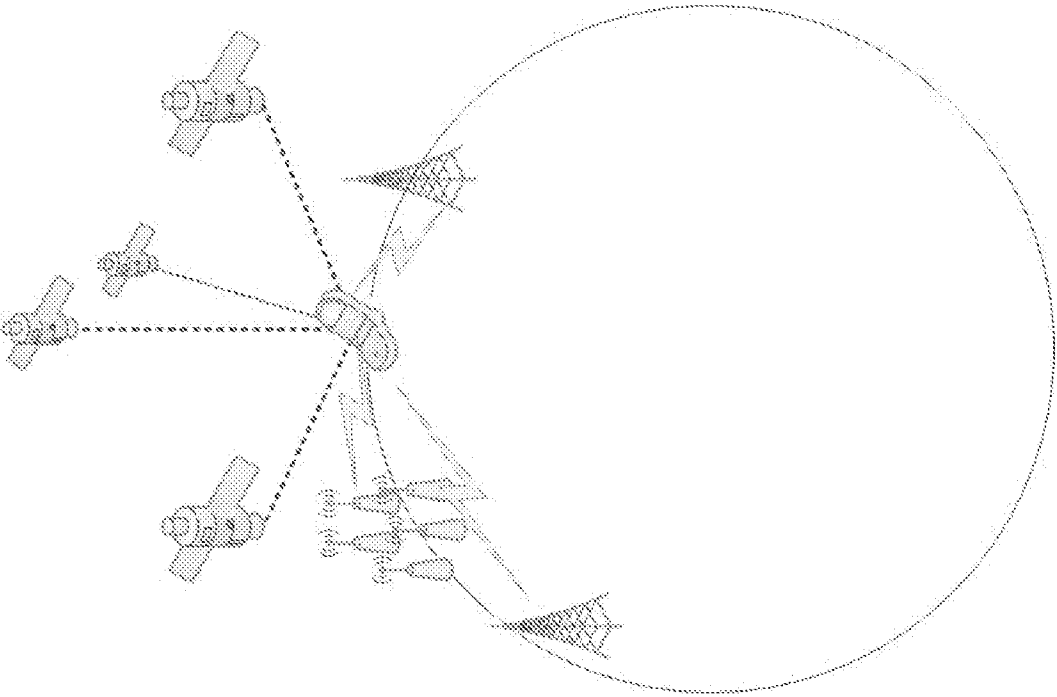


Fig. 1

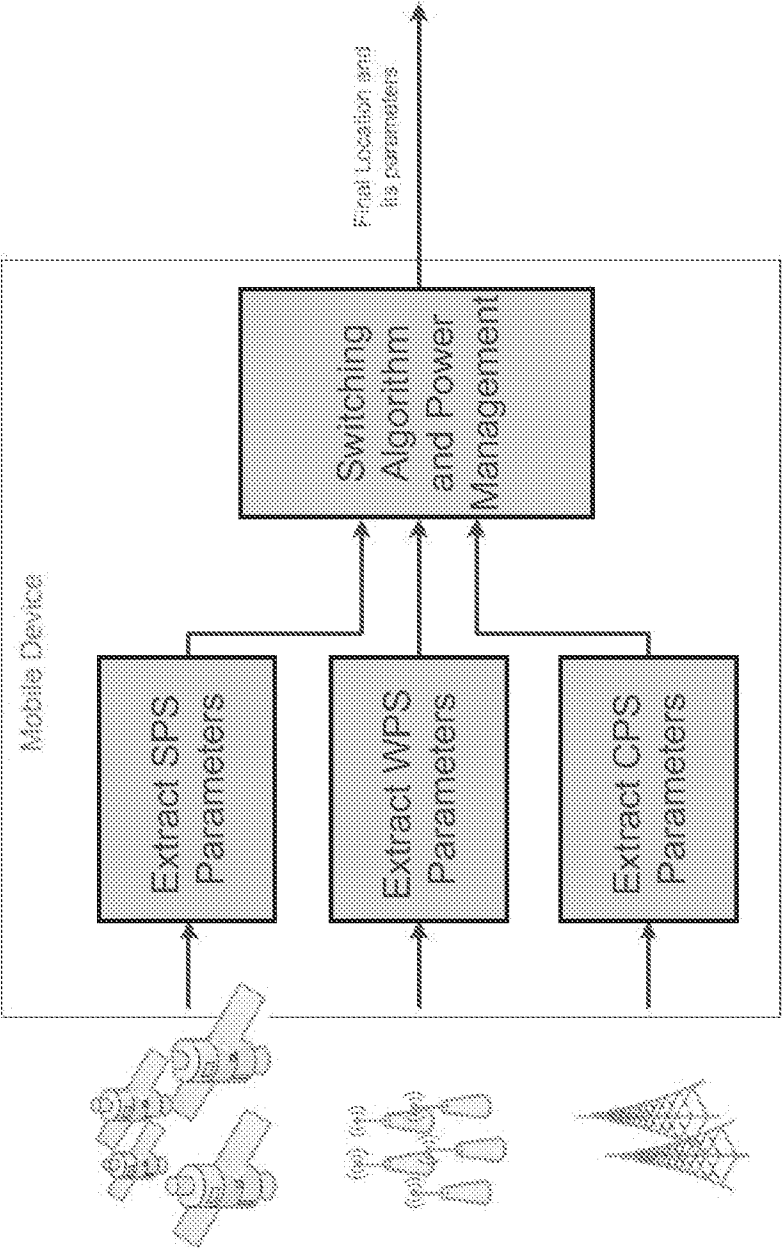


Fig. 2

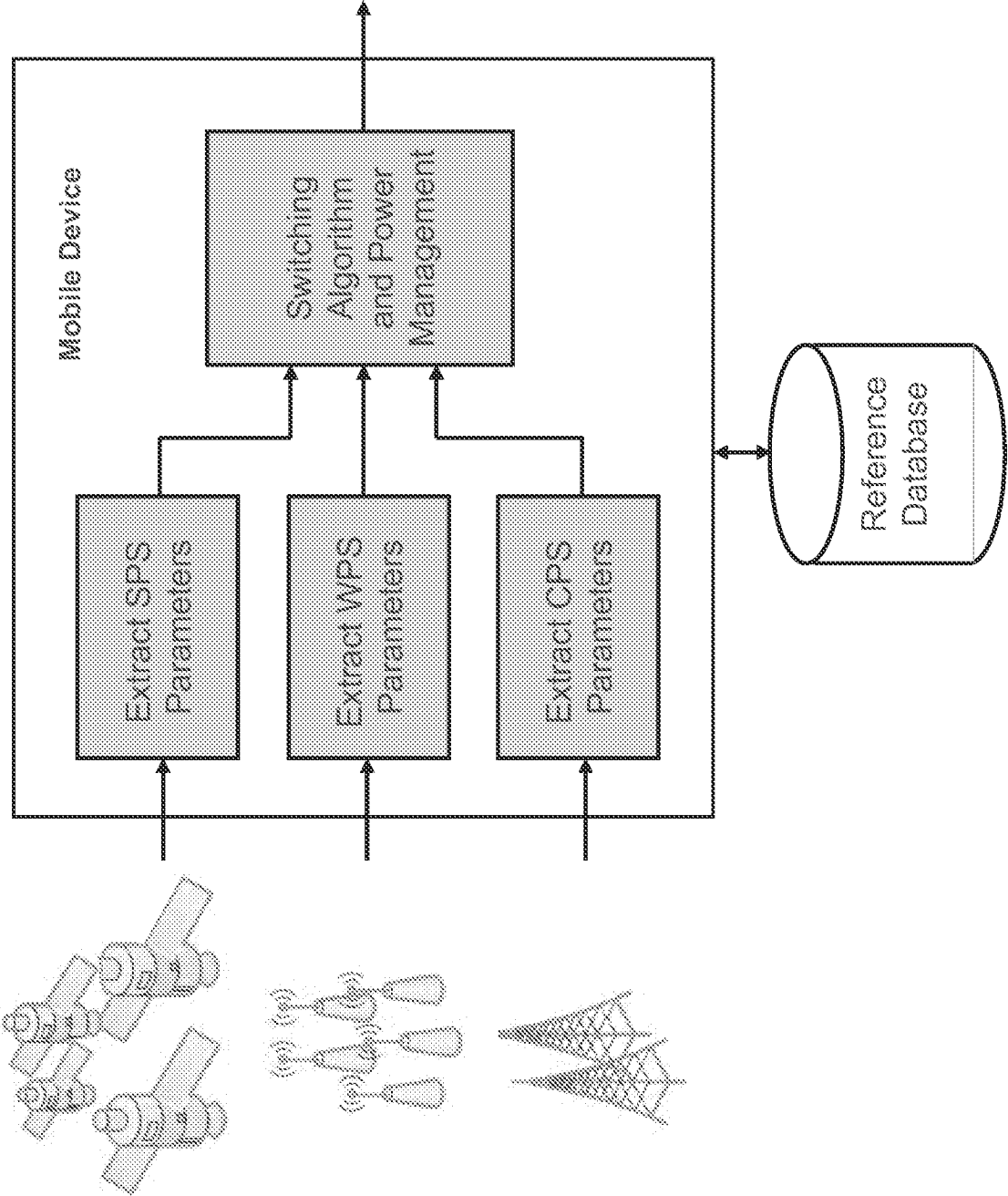


Fig. 3

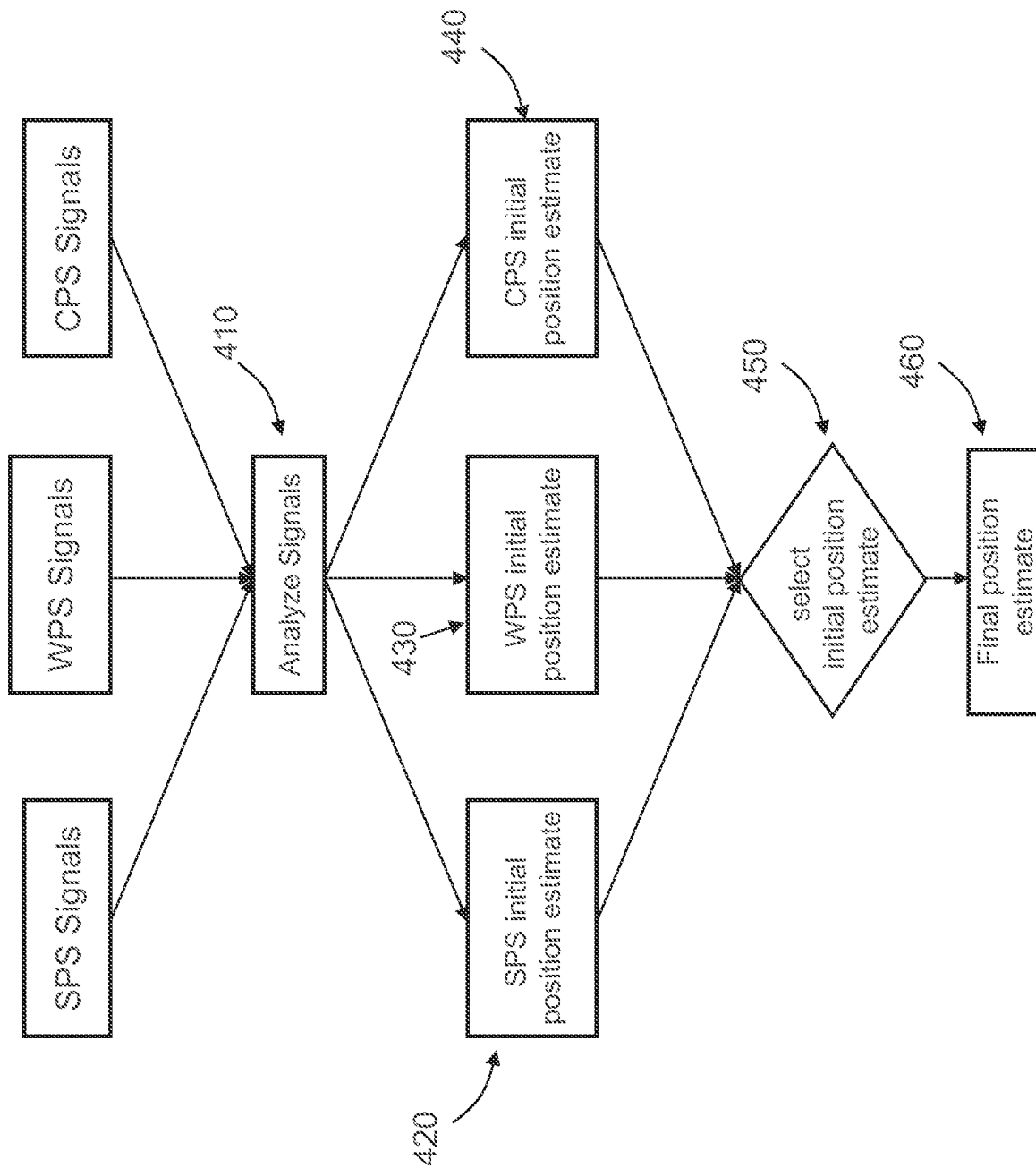
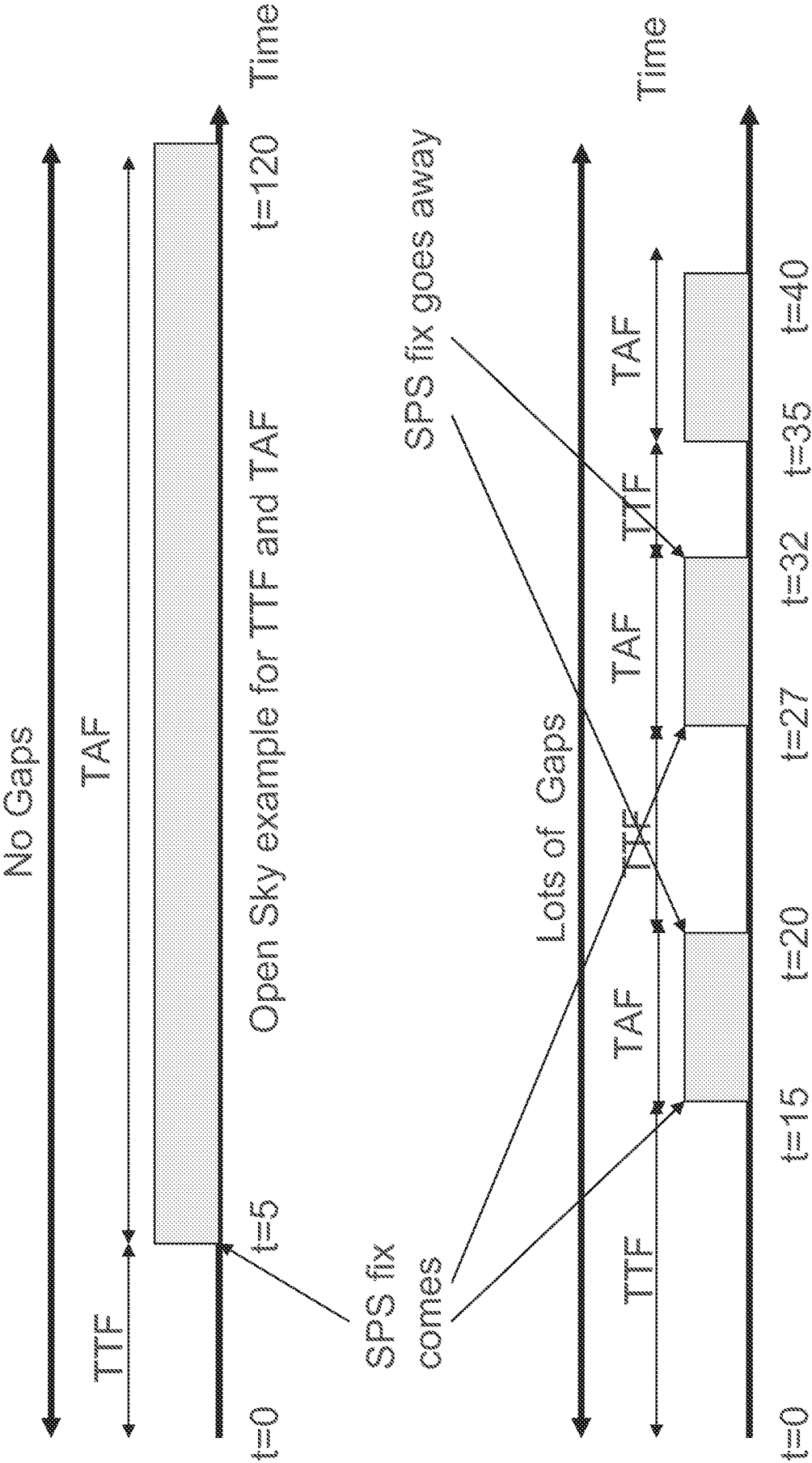


Fig. 4



Challenging Environment example for TTF and TAF

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2011/059139

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01S 3/00 (2012.01)

USPC - 342/450

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) - G01S 3/00, H04W 24/00, G01S 5/00 (2012.01)

USPC - 342/450, 455/456.1, 455/456.3, 342/463

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, Elsevier Inc Engineering Village: Compendex, Inspec, NTIS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/0192709 A1 (YONKER et al) 30 July 2009 (30.07.2009) entire document	1-2, 30-31, 36-39, 41-42
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Y		3-29, 32-35, 40
Y	US 7,660,588 B2 (SHEYNBLAT et al) 09 February 2010 (09.02.2010) entire document	3-29, 32-35, 40
Y	US 7,151,939 B2 (SHEYNBLAT) 19 December 2006 (19.12.2006) entire document	6-29, 32-35
Y	US 2006/0049982 A1 (WELLS) 09 March 2006 (09.03.2006) entire document	6-11
A	US 6,975,266 B2 (ABRAHAM et al) 13 December 2005 (13.12.2005) entire document	1-42
A	US 2010/0039323 A1 (KOSOLOBOV et al) 18 February 2010 (18.02.2010) entire document	1-42

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"O" document referring to an oral disclosure, use, exhibition or other means

"I" 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

31 January 2012

Date of mailing of the international search report

09 FEB 2012

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