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(54) **Title:** SYSTEM FOR THE LOCATION OF MOBILE UNITS BY INFORMATION ACCOMPANYING SATELLITE RECEPTION

(57) **Abstract:** An apparatus and method for determining the location of a mobile unit using signals from satellites of a constellation such as the Global Positioning System (GPS), in conjunction with a location calculation center that exploits a Geographic Information System, to simulate likely signal reception, including signal strength and delayed, reflected signals. The method also employs signals from a cellular communications system, wherewith the mobile receiver is also associated, to supplement GPS satellite data and to communicate with the location calculation center. By comparing actual reception with the simulated model, the method improves an approximate location fix of the mobile unit.

SYSTEM FOR THE LOCATION OF MOBILE UNITS BY INFORMATION ACCOMPANYING SATELLITE RECEPTION

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates generally to the field of satellite-based positioning systems and, more particularly, to enabling positioning of a mobile receiver in a positioning system based on a satellite network such as the Global Positioning System (GPS) satellites.

There are currently several methods for locating mobile units, in general, and mobile telephones, in particular. Many of the methods are based on the use of satellites of global navigation systems, such as the Global Positioning System (GPS), carrying beacons that transmit known signals. Some of the methods are based exclusively on the use of such satellites. Others are based on a system that combines measurements from such satellites and measurements from other sources, such as ground-based, stationary beacons that transmit signals as if they were satellites (so-called pseudolites), and base stations of a cellular communications network to which the mobile receiver also has access.

Most of the methods make use of a client-server method, whereby the mobile unit receives ancillary information from a server that relieves it of having to obtain all information from a satellite and thus enables a quicker acquisition of only necessary data from satellite signals. Although a mobile unit has the capacity to perform a calculation of the mobile unit's location, the option exists in a client-server method to include a transfer of raw measurement data from the mobile unit to the center/server, where the location calculation is performed instead and a result may be transmitted back to the mobile unit.

In all of the methods, the range of the satellites is calculated from a Time of Arrival measurement of the satellites' signals. This method is well known in the art and generally involves identification of a designated event in the received satellite signal, measuring the time of arrival thereof at the mobile unit and, from the known time of transmission of that event, determining the signal transit time and, thus, the range of the satellite. The method includes correction for local clock inaccuracies *vis à vis* satellite system time. By performing the measurement for signals transmitted simultaneously by least four satellites of the GPS system in view, and from knowledge of the position of each satellite at the time of transmission, it is possible, by triangulation, to locate the mobile receiver. Similarly, by measuring the Doppler effect on the received signals, relative velocity of the mobile unit with respect to each satellite can also be determined and thereby, the actual velocity of the mobile unit. This is possible because the signals transmitted from the satellites contain almanac and ephemeris data that provide information about the satellite positions and velocities at all times.

A comprehensive account of the GPS system and its application may be found in *Understanding GPS: Principles and Applications*, Elliott D. Kaplan, ed., Artech House Publications, 1996, which is incorporated by reference for all purposes as if fully set forth herein.

Many existing systems have unused capacity at the location calculation center. Moreover, there is extra, currently unused information in, or derivable from, received signals, such as received signal power, which can be measured and utilized, as in the present invention.

The disclosed invention also incorporates use of a Geographic Information System (GIS), a computer system capable of assembling, storing, manipulating, and displaying and otherwise providing geographically referenced information, i.e. data, of various types, identified according to the locations thereof.

In situations where there is a weak signal or deficient data, as can happen in built-up areas or areas where there are geographical features that produce shadow areas or cause reflections of signals so that some signals are received only indirectly and at reduced strength, a likely outcome is inadequate data, which precludes fixing a precise location by standard methods.

Prior art methods utilize a central location server communicating with the mobile unit for the purpose of assisting with location identification in situations where adequate data may be unavailable to the mobile unit or in order to save time by storing almanac and ephemeris data that need not be acquired by the mobile unit. Such location servers may also assist in calculating and transmit the results back to the mobile unit. Sheynblat, in U.S. Patent No. 5 999 124, which is incorporated by reference for all purposes as if fully set forth herein, describes an invention utilizing signals from a cell-based communication network (hereafter referred to as “cellular network”) to augment satellite position information in order to determine a location of a mobile receiver having a satellite positioning receiver and a cellular network receiver. A method for when precise timing information is not available in the mobile unit is instanced, whereby the time of arrival measurements may be forwarded to a location server or to some other site that has methods to derive the timing information, preferably from received satellite navigation signals which can be used to derive the precise timing of the transmission and receipt of cellular network signals. Camp, in PCT Application WO99/61934, and Watters et al., in U.S. Patent No. 5 982 324, also teach methods of using signals from both GPS satellites and terrestrial BTSs to determine the location of a mobile receiver. These prior art methods generally rely on triangulation, as described above, using signals received simultaneously from a combined total of four or more GPS satellites and BTSs.

There is thus a need for, and it would be highly advantageous to have, an alternative method and system for better determining precise location that can utilize currently underused capacity and work in congested, shadowed, or other areas where strong signals are unavailable for whatever reason and thereby overcome the disadvantages of presently known systems as described above.

SUMMARY OF THE INVENTION

According to the present invention there is provided an apparatus for fixing a location of a mobile unit including: (a) a positioning system including a plurality of satellites, each satellite emitting a signal receivable by the mobile unit and each signal being usable by the mobile unit to calculate at least an approximate location of the mobile unit; (b) a terrestrial, cellular communications network for providing supplementary locating data: (i) communicating with the mobile unit; and (ii) having at least one cell, wherein the mobile unit is located, including a base station; and (c) a mechanism for refining the calculation of the location of the mobile unit.

The mechanism for refining the calculation of the location includes a location calculation center for simulating the received signals and comparing the simulations with actually received signals.

In a preferred embodiment of the present invention, the terrestrial, cellular communications network is a GSM network.

In the present invention, the location calculation center includes: a geographic information system for providing data for simulating signal propagation, including data about physical features of the environment wherein the mobile unit is located; a memory for storing instructions; and a processor for executing the instructions.

In the present invention, the simulations of the signals include effects of physical features of an environment wherein the mobile unit is located, including absorption by and reflection from the physical features.

In another preferred embodiment of the present invention, the location calculation center communicates with the mobile unit through the terrestrial, cellular communications network.

According to the present invention there is provided a method for fixing a location of a mobile unit including the steps of: (a) providing: (i) a satellite positioning system including a plurality of satellites, each satellite emitting a signal receivable by the mobile unit and each signal being usable by the mobile unit, for determining at least an approximate location of the mobile unit; (ii) a terrestrial, cellular communications network, communicating with the mobile unit, for determining a supplementary estimate of the location of the mobile unit; and (iii) a geographic information system including information about geographical and other environmental features of an area wherein the mobile unit is located; and (iv) a mechanism for performing a simulation of signals from the satellite positioning system; (b) determining at least one probable location area from at least one of the approximate location and the supplementary estimate of the location; (c) simulating signals received from the satellite positioning system at a plurality of locations within the at least one probable location area, including effects of environmental features of said probable location area; (d) comparing the simulated signals with signals actually received from the satellite positioning system; and (g) selecting a location having simulated signals most closely matching the actually received signals as an improved location estimate.

In a preferred embodiment of the present invention, the terrestrial, cellular communications network has at least one cell, wherein the mobile unit is located, including a base station.

In a preferred embodiment of the present invention, the terrestrial, cellular communications network is a GSM network.

In the present invention, the simulated effects of environmental features include absorption and reflection by the environmental features of the signals from the satellite positioning system.

The simulated effects of environmental features also include absorption and reflection by the environmental features of the signals from the cellular communications network.

A feature of the present invention is that the geographic information system includes information about absorptive and reflective properties of the geographical and the other environmental features both in relation to the signals from the satellite positioning system and in relation to signals from the terrestrial, cellular communications network.

The simulation includes the step of calculating at least one satellite location.

The simulation further includes the step of calculating at least one ray path between each calculated satellite location and the plurality of locations within the probable location area.

The simulation further includes the step of calculating attenuation of the signals due to absorption by environmental features in each calculated ray path.

The simulation further includes the step of calculating delays of the signals due to reflection from environmental features in each calculated ray path.

In the present invention, the determination of the probable location area is effected by a method of areas intersection.

In the present invention, the comparing includes comparison of the simulated signals with at least one of: strengths of the actually received signals; and time delays between directly received actually received signals and reflected actually received signals.

In the present invention, the at least approximate location is determined using the received signals.

The supplementary estimate of the location is determined by using at least one of: a range from at least one the base station of the cellular network receivable by the mobile unit; a cell ID of the cell wherein the mobile unit is located; a reception power of a signal from at least one base station; a timing advance; and a timing relationship between the base stations.

The present invention, further provides a location calculation center for performing at least one of the determining of at least an approximate location of the mobile unit and of the determining of the supplementary estimate of the location of the mobile unit.

In the present invention, the mobile unit communicates with the location calculation center *via* the terrestrial, cellular communications network.

In a preferred embodiment of the present invention, the simulation is performed in the location calculation center.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 portrays direct, indirect, and attenuated reception of GPS signals;

Figure 2 shows the principal terrestrial elements of the disclosed system;

Figure 3 represents the principal components of a calculation center; and

Figure 4 is an outline flow-chart of a location calculation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a system and method for locating a mobile unit, for example a mobile unit of a terrestrial wireless communications network, based on timing signals, from mobile beacons such as GPS satellites and/or from stationary beacons such as base stations of the wireless communications network. Although also applicable to other types of mobile units, the present invention is used to locate a suitably equipped cellular telephone in an environment, such as an urban environment, wherein it is difficult to establish simultaneous lines of sight to at least four GPS satellites. The invention exploits the availability of other information about the local environment, available from Geographic Information Systems.

Although the present invention is described herein in reference to the GPS system, it will be appreciated that this description is purely illustrative, and that the scope of the present invention extends to the use of any suitable types of mobile and stationary beacons, as defined above. Thus it is to be understood that the descriptions below are illustrative, and are not intended to restrict the present invention to the specific details set forth below

Also, several types of terrestrial wireless communications networks are in use around the world. One such network in common use is the GSM (Global System for Mobile) communications network. For purposes of description, the discussion here is couched in terms of GSM, but the disclosed invention is realizable with any suitable type of cellular network.

The principles and operation of a locator system and method according to the present invention may be better understood with reference to the drawings and the accompanying description.

The disclosed invention exploits three factors:

a) The effect of the mobile unit's environment on received satellite signal strength and time of arrival, including the effect of reflection of GPS satellite signals from nearby environmental features;
b) The existence of a computerized center with high-level calculation and information-storage capabilities; and
c) The separate availability of detailed information about geographical and other environmental features.

<u>Effect of the Mobile Unit's Environment</u>

The main environmental consideration is the existence of obstructions to the passage of satellite signals or of reflecting surfaces and the resultant signal attenuation, partial or complete, and delay.

The GPS system's satellites (and similar systems) transmit with known, substantially identical power. Differences in received signal strengths are the results of local factors, such as obstructions or reflecting surfaces, and of satellite elevation and mobile unit antenna directional characteristics.

Attenuation

Several types of obstructions can attenuate the received signal. Examples are depicted in Figure 1, wherein are shown three in-view satellites, **SV_1**, **SV_2**, and **SV_3**, of a GPS constellation and a mobile receiver **10** situated inside a building **100**.

Several ray paths are shown: **130, 140, 150,** and **160**. Of these, ray **130**, from satellite SV_2 arrives unobstructed, directly through window **170**, and is substantially unattenuated.

Ray **150** from SV_1, on the other hand, is blocked by building **110**. In such cases, there is usually no reception of a signal, owing to effectively total attenuation.

In the intermediate case of ray **160** from SV_3, a single wall or roof blocks the line of sight to satellite SV_3. Owing to the sensitive GPS technologies that have recently been developed for mobile telephones, there is a good chance that this signal will be received, but greatly attenuated (~10-20 dB).

Signal Reflection

The effect of reflection of GPS satellite signals from environmental features, such as geographical features, buildings, and other ground features, can include both a delay and, depending on the character of the reflector, attenuation of the signal.

In Figure 1, ray **140** from SV_2 is reflected from a wall of building **120**. Ray **140** happens also to traverse window **170**, and differs from ray **130** only by a time delay and some attenuation due to partial absorption by the reflecting wall of building **120**. This is illustrated in the inset in Figure 1, for a case where the reflecting wall is 50m distant from mobile receiver **10**, resulting in a delay of 166ns.

The phenomenon, whereby reflections are received in the mobile unit, usually together with a signal that arrives *via* a direct line of sight, is called multipath. It is usually regarded as a problem, because it affects the accuracy of location measurement. There are various methods, known in the art, that make it possible to discriminate between a directly received, desired signal and reflected signals. For example, direct and reflected signals can be discriminated by identifying the first and following "peaks" of a signal after correlation with a reference signal. If the reflection is only briefly delayed after the direct ray, discrimination might be done by more sophisticated methods, the best known being the high-resolution MUSIC (multiple signal identification and classification) algorithm. As a by-product of such discrimination, the delay between a direct signal and a reflected signal can be determined, which indicates a distance of the reflecting object from the mobile unit and supplies additional information about the environment wherein this unit is located.

Location Calculation Center

In prior art, a calculation center with high-level calculation and information storage capabilities may exist, as referred to earlier, but be taxed well below capacity. In most cases, the computerized center performs simple location calculations that would normally be performed by the mobile unit, itself.

In the present invention, a location calculation center, **200** Figure 3, includes:

a) A data processor, **300**;
b) A Geographic Information System (GIS), **310**, including detailed maps that include a three-dimensional outline of buildings, as well as known details about reflective and absorptive properties of the surfaces thereof;
c) A program, **320**, for calculating signal attenuation; and
d) A program, **330**, for the calculation of expected reflections of signals from the local environment.

Location calculation center **200** is able to communicate with all base stations, **210** Figure 2, of the cellular network.

Cellular Network

Because mobile unit **10** is also part of a cellular network (represented by cellular network base station **210** in Figure 2), mobile unit **10** has access to other location information, including the identity of the particular cell wherein mobile unit **10** is located (**CELL ID**, equivalent to a geographical area), location of nearby base stations of the cellular network and signal reception strength therefrom, and Timing Advance. As well, cellular networks, themselves, may include positioning procedures that can locate a mobile unit, although not necessarily accurately. Two such methods are called Time of Arrival (TOA) and Enhanced Observed Time Difference (E-OTD).

In TOA, a plurality of base stations listen to handover access bursts from mobile unit **10**, and then triangulate the position thereof. TOA requires equipment and software at the base stations. In E-OTD, mobile unit **10** listens to bursts from a plurality of base stations and measures the observed time difference, the measurements being used to triangulate the position of mobile unit **10**. This requires modifications in mobile unit **10** and is less costly than TOA in terms of supporting infrastructure.

Method of the Present Invention

Mobile unit **10** compiles a set of positioning data, **220** in Figure 2, that is required for location calculation, using methods well known in the art. Positioning data is data related to the calculation of a position of the mobile unit based on signals received from GPS satellites and from a cellular network whereof the mobile unit is part. Positioning data **220** include at least some of the following data, collected or calculated from signals received from GPS satellites and from the cellular network, by mobile unit **10**:

- a) GPS-related data:
  - i) Signal time of arrival (**TOA**) from GPS satellites (equivalent to ranges to satellites);
  - ii) Signal-to-noise ratio (**C/N_0**) of received satellite signals; and
  - iii) Time delays between direct and reflected reception from GPS satellites, where applicable; and
- b) Cellular network-related data:
  - i) CELL ID;
  - ii) Ranges to at least one cellular network base station;
  - iii) Timing advance with respect to at least one cellular network base station (equivalent to a range from that station);
  - iv) Timing relationship between base stations; and
  - v) Received power from local and neighboring base stations.

Positioning data **220** are transferred to calculation center **200** *via* a cellular network base station **210** (stage **400** in Figure 4).

At location calculation center **200**, the most precise location calculation possible, on the basis of the measurement data **220** (a), (b), and (e), is performed by methods well known in the art, stage **410**.

For cellular networks, at least three methods are available and may be used together to try to reduce the imprecisions in each method.

- CELL ID identifies within which cell a mobile unit is located, thus defining a limited geographical area. It may happen, however, that a mobile unit communicates *via* a base station from another cell because the local base station is obscured.
- Timing advance is a measure of the time it takes for a signal to reach a mobile from a base station, and thus of the range from that base station. If signals are received from, or sent by the mobile unit to more than one base station, triangulation may be employed to determine a location.
- Received reception power may be compared with known transmission power thereby inferring a range, by assuming various parameters for propagation losses (terrain, weather, *etc*). As with timing advance, if applied to more than one base station, partial or complete triangulation can be done to determine a location, with more or less precision, depending on the quality of the data.

If the received data are not sufficient for a precise calculation, an approximate calculation is performed using areas intersection, whereby an area of intersection of best estimates is determined. For example, standard GPS location is done by triangulation, using signals from at least four satellites. In case fewer than four satellites are adequately observable, it will be impossible to make the most precise location but an approximate location will be possible; the fewer the available adequate satellite signals, the less the precision. In the worst case, the possible location is defined as the size of the whole local cell of the cellular network (CELL ID).

If only an imprecise location has been calculated, the locations of GPS satellites **SV_1**, **SV_2**, and **SV_3**, *etc* at time of transmission are calculated from pre-known satellite almanac and ephemeris data. Expected attenuations and/or reflections of respective satellite signals are simulated by data processor **300**, stage **420**, for the whole area of location imprecision using GIS system **310** and programs **320** and **330**.

The data thus simulated are compared, stage **430**, with measured data **220** (c) and (d) received from mobile unit **10**. Various methods are available for the comparison ranging from using a simple comparison with threshold to fuzzy logic. It is also possible to exploit adaptive methods while entering feedback from real data.

Stage **430** serves to narrow down the uncertainty about the area wherein the mobile unit is situated. The final calculated location is based on the zone with the highest probability of matching the received signals, or by any similar method.

Some prior art methods in cellular telephony exploit the received power and reflections of cellular network base station signals in a similar manner to the present invention, but the circumstances surrounding the application are different. The principal differences that necessitate an innovative approach when applied to processing GPS signals are:

a) Unlike stationary cellular-network base stations, GPS satellites are moving all the time so that when simulating GPS reception levels, one has to calculate every satellite position at the appropriate times;

b) Cellular network base station transmissions are always from a low altitude and are therefore usually hidden, at least to some extent, from cellular mobile units so that the received transmission usually arrives from reflections only. GPS satellites, on the other hand, can always be found at high altitude. In other words, the data on power and reflections of the signals are less reliable for cellular-network base-station transmissions than for satellite-based transmissions; and

c) Transmissions from cellular base-stations vary power dynamically and received power depends, among other factors, on antenna gain in the relevant direction. In short, received signal power from a base station is unpredictable, in general. By contrast, GPS transmissions are of constant power.

These differences make the process of the present invention different from that used in some cellular networks and make it feasible to apply the method of the present invention to find a location on the basis of received signals to a greater degree of accuracy that is normally possible in cellular networks.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

What is Claimed Is:

1. An apparatus for fixing a location of a mobile unit comprising:

   a) a positioning system including a plurality of satellites, each said satellite emitting a signal receivable by the mobile unit and each said signal being usable by the mobile unit to calculate at least an approximate location of the mobile unit;

   b) a cellular communications network for providing supplementary locating data:

      i) communicating with the mobile unit; and

      ii) having at least one cell, wherein the mobile unit is located, including a base station; and

   c) a mechanism for refining said calculation of said location of the mobile unit.

2. The apparatus of claim 1, wherein said mechanism for refining said calculation includes a location calculation center for simulating received said signals and comparing said simulations with actually received said signals.

3. The apparatus of claim 1, wherein said cellular communications network is a GSM network.

4. The apparatus of claim 2, wherein said location calculation center includes:

i) a geographic information system for providing data for simulating said signal propagation, including data about physical features of an environment wherein the mobile unit is located;

ii) a memory for storing instructions; and

iii) a processor for executing said instructions.

5. The apparatus of claim 4, wherein said data includes data about locations of said physical features, shapes of said physical features, sizes of said physical features, and reflective and absorptive properties, in relation to said signals, of said physical features.

6. The apparatus of claim 2, wherein said location calculation center communicates with the mobile unit through said cellular communications network.

7. A method for fixing a location of a mobile unit comprising the steps of:

a) Providing:

i) a satellite positioning system including a plurality of satellites, each said satellite emitting a signal receivable by the mobile unit and each said signal being usable by the mobile unit, for determining at least an approximate location of the mobile unit; and

ii) a cellular communications network, communicating with the mobile unit, for determining a supplementary estimate of the location of the mobile unit; and

b) Determining at least one probable location area from at least one of said approximate location and said supplementary estimate of said location;

c) Simulating said signals received from said satellite positioning system at a plurality of locations within said at least one probable location area, including effects of environmental features of said probable location area;

d) Comparing said simulated signals with said signals actually received from said satellite positioning system; and

e) Selecting a location having said simulated signals most closely matching said actually received signals as an improved location estimate.

8. The method of claim 7, wherein said cellular communications network has at least one cell, wherein the mobile unit is located, including a base station.

9. The method of claim 8, wherein said cellular communications network is a GSM network.

10. The method of claim 7, wherein said effects of environmental features include absorption and reflection by said environmental features of said signals from said satellite positioning system.

11. The method of claim 7, wherein said effects of environmental features include absorption and reflection by said environmental features of signals from said cellular communications network.

12. The method of claim 7, wherein said simulating includes the step of calculating at least one location of at least one said satellite.

13. The method of claim 12, further including the step of calculating at least one ray path between each said at least one location of at least one said satellite and said plurality of locations within said probable location area.

14. The method of claim 13, further including the step of calculating an attenuation of said signals due to absorption by said environmental features in said calculated at least one ray path.

15. The method of claim 14, further including the step of calculating delays of said signals due to reflection from said environmental features in said calculated at least one ray path.

16. The method of claim 7, wherein said determination of said probable location area is effected by a method of areas intersection.

17. The method of claim 7, wherein said comparing includes comparison of said simulated signals with at least one of:

i) strengths of said actually received signals; and

ii) time delays between directly received said actually received signals and reflected said actually received signals.

18. The method of claim 7, wherein said at least approximate location is determined using said received signals.

19. The method of claim 7, wherein said supplementary estimate of the location is determined by using at least one of:

i) a range from at least one said base station of said cellular network receivable by the mobile unit;

ii) a cell ID of said cell wherein the mobile unit is located;

iii) a reception power of a signal from at least one said base station;

iv) a timing advance; and

v) a timing relationship between said base stations.

20. The method of claim 7, further including providing a location calculation center wherein is performed at least one of said determining of at least an approximate location of the mobile unit and of said determining of said supplementary estimate of the location of the mobile unit.

21. The method of claim 17, wherein the mobile unit communicates with said location calculation center *via* said cellular communications network.

22. The method of claim 7, wherein said simulation is performed in said location calculation center.

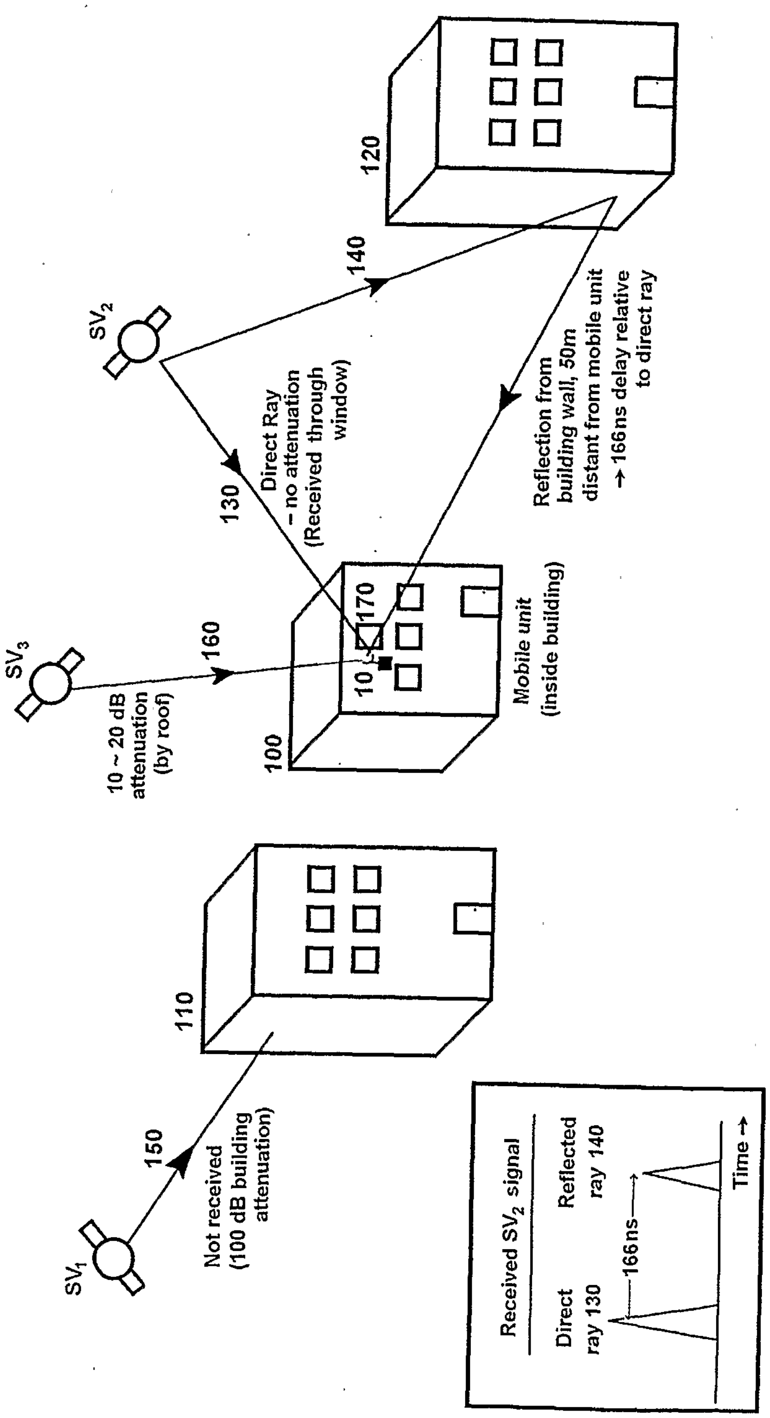

Figure 1 — Transmission paths of GPS signals

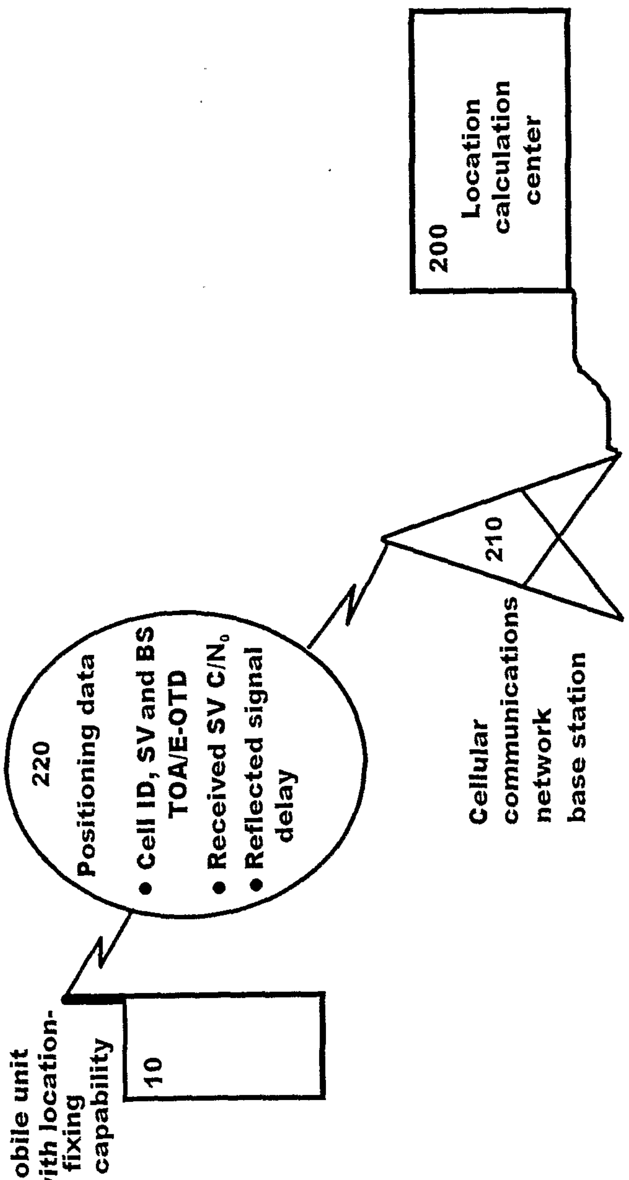

Figure 2 — Principal features of the system

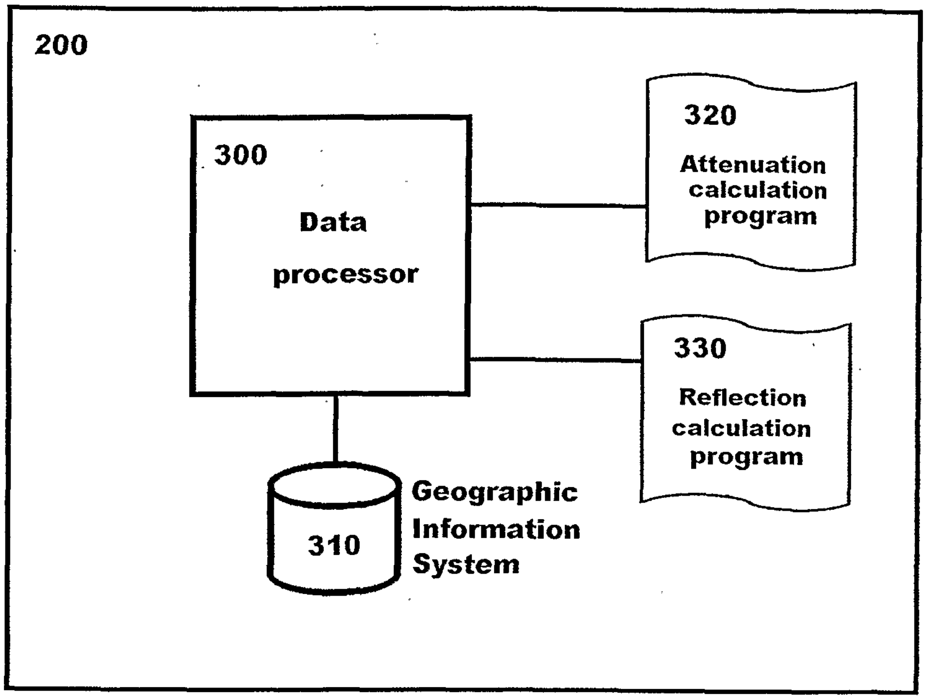

Figure 3 — Detail of calculation center

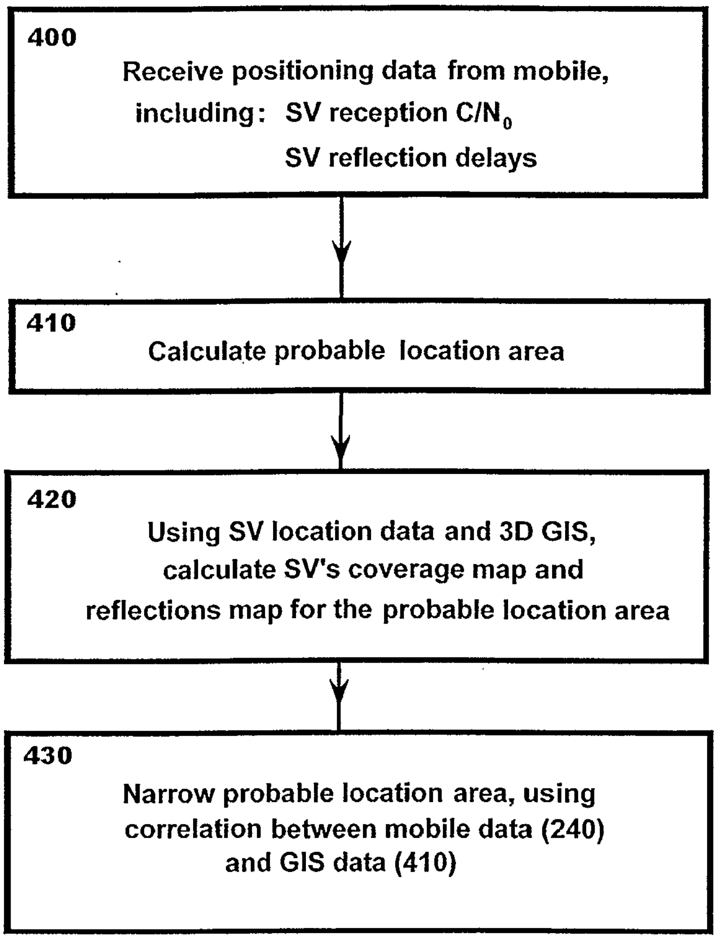

Figure 4 — Process at location calculation center