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(71) Applicant(s):
Sageloc Ltd.
PO BOX 17159, Rishon Le Tsiyon 7565828, Israel

(72) Inventor(s):
Alexander Tyomkin
Evgeny Rubinshtein

(74) Agent and/or Address for Service:
Venner Shipley LLP
200 Aldersgate, LONDON, EC1A 4HD,
United Kingdom

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US 6014101 A1

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(54) Title of the Invention: **System for providing location corrections**
Abstract Title: **System and method for providing GNSS location corrections**

(57) A system 100 for determining location correction information for correcting GNSS data comprises a communication interface (151, fig 2) for receiving GNSS data to be corrected from a plurality of mobile devices 110a/b/c. A storage unit (152) stores the data to be corrected, an indication that each data was obtained at a reference location in a first geographical area and reference GNSS information for each reference location. A processor (153) uses the data to be corrected and the reference GNSS information for the particular reference location to determine location correction information. The mobile device may determine the data to be corrected was obtained at a reference location based upon a user indication or upon reception of a beacon signal located at the reference location. The data may be considered to be obtained at the reference location if it is obtained in the vicinity of 1 to 2 meters from a reference point. An analogous computer-implemented method is also provided.

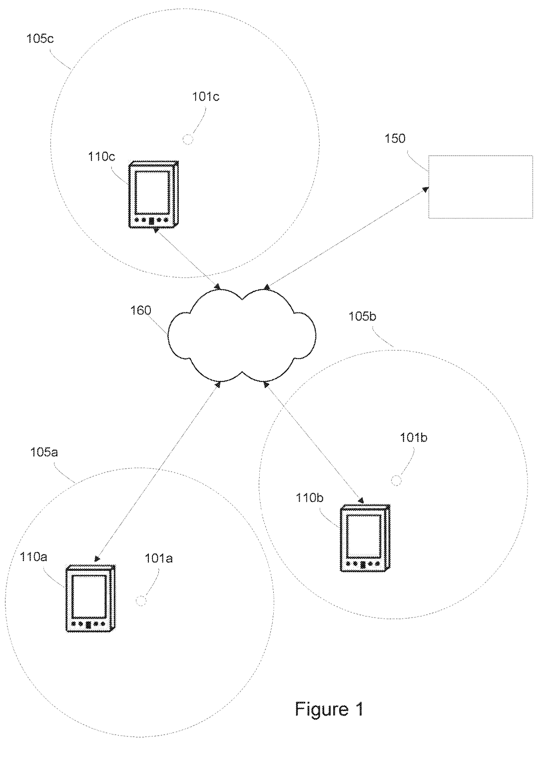

Figure 1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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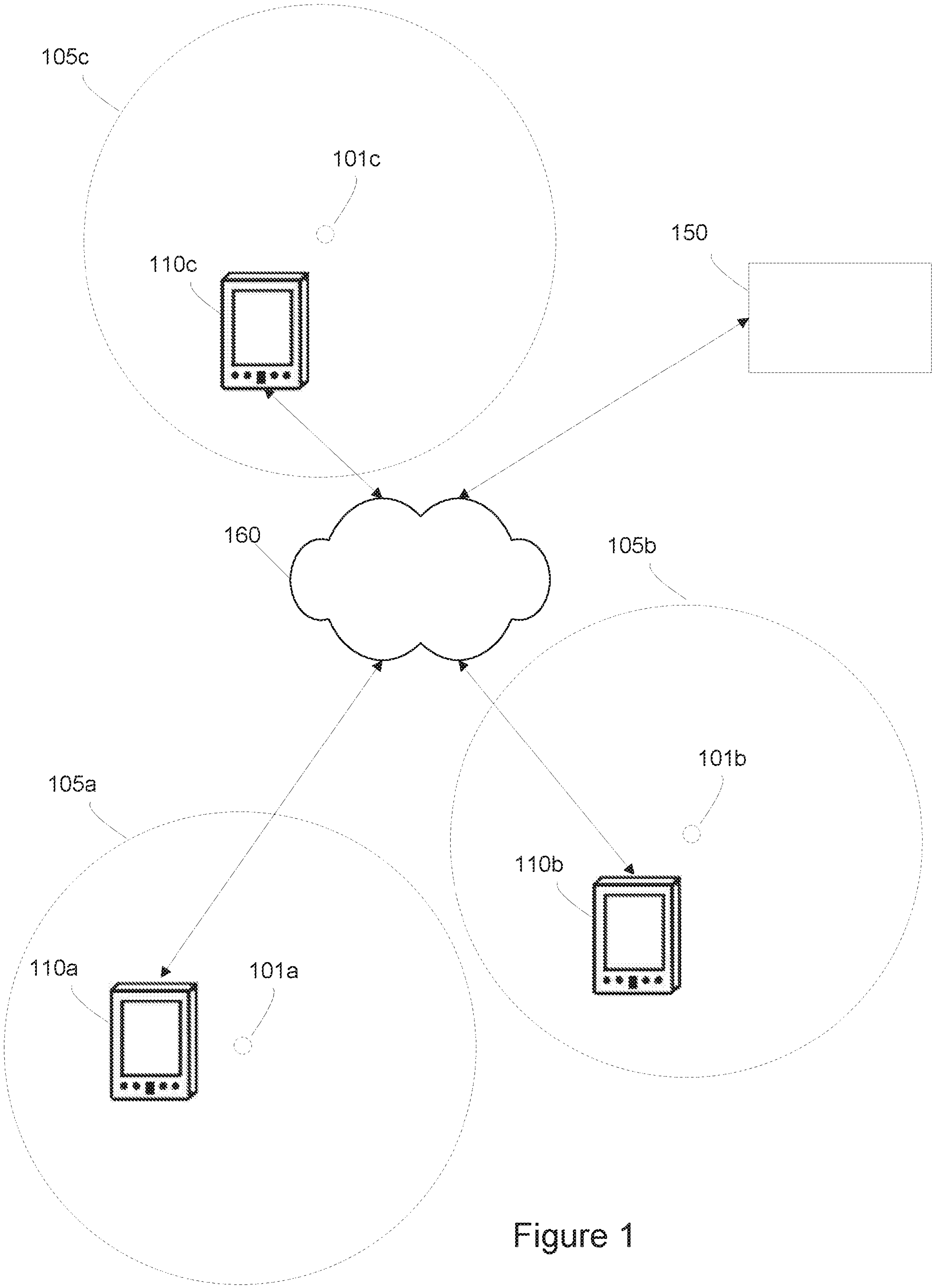

Figure 1

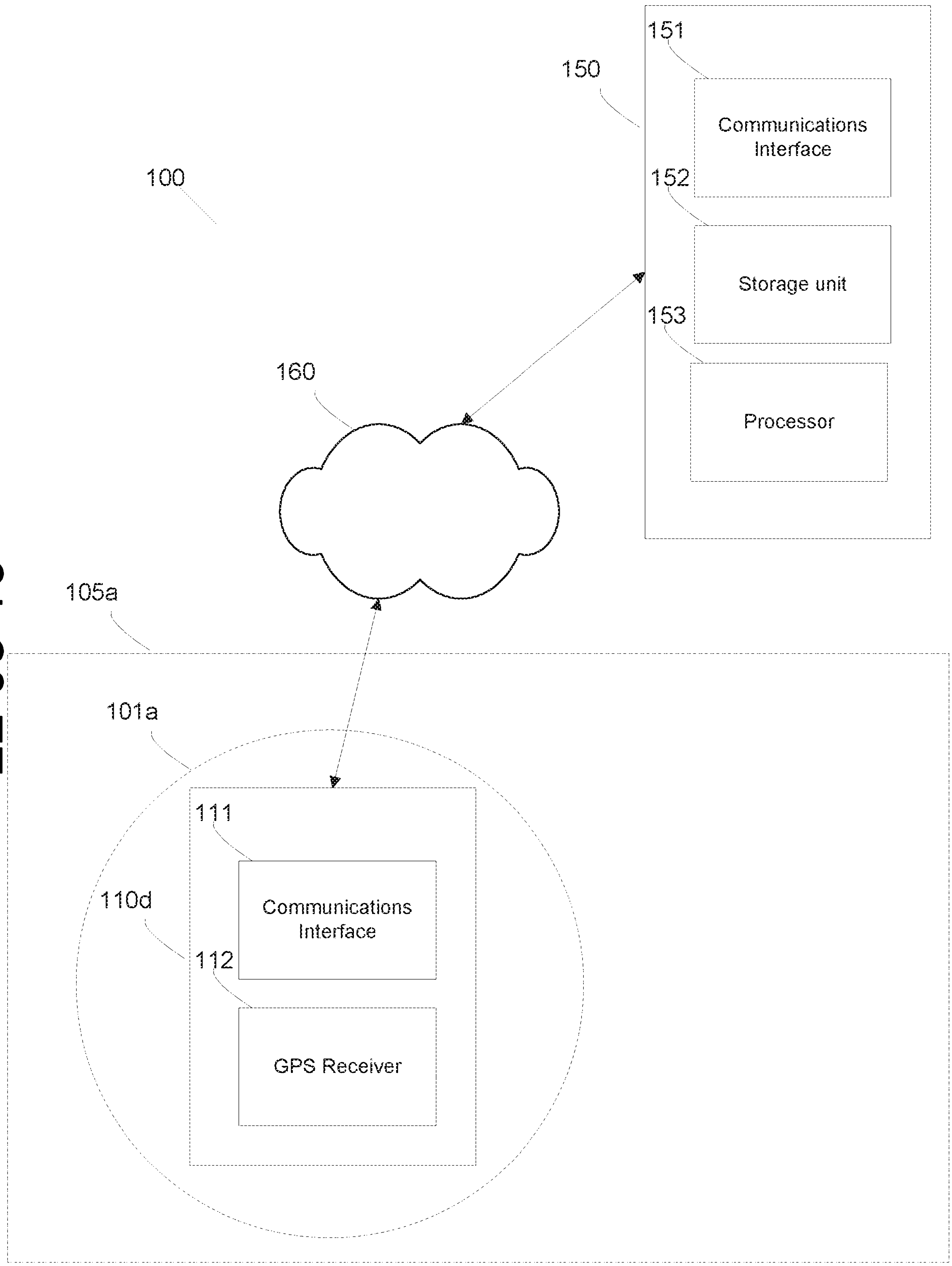
100
150
151
Communications Interface
152
Storage unit
153
Processor
160
105a
101a
111
Communications Interface
110d
112
GPS Receiver

Figure 2

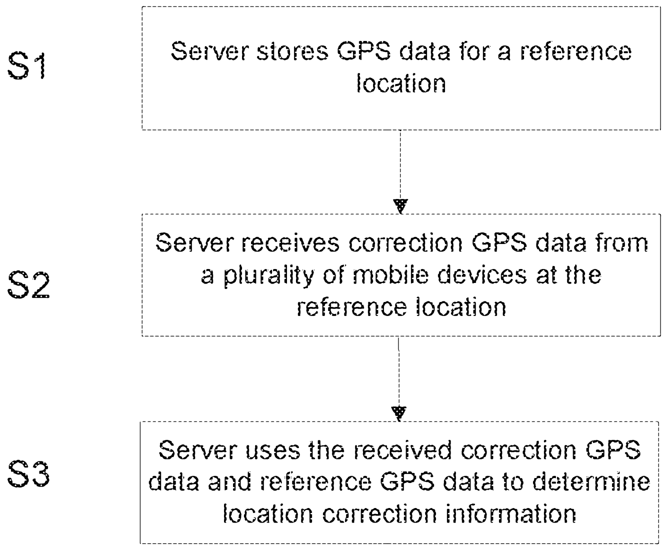

Figure 3

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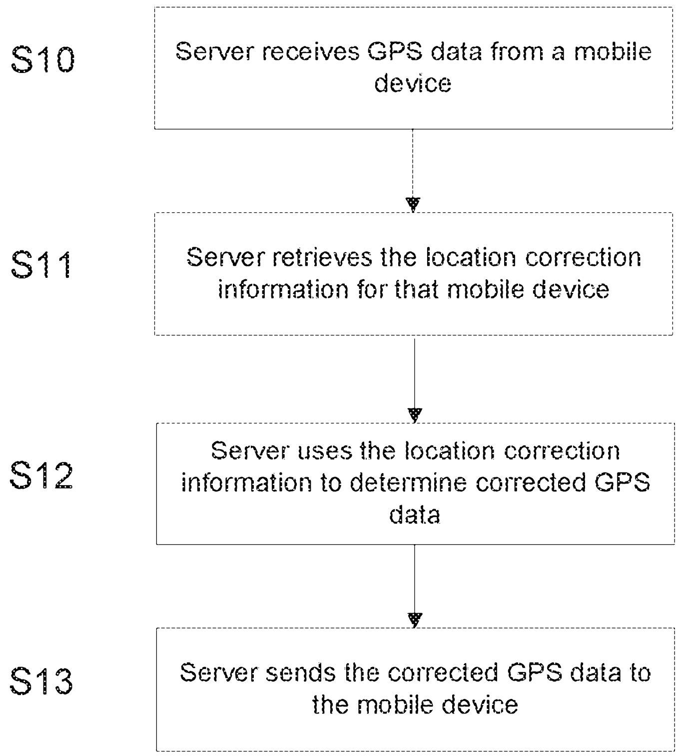
S10
Server receives GPS data from a mobile device
S11
Server retrieves the location correction information for that mobile device
S12
Server uses the location correction information to determine corrected GPS data
S13
Server sends the corrected GPS data to the mobile device

Figure 4

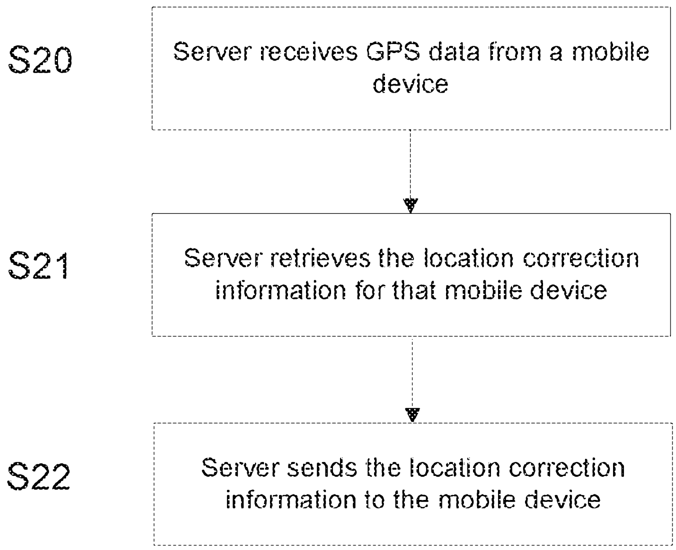
S20
Server receives GPS data from a mobile device
S21
Server retrieves the location correction information for that mobile device
S22
Server sends the location correction information to the mobile device

Figure 5

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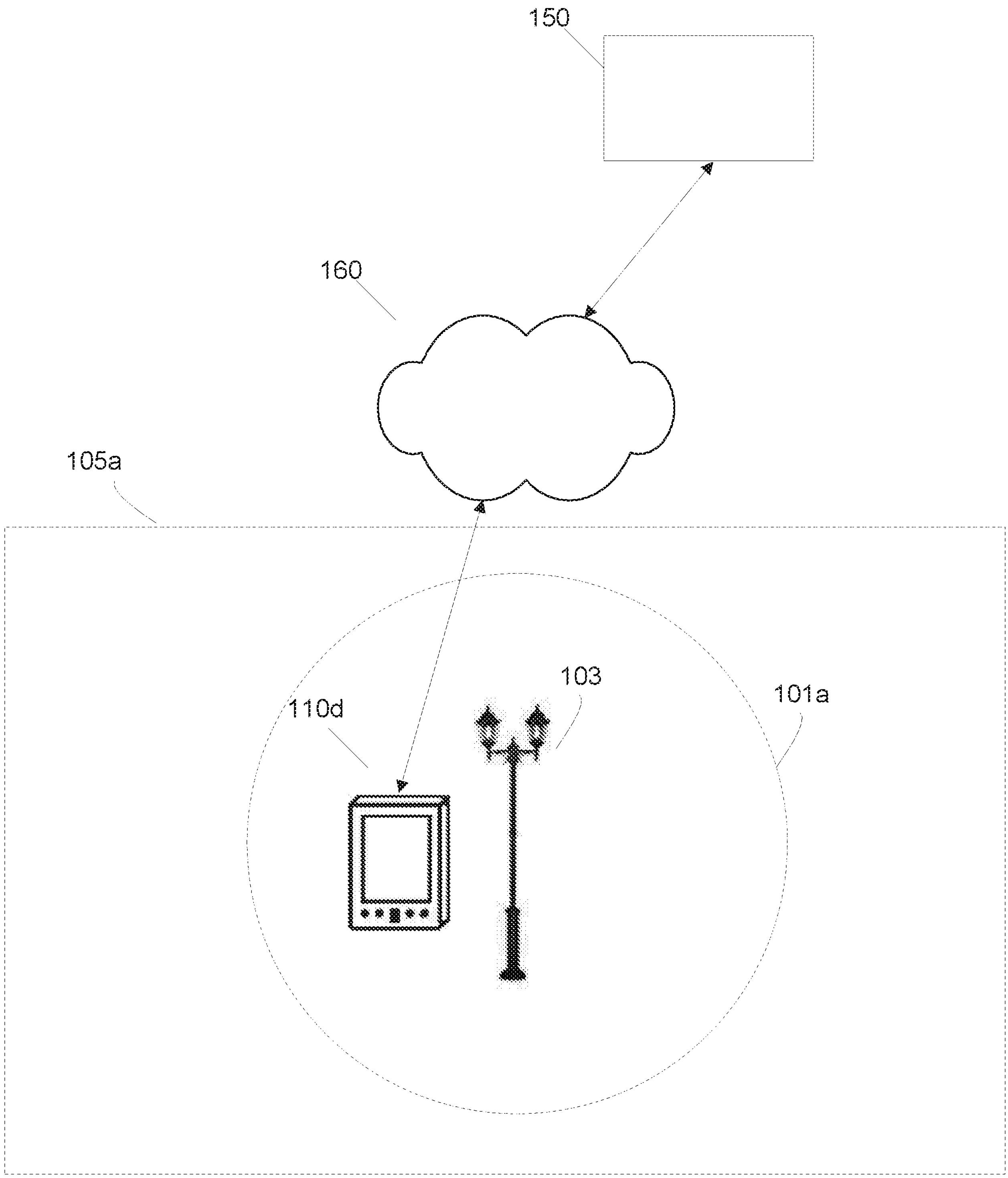

Figure 6

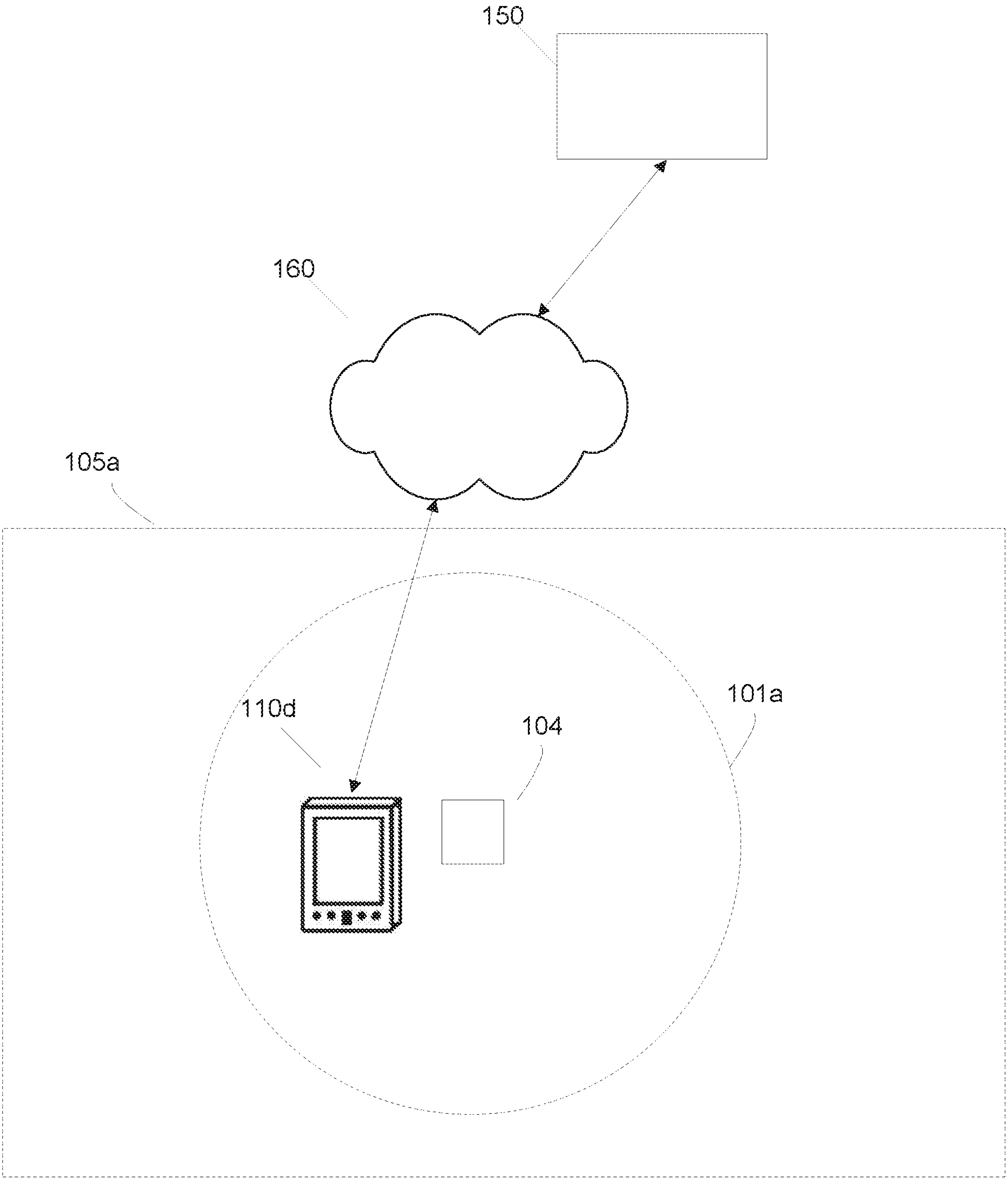

Figure 7

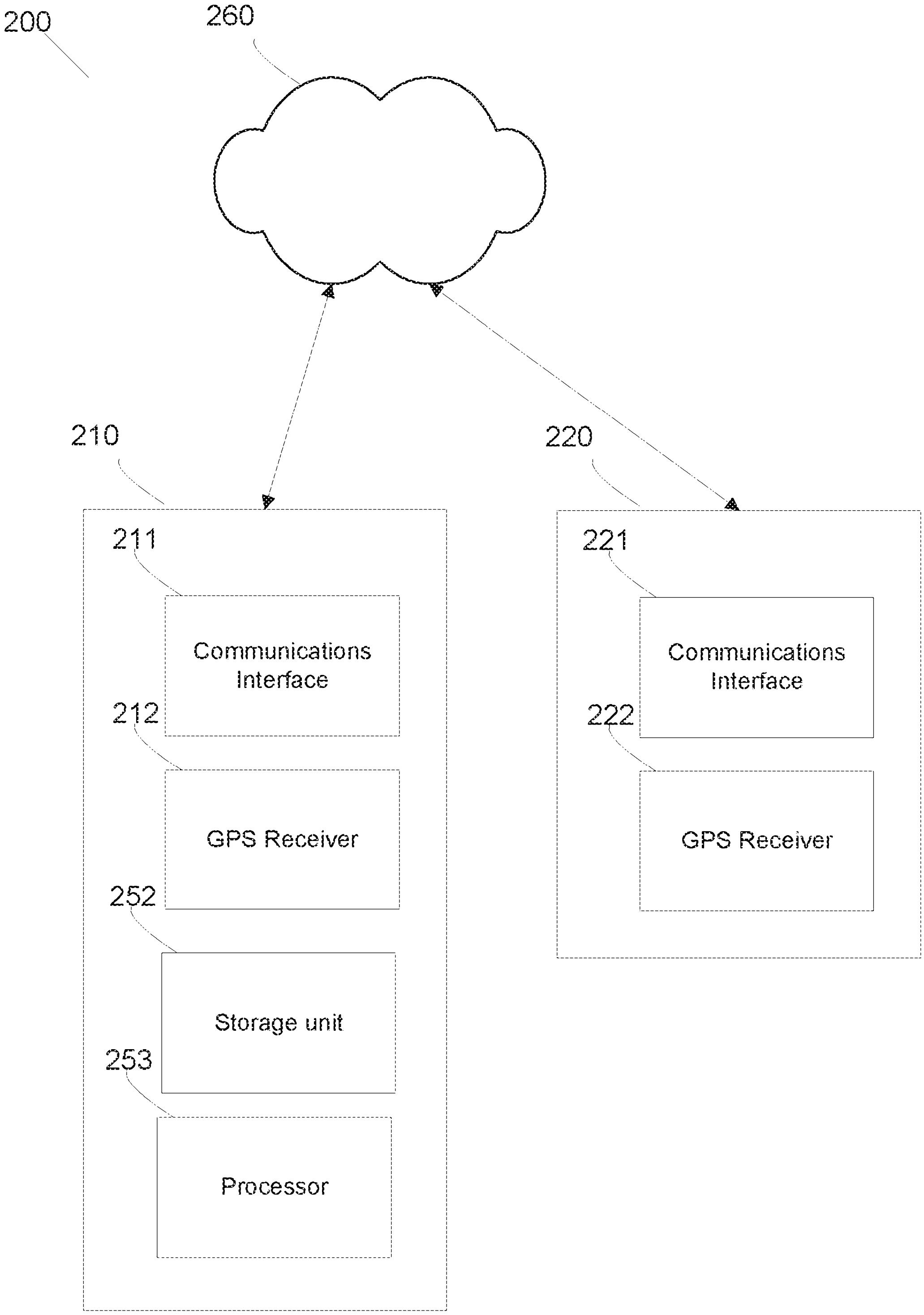

Figure 8

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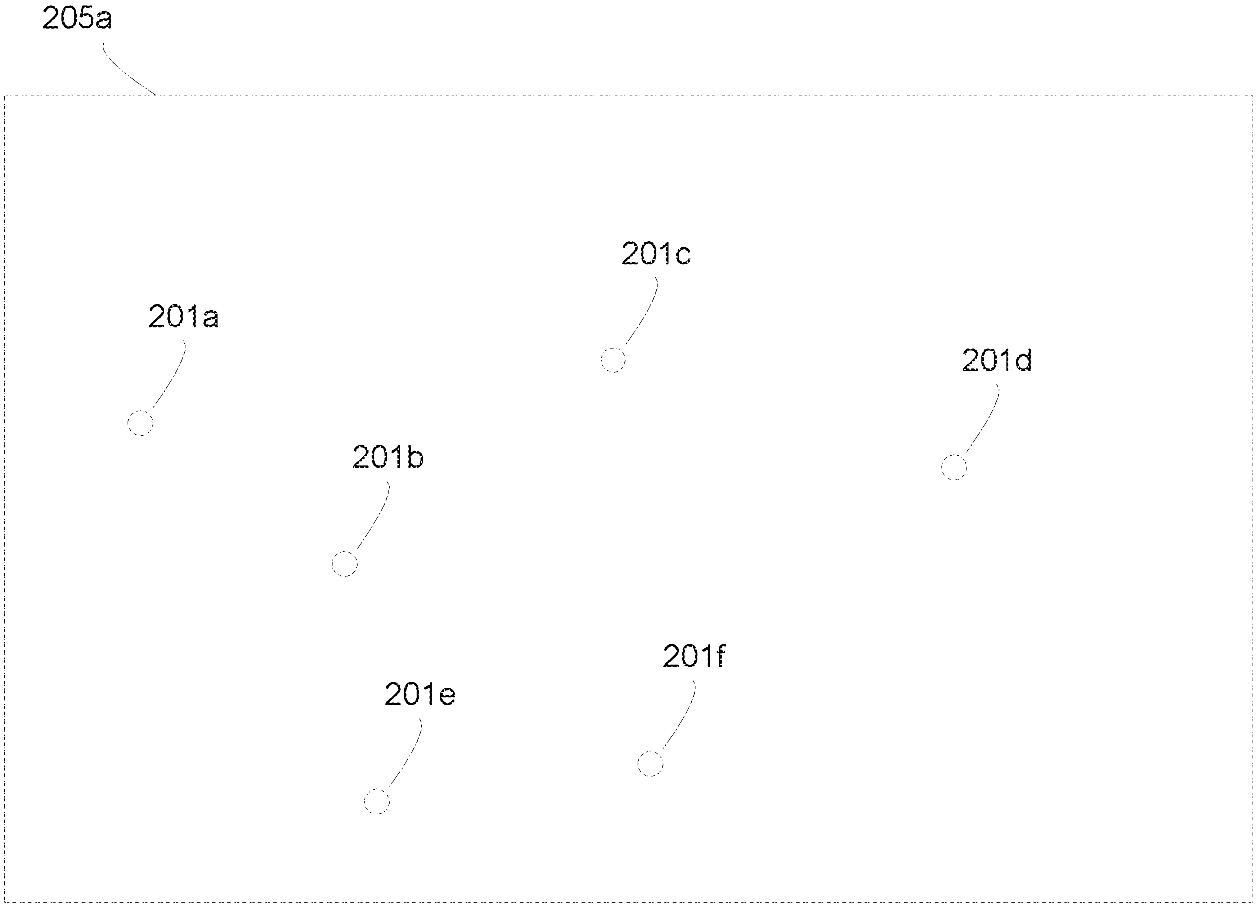

Figure 9

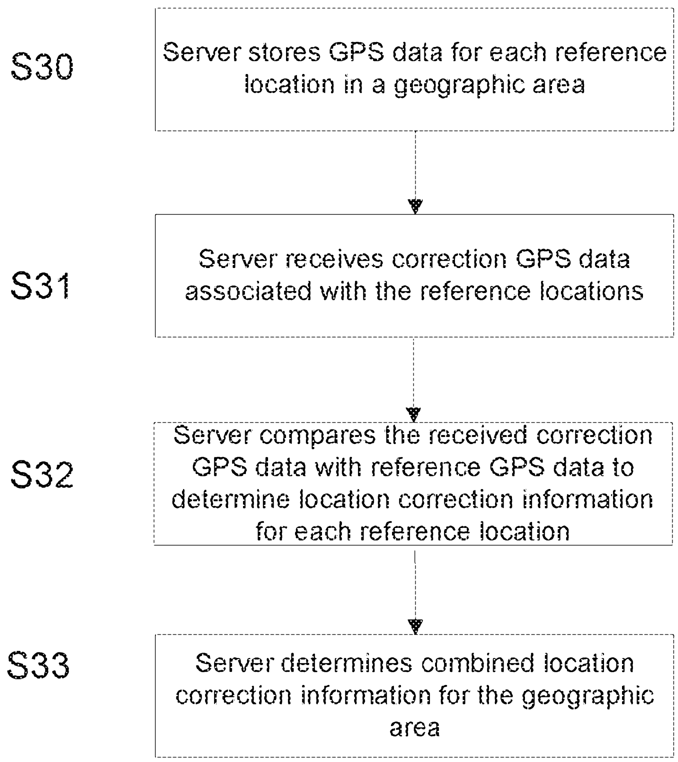
S30
Server stores GPS data for each reference location in a geographic area
S31
Server receives correction GPS data associated with the reference locations
S32
Server compares the received correction GPS data with reference GPS data to determine location correction information for each reference location
S33
Server determines combined location correction information for the geographic area

Figure 10

System for providing location corrections

The present invention relates to a system for correcting position measurements of mobile devices in a Global Navigation Satellite System (GNSS). More particular, the present invention relates to a system, server and mobile device for determining a location correction value for correcting GNSS data.

A GNSS system comprises a plurality of satellites, each of which broadcasts signals to GNSS receivers to allow the GNSS receivers to determine their location. A GNSS receiver can receive information broadcast from multiple GNSS satellites so as to determine a distance between the GNSS receiver and each of the GNSS satellites, and to determine a position of the GNSS receiver based on the determined distances from each satellite and known positions of the satellites.

Examples of GNSS systems include the Global Positioning System (GPS), the Global Navigation Satellite System (GLONASS), the European Galileo system and Chinese BeiDou Navigation Satellite System. Such GNSS systems can be used independently or in combination with one or more other GNSS systems.

A high precision GNSS receiver, such as a receiver of a geodetic reference system or a military receiver can use information received from GNSS satellites to measure its position to an accuracy of less than 1 metre. However, high precision receivers are expensive and are not cost effective for use in many devices, particularly mobile devices such as smartphones.

Cheaper receivers are used in many mobile devices, such as smartphones and tablets. Such receivers have an accuracy of several metres, or even tens of metres. For example, GPS-enabled smartphones are typically accurate to within around 5 metres under an open sky. This accuracy is reduced near to obstructions such as high buildings, bridges and trees.

A number of factors cause errors in the signals received by GNSS receivers, resulting in reductions of accuracy of measured positions of the GNSS receivers. These factors include delays in the transmission of radio waves from GNSS satellites through the troposphere and ionosphere, as well as satellite clock errors, satellite orbit information errors, multipath errors, and receiver noise.

It is an object of the invention to provide a system, server and mobile device that overcomes problems associated with conventional systems and devices.

According to an aspect of the invention, there is provided a system for determining location correction information for correcting GNSS data, the system comprising: a communication interface arranged to receive correction GNSS data from a plurality of mobile devices; a storage unit arranged to store the correction GNSS data from the plurality of mobile devices, to store an indication that each correction GNSS data was obtained at a reference location in a first geographical area, and to store reference GNSS information for each reference location; a processor arranged to determine location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location. The reference GNSS information may be reference GNSS data or may be information usable by the processor for determining reference GNSS data for each reference location.

Each set of correction GNSS data may comprises a set of measured pseudo range values for each satellite obtained by a mobile device. It may be assumed that each individual set of correction GNSS data is inaccurate, and that there are three sources of error: propagation and orbital errors (i.e. atmosphere etc.); measurements point inaccuracy own errors of the mobile devices. The first source of error will be constant for all mobile devices at (or nearby) a reference location. The second and third sources of error can be assumed to be random for devices assumed to be within a certain distance (e.g. less than 1m) from the reference location. It can also be assumed that the second and third sources of error would cause location values to be calculated that are akin to a scatter plot (or cloud of values) with a centre that is the actual location of the reference location. In other words, if many measurements are received from mobile devices at the reference location (e.g. within a certain distance of the reference location), then the second and third sources of error can be corrected for by the system.

In some embodiments, the reference GPS information comprises information for enabling the processor to calculate a set of reference pseudo range values for each satellite at the reference location at a given time, and wherein the correction GNSS data from each mobile device comprises a set of measured pseudo range values; wherein the processor is arranged to, for each satellite, use the measured pseudo range values and the corresponding reference pseudo range value to calculate the location correction information, wherein the location correction information comprises location correction values for each satellite.

In some embodiments, the processor is arranged to, for each satellite, determine an average of the measured pseudo range values, and wherein the processor is arranged to determine the location correction information using the average of the measured pseudo range values and the corresponding reference pseudo range value.

In some embodiments, the processor is arranged to, for each satellite, determine a predetermined percentage of the large values and a predetermined percentage of the small values of the measured pseudo range values, and to discard them from the calculation of the location correction information.

In some embodiments, the processor is arranged to, for each satellite, determine a median value of the measured pseudo range values, and to discard from the calculation of the location correction information any measured pseudo range values that deviate from the median value of the measured pseudo range values by more than a predetermined amount.

In some embodiments, the first geographical area comprises a single reference location, and the location correction information is determined using the correction GNSS data and the reference GNSS information for the reference location.

In some embodiments, the first geographical area comprises a plurality of reference locations, wherein the processor is arranged to determine the location correction information for the first geographical area based on a comparison of the location correction information for each reference location.

In some embodiments, the processor is arranged to use a statistical model with the correction GNSS data to determine the location correction information.

In some embodiments, the processor is arranged to discard from the determination of the location correction information any correction GNSS data that differs from the other correction GNSS data by more than a predetermined amount.

In some embodiments, the processor is arranged to discard from the determination of the location correction information any correction GNSS data that was received more than a predetermined time ago.

In some embodiments, the communication interface is arranged to receive the correction GNSS data along with an indication from each of the plurality of mobile devices that the correction GNSS data was obtained at a reference location.

In some embodiments, each mobile device is arranged to determine that the correction GNSS data was obtained at a reference location on the basis of a user indication received at said mobile device.

In some embodiments, each mobile device is arranged to determine that the correction GNSS data was obtained at a reference location on the basis of the reception of a beacon signal from a beacon located at said reference location.

In some embodiments, the system further comprises the beacon located at the reference location, the beacon being arranged to provide the beacon signal to mobile devices at said reference location.

In some embodiments, the communication interface is arranged to receive GNSS data from mobile devices located at a plurality of different locations in the first geographical area; wherein the processor is arranged to determine that certain GNSS data for a mobile device was obtained at a reference location on the basis of a comparison of the GNSS data for that mobile device at different locations within the first geographical area and at least one of user path information and map information.

In some embodiments, the communication interface is arranged to send information related to the location correction information for the first geographical area to a mobile device in the first geographical area to enable that mobile device to use the location correction information to correct GNSS data received at that mobile device.

In some embodiments, wherein the communication interface is arranged to receive GNSS data from a mobile device in the first geographical area; wherein the processor is arranged to use the location correction information for the first geographical area to correct the received GNSS data from that mobile device; and wherein the communication interface is arranged to send corrected GNSS data to that mobile device.

In some embodiments, the first geographical area is determined on the basis of being within a predetermined distance from a reference location.

In some embodiments, the storage unit is arranged to store reference GNSS information for a plurality of reference locations each associated with a different geographical area; wherein the communication interface is arranged to receive a plurality of sets of correction GNSS data from mobile devices in different geographical areas, and wherein the storage unit is arranged to store indications that each set of received correction GNSS data was obtained at a corresponding reference location; wherein the processor is arranged to determine location correction information for each geographical area using the correction GNSS data and the reference GNSS information for the corresponding reference location.

In some embodiments, the system is arranged to receive GNSS data from a plurality mobile devices located in the different geographical areas, and is arranged to determine the corresponding location correction information for each mobile device based on which one of the different geographical areas each mobile device is located in.

In some embodiments, the system comprises a server mobile device including the communication interface, the storage unit, and the processor.

In some embodiments, the system comprises a plurality of mobile devices; a server comprising the communication interface, the storage unit, and the processor.

According to an aspect of the invention, there is provided a system for determining a location correction value for correcting GNSS data, the system comprising: a communication interface arranged to receive correction GNSS data from a plurality of mobile devices; a storage unit arranged to store the correction GNSS data from the plurality of mobile devices, to store an indication that each correction GNSS data was obtained at a reference location in a first geographical area, and to store reference GNSS data for each reference location; a processor arranged to compare the correction GNSS data with the reference GNSS data for the corresponding reference location to determine location correction information based on the comparison.

According to an aspect of the invention, there is provided a system for determining a location correction value for correcting GNSS data, comprising: a storage unit arranged to store first GNSS data for a first mobile device, an indication that the first GNSS data was obtained at a reference location in a first geographical area, and reference GNSS data for the reference location; a processor arranged to compare the first GNSS data with the reference GNSS data for the reference location to determine location correction information based on the comparison. A communication interface may be arranged to send information related to the location correction information to a second mobile device in the first geographical area to correct GNSS data for the second mobile device.

According to an aspect of the invention, there is provided a system for determining a possible collision event comprising: at least one processor; and a memory storing instructions that, when executed by the at least one processor, cause the system to perform: receiving correction GNSS data from a plurality of mobile devices; storing the correction GNSS data from the plurality of mobile devices and an indication that each correction GNSS data was obtained at a reference location in a first geographical area; storing reference GNSS information for each reference location; determining location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location.

Embodiments of the invention can provide a computer-implemented method for determining location correction information for correcting GNSS data, the method comprising: receiving correction GNSS data from a plurality of mobile devices; storing the correction GNSS data from the plurality of mobile devices and an indication that each correction GNSS data was obtained at a reference location in a first geographical area; storing reference GNSS information for each reference location; determining location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location.

According to an aspect of the invention, there is provided a computer a non-transitory computer-readable medium storing software comprising instructions executable by one or more computers which, upon such executions, causes the one or more computers to perform the method of embodiments of the invention.

Many other features, applications, embodiments, and/or variations of the disclosure will be apparent from the accompanying drawings and from the following detailed description. It should be appreciated that alternative and/or additional implementations of the systems, non-transitory computer readable media, and methods described herein can be employed without departing from the principles of the disclosure.

Embodiments according to the invention are in particular disclosed in the attached claims directed to a system, method and a computer program product, and any feature mentioned in one claim category, e.g. method, can be claimed in another claim category, e.g. system, as well.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows a schematic illustration of a system according to a first embodiment of the invention;
Figure 2 shows a schematic illustration of a system according to the first embodiment of the invention;
Figure 3 shows a flow chart of the operation of the first embodiment;
Figure 4 shows a flow chart of the operation of the first embodiment;
Figure 5 shows a flow chart of the operation of the first embodiment;
Figure 6 shows a schematic illustration of a modification of the first embodiment;
Figure 7 shows a schematic illustration of a modification of the first embodiment;
Figure 8 shows a schematic illustration of a system according to a second embodiment of the invention;
Figure 9 shows a schematic illustration of a system according to an embodiment of the invention; and
Figure 10 shows a flow chart of the operation of an embodiment.

Figure 1 shows a system 100 according to a first embodiment. This embodiment will be described in relation to GNSS data being GPS data. However, embodiments of the invention are not limited to this, and any form of GNSS data (i.e. any type of GNSS system) could be used.

As mentioned above, GPS-enabled smartphones are typically accurate to within around 5 metres under an open sky with a good location of viewed satellites. This accuracy is reduced near to obstructions such as high buildings, bridges and trees.

The main components of measurement error are:

Component	**Typical Error in Meters**
Orbit Errors	0.5
Ionosphere	4.0
Troposphere	0.5
Receiver Noise	0.7
Multipath	0.9

The system 100 comprises a plurality of mobile devices 110a, 110b, 110c, and a server 150. The plurality of mobile devices can communicate with the server 150 via the network 160. It will be appreciated that in practical implementations of embodiments of the invention there may be many such mobile devices, but three such mobile devices will be described in relation to Figure 1 for ease of explanation.

Figure 2 shows more detail regarding one of the plurality of mobile devices and the server 150. The mobile device 110d shown in Figure 2 is located at the reference location 101a, as discussed in more detail below.

The mobile device 110a comprises a communication interface 111 and a GPS receiver 112. The other mobile devices in the system comprise equivalent components. In this embodiment, the mobile device 110a is a smartphone, as are the other mobile devices in the system. However, embodiments of the invention are not limited to this and the mobile devices could be any suitable GPS enabled device (e.g. personal or in vehicle satellite navigation system, tablet, laptop, PDA etc.).

In this embodiment, the mobile devices 110a, 110b, 110c can determine their locations using GPS data obtained by their respective GPS receivers. However, as mentioned above, such GPS receivers are typically only accurate to around 5 m.

The server 150 comprises a communication interface 151, a storage unit 152, and a processor 153. In this embodiment, the server 150 is a single apparatus. However, embodiments of the invention are not limited to this and the server functionality of other embodiments could be provided in more than one connected apparatus.

In this embodiment, the storage unit 152 of the server 150 stores reference GPS information for a plurality of reference locations 101a, 101b, 101c. In this embodiment, each reference location 101a, 101b, 101c corresponds to a respective geographic area 105a, 105b, 105c. It will be appreciated that in practical implementations of embodiments of the invention there may be many such reference locations and geographic areas, but three such combinations of reference location and geographic area will be described in relation to Figure 1 for ease of explanation. Alternatively, in some embodiments, the system may be used with a single reference location within a single geographic area. Furthermore, in some embodiments each geographic area may be associated with a plurality of reference locations.

The reference GPS information comprises information that enables the system to calculate a set of reference GPS data for each satellite at each reference location 101a, 101b, 101c at that time. The reference GPS data is accurate GPS data for each reference location, and (as described in detail below) is used to correct GPS data received at the mobile devices within the geographic area corresponding to each reference location.

In this embodiment, the reference GPS data is derived from reference location coordinates obtained by using a more accurate GPS receiver than those found in mobile devices 110a, 110b, 110c. The reference location coordinates accuracy is, for example, less than 50 cm. Embodiments of the invention are not limited to any specific methodology for obtaining and storing the reference GPS data.

The network 160 in this embodiment is the internet. However, embodiments of the invention are not limited to this and any suitable communications technology could be used.

In this embodiment, the server 150 is arranged to determine location correction information for correcting GPS data within each geographic area 105a, 105b, 105c. The location correction information determined by the server 150 can be used to correct GPS data of the mobile devices in each geographic area 105a, 105b, 105c to provide more accurate location determination.

Conventional systems to improve GPS accuracy may use differential GPS (DGPS), which uses a network of fixed ground-based reference stations to broadcast the difference between the positions indicated by the GPS satellite systems and known fixed positions. These fixed ground-based reference stations broadcast the difference between their own measured satellite pseudo ranges and actual (internally computed) pseudo ranges, and receiver stations may correct their pseudo ranges by the same amount.

Embodiments of the invention can provide more accurate location determination without the use of fixed ground-based reference stations.

The operation of the embodiment discussed in relation to Figure 1 will be explained in relation to the flow chart Figure 3, which shows operations of the server 150 with respect to mobile devices in geographic area 105a, corresponding to reference location 101a. It will, however, be approached that such a process may be performed for all geographic areas and corresponding reference locations in the system.

At step S1, the server 150 stores reference GPS information for the reference location 101a in the storage unit 152. As mentioned above, the reference GPS information enables the server 150 to determine reference GPS data, with is accurate GPS data for the reference location 101a.

At step S2, the communication interface 151 of the server 150 receives correction GPS data from a plurality of mobile devices at the reference location 101a. The term "correction GPS data" is used herein to refer to GPS data that has been obtained by a mobile device located at a reference location in the system. Hence, the "correction GPS data" is GPS data measured by a mobile device at a reference location.

In other words, over a given time period, the server 150 will receive at step S2 multiple sets of correction GPS data from a plurality of mobile devices at the reference location 101a. As a result, the server 150 will obtain multiple measurements of correction GPS data.

It will be appreciated that in practical arrangements, there may be issues with determining that a particular mobile device is precisely at a fixed location (e.g. at the reference location 101a) at the time of measurement of the correction GPS data. Hence, in this embodiment, as illustrated in Figure 2, the reference location 101a is schematically shown a circle within which the mobile device 110d is considered to be at the reference location 101a. Hence, in this embodiment, the correction GPS data is considered to be obtained at the reference location 101a if it is within a first distance (i.e. a certain radius, e.g. 1 m) from the stored coordinates of the reference location 101a. The first distance may be, for example, up to 2 m.

In this embodiment, the server 150 receives the correction GPS data along with an indication that each set of correction GPS data was obtained by a mobile device located at the reference location 101.

As mentioned below, in this embodiment, the indication that the correction GPS data was obtained by a mobile device at the reference location 101a takes the form of a user indication by the user of that mobile device.

In this embodiment, the correction GPS data received by the server 150 from each mobile device at the reference location 101a comprises pseudo range values. For example, considering what is shown in Figure 2, the mobile device 110d obtains pseudo range values based on GPS information received at the GPS receiver 112. The mobile device 110d then sends the pseudo range values to the server 150 using the communications interface 111. It will be appreciated that in some practical arrangements, the correction GPS data may be accompanied by additional data such as satellite number and location, S/N ratio and so on. The list of additional data may be enhanced in accordance with server demands.

However, embodiments of the invention are not limited to the use of pseudo range values, and the mobile devices may send other or additional GPS data to the server. For example, each mobile device may calculate GPS (geodesic) coordinates based on GPS information received at their respective GPS receiver and may send these GPS coordinates to the server 150.

In this embodiment, the reference GPS data for the reference location 101a (calculated from stored reference GPS information) also comprises reference pseudo range values calculated using known both reference location and specific satellite coordinates, though other embodiments may use other types of GPS data. For example, the correction GPS data and the reference GPS data may comprise only geodesic coordinates (i.e. altitude, latitude and longitude).

As a result, prior to step S3, the server 150 has stored for the reference location 101a (corresponding to geographic area 105a), reference GPS data for the reference location 101a, and a plurality of sets of correction GPS data obtained by a plurality of mobile devices at the reference location 101a over a certain time period.

It will be appreciated that if the GPS data received by the GPS receiver of each mobile device were carried out exactly in reference location and were as accurate as the reference GPS data stored at the storage unit 152 of the server 150, then the plurality of sets of correction GPS data obtained by a plurality of mobile devices at the reference location 101a would be equal to zero (or very similar to) in terms of pseudo range delta values to the reference pseudo range values. However, as mentioned above, GPS receivers of mobile devices (e.g. smartphones) are only typically accurate to around 5 m and the measurements are carried out only around reference location within first distance. Hence, it will be appreciated that in practice the pseudo range values of the sets of correction GPS data will not be the same as the reference pseudo range values of the reference GPS data and pseudo range delta values will not be zero.

At step S3, the processor 153 of the server 150 uses the correction GPS data obtained by the plurality of mobile devices and the reference location 101a with the reference GPS data for the reference location 101a to determine location correction values (delta between the measured and the reference pseudo range values. This is done, for example, on a per satellite basis to obtain a set of location correction values that forms location correction information.

In this embodiment, a location correction value may be calculated by averaging the location correction values obtained by using data from the plurality of mobile devices within a certain time period for the reference location 101a. An example of a suitable time period for the correction GPS data is up to 30 minutes depending on satellite orbit. However, other embodiments may use different time periods.

In some embodiments, the location correction value may be obtained periodically (e.g. every second or number seconds) based on the correction GPS data received within a certain previous time period (e.g. the last 30 minutes). Hence, the location correction information may be obtained periodically (e.g. every second or number seconds).

In some embodiments, prior to the averaging the location correction values, those correction GPS data that are outliers are discarded. This is because it will be appreciated that in practical arrangements, users may provide an incorrect indication that GPS data was obtained at the reference location. Hence, accuracy may be improved if outlying data is excluded. In other words, in such embodiments, any pseudo range values (or other GPS data) that deviate from the reference GPS data by more than a predetermined amount are discarded. The “predetermined amount” may be an absolute amount depend on satellite position or a relative amount (i.e. discard anything greater than, for example, 10% depend on correction GPS data quantity).

In other embodiments, the location correction information for the reference location 101a is based on other forms of comparisons of the correction GPS data obtained by the plurality of mobile devices at the plurality of reference locations in the geographic area 105a with the reference GPS data for the corresponding reference location. For example, a more sophisticated statistical model may be used, as discussed in more detail below.

Steps S1, S2 and S3 may be performed for all geographic areas and corresponding reference locations in the system. Hence, considering the illustrative example of Figure 1, the server 150 may obtain separate location correction values for reference location 101a (corresponding to geographic area 105a), reference location 101b (corresponding to geographic area 105b), and reference location 101c (corresponding to geographic area 105c).

The location correction information as calculated above may be accurate for around a distance of 200 km from the reference location 101a. In other words, the main components of measurement error are roughly constant for a distance of around 200 km. Hence, the location correction value calculated on the basis of the corrected GPS data may be used to correct for GPS data for devices located around 200 km from reference location 101a, e.g. defining the geographic area 105a in the form of a circle with a radius of 200 km from the reference location 101a. Hence, for example, the geographic area 105a associated with the reference location 101a may be a circle with a radius of 200 km from reference location 101a.

Furthermore, it will be appreciated that a determined location correction value will only be valid for a certain time period (e.g. up to 30 minutes). This is because it will be appreciated that the various factors that determine the error in the GPS data determined by the mobile devices slowly change with time. Hence, in some embodiments, the server 150 may use the most recently determined location correction value for each geographic area.

Hence, as discussed above, methods according to the invention may involve determining reference GPS data for a reference location. This reference GPS data may be the same data that is stored for a DGPS base station. The reference GPS data may be calculated from reference GPS information that enables the system to calculate a set of pseudo range values for each satellite at the reference location at a given time.

Such methods then comprise receive correction GPS data from a plurality of mobile devices that are approximately at the reference location (e.g. within 1 m). Each set of correction GPS data may comprises a set of measured pseudo range values for each satellite obtained by a mobile device. It may be assumed that each individual set of correction GPS data is inaccurate, and that there are three sources of error:

- propagation and orbital errors;
- measurements point inaccuracy
- own errors of the mobile devices

The first source of error with the “correction GPS data” is the type of GPS errors that DGPS attempts trying to correct (i.e. atmosphere etc.).

The second source of error with the correction GPS data is that it cannot be assumed that an individual set of correction GPS data was measured exactly at the reference location. This is because it can only be assumed that the mobile device is within a certain distance (e.g. < 1m or between 1-2 m) from the reference location. In contrast, the equivalent data to the correction data in a DGPS system (i.e. the measured data at the base station) does not have this source of error because the base station cannot move. This second source of error may be assumed to be random.

The third source of error with the correction GPS data is associated with the GPS receiver of the mobile device. It will be appreciated that consumer mobile devices have larger errors relative to the precise equipment of a DGPS station. The measured data by the GPS receiver of the mobile device will be dependent on the orientation of the mobile device, for example.

The first source of error will be constant for all mobile devices at the reference location. The second and third sources of error can be assumed to be random. It can also be assumed that the second and third sources of error will cause location values to be calculated that are akin to a scatter plot (or cloud of values) with a centre that is the actual location of the reference location. In other words, if many measurements are taken, then the second and third sources of error can be corrected for.

As an example, the correction GPS may comprise pseudo range values for a number of satellites. The server 150 may perform pseudo range correction as detailed below. Consider satellite coordinates$(\boldsymbol{x_s}, \boldsymbol{y_s}, \boldsymbol{z_s})$. A reference location may be consider to have actual (i.e. accurate) coordinates$(\boldsymbol{x_r}, \boldsymbol{y_r}, \boldsymbol{z_r})$. A mobile device that is considered by the system to be “at the reference location” (e.g. within 1 m) may be considered to have the following mobile device coordinates:

$$(\boldsymbol{x_u}, \boldsymbol{y_u}, \boldsymbol{z_u}) = (\boldsymbol{x_r}, \boldsymbol{y_r}, \boldsymbol{z_r}) + (\boldsymbol{\varepsilon_x}, \boldsymbol{\varepsilon_y}, \boldsymbol{\varepsilon_z}) \quad \text{[Equation 1]}$$

where $(\boldsymbol{\varepsilon_x}, \boldsymbol{\varepsilon_y}, \boldsymbol{\varepsilon_z})$ represents errors of user device coordinate relative to reference point coordinates.

The satellite to reference point range may be considered to be:

$$\boldsymbol{R_{sr}} = \sqrt{(\boldsymbol{x_s} - \boldsymbol{x_r})^2 + (\boldsymbol{y_s} - \boldsymbol{y_r})^2 + (\boldsymbol{z_s} - \boldsymbol{z_r})^2} \quad \text{[Equation 2]}$$

For a DGPS system, the satellite to DGPS base station range may be considered to be:

$$\boldsymbol{R_{sd}} = \boldsymbol{R_{sr}} = \sqrt{(\boldsymbol{x_s} - \boldsymbol{x_r})^2 + (\boldsymbol{y_s} - \boldsymbol{y_r})^2 + (\boldsymbol{z_s} - \boldsymbol{z_r})^2} \quad \text{[Equation 3]}$$

For a DGPS system, the satellite to DGPS base station measured pseudo range may be considered to be:

$$\boldsymbol{R_{msd} = R_{sr} + \varepsilon_m} \qquad \text{[Equation 4]}$$

The correlated error (i.e. measurement error: orbital and propagation) is the same for all devices placed around such a DGPS base station up to around 200 km. This error is the correction value to all devices. The correlated error in such a DGPS system could be considered to be:

$$\boldsymbol{\varepsilon_m = R_{msd} - R_{sr}} \qquad \text{[Equation 5]}$$

For the above mentioned embodiments of the invention, the satellite to mobile range may be considered to be:

$$\boldsymbol{R_{su} = \sqrt{(x_s - x_u)^2 + (y_s - y_u)^2 + (z_s - z_u)^2} = R_{sr} + \varepsilon_p} \qquad \text{[Equation 6]}$$

where $\boldsymbol{\varepsilon_p}$ is the mobile device to reference point positional error.

The satellite to mobile device measured pseudo range may be considered to be:

$$\boldsymbol{R_{msu} = R_{sr} + \varepsilon_m + \varepsilon_p + \varepsilon_d} \qquad \text{[Equation 7]}$$

where $\boldsymbol{\varepsilon_d}$ is the mobile device's own GPS receiver error (noise, orientation and so on).

Hence, the difference between range and pseudo range includes additional random errors $\boldsymbol{\varepsilon_p}$ and $\boldsymbol{\varepsilon_d}$.

Using averaging of mass measurements, it is possible reduce these errors to provide increased accuracy:

$$\boldsymbol{mean(R_{msd} - R_{sr}) = mean(\varepsilon_m + \varepsilon_p + \varepsilon_d) = \varepsilon_m + mean(\varepsilon_p + \varepsilon_d) \approx \varepsilon_m}$$

[Equation 8]

Hence, methods according to the present invention can calculate location correction information using the correction GPS data from the plurality of mobile devices and the reference GNSS data for the corresponding reference location. The correction GPS data from the plurality of mobile devices is processed (for example averaging of mass measurements) and then used with the reference GNSS data to produce location correction information. The location correction information comprises a set of correction values for each satellite at that time. The location correction information will need periodic (e.g. every second or few seconds) updating.

The step of determining the location correction information using the correction GPS data from the plurality of mobile devices and the reference GNSS data for the corresponding reference location may be performed in a number of different ways.

For example, the measured pseudo ranges for each satellite may be averaged, and the average may be used to determine location correction values for each satellite using the corresponding reference pseudo range (i.e. using average measured pseudo ranges in an analogous way to using pseudo ranges measured at a DGPS base station). The set of location correction values can be considered to be location correction information for the corresponding geographic region.

In some embodiments, outlying values of the correction GPS data may be discarded from the calculations. This could be done because, given that the system is are dealing with mobile devices and possible user errors (e.g. the user stating the device is at the reference location when it is too far away etc.), not all of the sets of correction GPS data may have actually been received within certain distance (e.g. < 1m) from the reference location. Hence, any data that is clearly incorrect could be discarded to improve accuracy.

This discarding of inaccurate could be done in a number of ways. For example, for each satellite, a predetermined percentage of the large values and a predetermined percentage of the small values may be discarded. For example, the server may be arranged to, for each satellite, determine an average value of the measured pseudo range values , and to discard from the calculation of the location correction information any measured pseudo range values that deviate from the average value of the measured pseudo range values by more than a predetermined amount.

Once, outlying measured pseudo range values for a satellite are discarded, the remaining data could be averaged and used as described above to determine location correction values for each satellite using the corresponding reference pseudo range.

Once location correction information for a reference location corresponding to a geographic area has been obtained it may be used in various different ways in embodiments of the invention. One such use is illustrated with reference to Figure 4.

For ease of illustration, Figure 4 shows operations of the server 150 with respect to a mobile device 110a in geographic area 105a corresponding to reference location 101a. It will, however, be approached that such a process may be performed for all geographic areas and corresponding reference locations in the system.

At step S10, the communication interface 151 of the server 150 receives GPS data from the mobile device 110a in the geographic area 105a via the network 160. The mobile device 110a is located anywhere in the geographic area 105a, rather than at a specific location such as the reference location 101a (though in principle it could be at the reference location 101a). This received GPS data from the mobile device 110a will suffer from all the inaccuracies mentioned above (i.e. the first, second and third sources of error).

At step S11, the processor 153 determines based on the received GPS data from the mobile device 110a which of the stored location correction information is appropriate for mobile device 110a. In other words, the server 150 determines that the mobile device 110a is in geographic area 105a, and therefore that it should use the location correction value calculated with respect to reference location 101a. In other words, while the received GPS data from the mobile device 110a is not as accurate as it could be, it is still clearly accurate enough to determine the corresponding location correction information (e.g. given that location correction information may be accurate for distances of around 200 km).

At step S12, the processor 153 uses the appropriate location correction information to correct the received GPS data from the mobile device 110a. Hence, the processor 153 determines corrected GPS data, which in this embodiment takes the form of a corrected set of pseudo range values.

At step S13, the communication interface 151 sends the corrected GPS data to the mobile device 110a. The mobile device 110a therefore now has more accurate GPS data than the GPS data provided by its own GPS receiver. Hence, location accuracy is improved at mobile device 110a.

In another embodiment that uses the same hardware components as Figures 1 and 2, the method may be modified so that mobile devices that require GPS data correction do not need to send their GPS data to the server 150 each time corrected GPS data is needed. Figure 5 illustrates such an embodiment and shows operations of the server 150 with respect to a mobile device 110a in geographic area 105a corresponding to reference location 101a. It will, however, be approached that such a process may be performed for all geographic areas and corresponding reference locations in the system.

Steps S20 and S21 of Figure 5 are the same as steps S10 and S11 of Figure 4. However, step S22 is performed instead of steps S12 and S13. Hence, in Steps 20 and S21, the server 150 receives GPS data from mobile device 110a (e.g. this may happen once) and retrieves the location correction value related to all visible satellites for mobile device 110a based on which geographic area 105a that mobile device 110a is in. Alternatively, the server 150 may determine which location correction value is appropriate for the mobile device 110a in another way (e.g. based on a user indication).

In step S22, the communication interface 151 of the server 150 sends the location correction value to mobile device 110a. That mobile device 110a then uses the location correction value to correct its own received GPS data received at different locations within the geographic area 105a that it is in.

Again, it will be appreciated that determined location correction information will only be valid for a certain time period (e.g. up to 30 minutes). Hence, in such methods each mobile device may request a new location correction value after a certain time period (e.g. up to 30 minutes) from receipt. It will be appreciated that such a request could take many forms, for example by the mobile device 111a sending GPS data to the server as in step S20.

Each mobile device may request new location correction information if it moves to a different geographic area. Hence, the location correction information sent by the server may be sent with an indication regarding which area is it appropriate for. If the uncorrected GPS data of the mobile device is out of this area, the mobile device may request a new location correction value from the server 150.

Hence, using the methods discussed above can improve the accuracy of GPS measure at mobile devices. Such method can reduce the GPS location error to the level of 1-2 m.

In the above mentioned embodiments, the server 150 receives correction GPS data along with an indication that this correction GPS data was obtained by a mobile device at a reference location (e.g. mobile device 110d at reference location 101a shown in Figure 2). In other words, in such embodiments, this indication is sent to the server 150 by each mobile device at a reference location along with the correction GPS data. In such embodiments, each mobile device may determine that it is at a reference location (e.g. that the mobile device is within a certain radius of the reference location) in a number of ways.

For ease of illustration, considering the mobile device 110d at reference location 101a shown in Figure 2, the mobile device 110d may be arranged to determine that the correction GPS data was obtained at the reference location 101a on the basis of a user indication received at the mobile device 110d. In other words, the user of the mobile device 110d may indicate that the mobile device 110d is at the reference location (or within a certain distance from a set points), and this indication may be sent to the server 150.

For example, the reference location 101a may be set as a publicly known and visible point that a user of the mobile device 110d can identify and approach. Once at the reference location (i.e. within a certain distance, e.g. 1 m, from this publicly known and visible point), the user can input information into the mobile device 110d to inform the mobile device 110d that it is at a reference location.

As an example, as illustrated in Figure 6, the reference location 101a could be defined as being a certain distance of 1 m away from a lamppost 103. A user of the mobile device 110d can identify and approach the lamppost 103. The user can then input information into the mobile device 110d to inform the mobile device 110d that it is in close proximity to the lamppost (e.g. within the certain distance 1 m). For example, the input could be through a touch screen of the mobile device 110d.

Such a user indication may be provided in a variety of different ways. For example, in some embodiments, the user may match an image provided in the augmented reality display with a real world object -e.g. matching a picture in the augmented reality display of an augmented reality image of a bridge with the real world image of the bridge.

As another example, as illustrated in Figure 7, the system may comprise a beacon 104 that is capable of sending beacon signals via short range wireless transmission. For example, the reference location 101a could be defined as being a certain distance of 1 m away from the beacon 104, this certain distance being the short range wireless transmission range of the beacon signal. Hence, on reception of such a beacon signal, the mobile device 110d can determine that it is at the reference location 101d. An example of a suitable short range wireless transmission protocol is Bluetooth, which can be configured to transmit up to 1m radius, but embodiments of the invention are not limited to this.

It will be appreciated that any of the above methods may be combined. For example, the system may comprise a beacon 104 in or on a landmark (e.g. a lamppost) that is capable of sending beacon signals via short range wireless transmission. On reception of a beacon signal, the mobile device 110d may prompt the user to provide a suitable user indication that the mobile device 110d is certain distance (e.g. 1 m) away from the landmark (e.g. a lamppost). For example, the user may be prompted by the mobile device 110d on reception of a beacon signal to enter a “location mode”. In such a location mode, the user of the mobile device 110d may provide a simple user input (e.g. via a touch screen or other user interface) to indicate that the mobile device 110d is the certain distance (e.g. 1 m) away from the landmark. In other embodiments, in such a location mode, the mobile device 110d may display an augmented reality display via its camera, and the user may indicate that the mobile device 110d is the certain distance (e.g. 1 m) away from the landmark using the augmented reality display.

Another option is for determination that the mobile device is at a reference location using corrected device position. The accuracy of corrected device position may be enough for this purpose. This may be performed in an iterative process, with already obtained correction values used to determine location of a mobile device with accuracy about 1m. This may allow the system to determine that the mobile device is located in vicinity of 1 – 2 meters from reference point meaning that the mobile device is at the reference location.

In the some of above mentioned embodiments, the mobile device sending correction GPS data at reference locations send an indication that they are at a reference location along with the correction GPS data. However, embodiments of the invention are not limited to this. In other embodiments, the server 150 may obtain a suitable indication in different ways. For example, the server 150 may determine that a set of received GPS data from a certain mobile device was obtained at a reference location without that mobile device needing to send a suitable indication to the server 150. In other words, the server 150 may automatically determine that mobile devices are at reference locations on the basis of received GPS data, and then store such an automatically determine indication along with the received GPS data as “correction GPS data”.

For example, the server 150 may store information about travel patterns of mobile devices by analysing information received from GPS data from the plurality of mobile devices in the network. Although such received GPS data will be “uncorrected”, the server 150 may use it to determine general patterns of movement. Once the server 150 determines travel patterns of the plurality of mobile devices, it can set a reference location at a specific point within a determined travel pattern, and identify when a mobile device is at the reference location based on the travel pattern of the mobile device.

As an example, the server 150 may store map information and link the stored travel patterns of mobile devices to particular map features in the map information.
For example, the server 150 may determine that a traffic island of a pedestrian crossing falls within a common travel pattern of the mobile devices. The expected pattern for such a situation is that normally a person will arrive to such crossing, stop for few seconds, walk to the traffic island, stop for next few seconds and then walk the remaining half of the crossing. Such a travel pattern can be detected by the server 150, using known path analysis techniques.

A reference location may be placed at the centre of the traffic island. Since normally a traffic island is about 1 m width, it will be enough to measure location of the crossing person anywhere on the island. In case of the person standing at the edge of the island – it is just 1 m off the centre.

It is noted that this method of reference location setting and measurement using only a single pedestrian crossing will serve in only the direction of crossing (i.e. perpendicularly to the road at the crossing point). It is noted that the correction value from this crossing will be only in a certain direction - which can be considered as vector a. In order to calculate an overall multi-direction correction value for this area, the results from the first crossing would be combined with results from a second independent crossing in a similar area (e.g. within tens of kilometres from the first crossing). The second independent crossing would have a direction vector non-collinear to that of the first crossing, - which can be considered as a vector b. A sum of the vector corrections from the two independent crossings can then be combined to calculate an overall correction value R for this area.

Other embodiments could use other ways of automatic detection of mobile devices at reference locations. For example, such automatic detection could be based on known paths taken by the mobile device (e.g. either the user pre-sets a known path between two points on a map, or the server 150 determines the path based on historic movement data). Hence, a known path can be analysed and the server 150 can identify path parts that can serve as a reference location. For example narrow ways, or turns could be used as the position of the mobile device of the user at such points can be inferred more precisely than from the received GPS data alone.

As an alternative or in addition, the server 150 may use map integration features to automatically detect of mobile devices at reference locations. For example, on a narrow straight road segment with single lane in a given direction averaging passing vehicles paths will provide error offset in direction, perpendicular to the road segment direction.

Hence, in general terms, the server 150 may store GPS data for mobile devices at a plurality of different locations, and may determine that the received GPS data was obtained at a reference location (i.e. that it is “correction GPS data”) on the basis of a comparison of the stored GPS data for and stored location information, wherein the stored location information comprising at least one of user path information, map information etc.

Figure 8 shows a system 200 according to a second embodiment. This embodiment will be described in relation to GNSS data being GPS data.

However, embodiments of the invention are not limited to this, and any form of GNSS data could be used.

The system 200 comprises a server mobile device 210 and a plurality of other mobile devices 220. One such mobile device 220 illustrated for simplicity. The mobile device 220 and the server mobile device 210 communicate with each other via the network 260.

Hence, this embodiment differs from the embodiments discussed in relation to Figures 1 to 6 in that there is no separate server. In this embodiment, the “server” functionality is carried out by the server mobile device 210.

The server mobile device 210 comprises a communication interface 211, a GPS receiver 212, a storage unit 252, and a processor 253. The storage unit 252 of the server mobile device 210 stores reference GPS data for a number of reference locations.

The mobile devices 220 each comprise a communication interface 221 and a GPS receiver 222. In this embodiment, both the server mobile device 210 and the other mobile devices 220 are smartphones. However, embodiments of the invention are not limited to this and in other embodiments the mobile devices could be any other GPS enabled device.

The network 260 in this embodiment is the internet. However, embodiments of the invention are not limited to this and any suitable communications technology could be used.

In such embodiments, the server mobile device 210 acts in the same way as the server 150 in any of the above mentioned embodiments. In other words, the server mobile device 210 can obtain a location correction value for one or more geographic areas, and use that location correction value to correct GPS data of other mobile devices (or its own GPS data).

As mentioned above, each geographic area may be associated with one reference location. For example, each geographic area may be defined as a certain radius around each reference location. However, in some embodiments, a geographic area may be associated with more than one reference location. An example of this is shown in Figure 9.

In Figure 9, there is illustrated a geographic area 205a associated with reference locations 201a, 201b, 201c, 201d, 201e, and 201f. The geographic area 205a may, for example, have an area of 200 square miles, and the reference locations 201a, 201b, 201c, 201d, 201e, and 201f may be distributed within this area.

By providing a plurality of reference locations for the geographic area 205a, the system may obtain location correction information for the geographic area 205a based on a combination of the sets of location correction information calculated for each reference location 201a, 201b, 201c, 201d, 201e, and 201f. Such a method is illustrated in Figure 10.

At step S30, the server (e.g. a dedicated server or a mobile device acting as server) stores reference GPS data for each reference location 201a, 201b, 201c, 201d, 201e, and 201f in the single geographic area 205a.

At step S31, the server receives correction GPS data from at least one mobile device at each of the plurality of reference locations 201a, 201b, 201c, 201d, 201e, and 201f.

At step S32, the server compares the received correction GPS data for each of the plurality of reference locations 201a, 201b, 201c, 201d, 201e, and 201f with corresponding reference GPS data to determine a separate location correction value for each reference location 201a, 201b, 201c, 201d, 201e, and 201f. In other words, the server obtains separate location correction information for each of the plurality of reference locations using received correction GPS data and the corresponding reference GPS data.

Hence, following step S32 the server will have a plurality of separate location correction information.

At step S33, the server determines combined location correction information for the geographic area based on a comparison of the plurality of location correction values. For example, the server may average the plurality of location correction values (e.g. for each satellite) from the sets of location correction information to obtain a location correction information for the geographic area.

Another way to calculate location correction value based on all correction GPS data received from all reference location is to process together all the delta between the measured pseudo ranges and the relevant reference pseudo ranges which are to be sum of a propagation and measurement errors (for example, averaging of all delta is about propagation error for area 205a).

In general, each geographic area may have a large set of reference locations P*i* with known locations. These reference locations need not be ordered and their amount and geographic location may be determined by different conditions.

Each reference location P*i* is defined by coordinates and vicinity Li (e.g. approximately 1 m) around a point, in which measurements are considered valid. For different reference locations vicinity can have different size but will normally not exceed 2m.

Reference locations P*i* along with its vicinity L*i* may be referred to as network "node" N*i*. Information about the nodes N*i* is stored at the server and if required can be transmitted to network users (e.g. mobile devices). The arrangement of nodes N*i* may be an open system in the sense that reference locations P*i* may be freely added and removed.

In addition, when determine the location correction information, embodiments of the invention can use a "statistical model", which defines statistical processing of mass measurements. Such models may include selection, multipath removal and averaging for the measured pseudo range values or delta between the measured and the reference pseudo ranges. However, such models can also include any relevant algorithm that will allow further improving of estimate of correlated error.

Due to quasi stationary nature of estimate of correlated error, such a statistical model may allow co-processing of measurements received in timeframe of $\Delta T < 30$ minutes. Any mobile devices, which in any time are located at a node N*i*, i.e. at distance $l < L$ from a reference location P*i* may be considered to be part of the system as they carry out measurements needed for calculation of estimates of correlated error by statistical model.

Such a “statistical model” may be implemented in a number of ways. For example, a suitable statistical model may carry out the following steps:

1. Selection by error level for eliminating measurement mistakes and large multipath factors
2. Time selection. Taking into account time of correlated error factors changes, only measurements that belong to ΔT interval are selected.
3. Averaging of pseudo range errors (delta between the measured and the reference pseudo ranges) of all measurements in ΔT interval – separately for every reference location and device type. In addition, if required, averaging can be done by group of users, preselected by certain criteria.
4. Estimating multipath factor by comparing pseudo range from different nodes Ni and taking into account local geodesic conditions and landscape.
5. Deriving specific receiver type error by taking into account mobile device type of every measurement.
6. Due to moving average usage the model is first initialized with averaging on a shorter interval than ΔT. Once the system is on for ΔT time, averaging is done on ΔT interval.

Typically, all position measurements may be carried out one time per second. All pseudo ranges measured in the same time in all nodes Ni of the system placed in vicinity less then approximately 100 km are processed using the statistical model. The early received pseudo ranges are processed together with new ones as well.

As discussed, embodiments of the invention can provide a system for determining location correction information for correcting GNSS data, the system comprising: a communication interface arranged to receive correction GNSS data from a plurality of mobile devices; a storage unit arranged to store the correction GNSS data from the plurality of mobile devices, to store an indication that each correction GNSS data was obtained at a reference location in a first geographical area, and to store reference GNSS information for each reference location; and a processor arranged to determine location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location.

The above described embodiments can allow for reaching low GNSS location error levels using low accuracy GNSS devices. Some advantages of such methods are unlimited number of users (mobile devices), and a wide network of reference locations with known location which provide mass measurements to the system. Also, compared to DGPS systems, no fixed base stations are required.

In such embodiments, it is possible to define any number of reference locations as there are no requirements relating to additional equipment, all that is required – an accurate definition of point location. Large number of measurements with subsequent processing, e.g. based on appropriate statistical model, allow such embodiments to reach the required level of correlated error.

It will be appreciated that there is a typically a problem with conducting measurements by network users, which we can refer to as “uncontrolled measurements”.
For measurements done by regular users (e.g. smart phone users) and not by service personal, this can lead to additional source of “random” measurement errors. For instance, in systems such as those described above such “random” measurements errors could potentially be caused by:

- a user’s inability to conduct the measurement exactly at the reference location. In reality measurements are done in a random point, located in some proximity of the reference point
- device (and GNSS antenna) orientation is random, which affects measurement point and received signal parameters
- different types of GNSS receivers, with different specifications
- multipath.

There might exist other causes for the error, which from the stand point of such systems will still have random nature. For example – the noise of each GNSS receiver, which may depend on its electronic parts. Such errors may be referred to as “network own errors” (“inherent network errors”).

For solving the problem of reducing “network own errors”, the above system may use correction GNSS data from a plurality of mobile devices and reference GNSS data for one or more reference locations for a certain geographical area. Based on such a comparison (e.g. using an appropriate statistical model), the system may provide a location correction value for the geographical area. The location correction value can be used to correct GNSS data to achieve accuracy levels of 1-2 m.

The term “server” has been used for convenience. However, it will be appreciated that the functionality of the “servers” in the present disclosure could be carried out by one of more computers.

Embodiments of the invention can provide a system for determining location correction information for correcting GNSS data, the system comprising: a communication interface to receive correction GNSS data from a plurality of mobile devices; a storage unit to store the correction GNSS data from the plurality of mobile devices, to store an indication that each correction GNSS data was obtained at a reference location in a first geographical area, and to store reference GNSS information for each reference location; and a processor arranged to determine location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location. Such a system may be implemented by one or more computers.

Embodiments of the invention can provide a computer-implemented method for determining location correction information for correcting GNSS data, the method comprising: receiving correction GNSS data from a plurality of mobile devices; storing the correction GNSS data from the plurality of mobile devices and an indication that each correction GNSS data was obtained at a reference location in a first geographical area; storing reference GNSS information for each reference location; determining location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location.

Embodiments of the invention can provide a computer a non-transitory computer-readable medium storing software comprising instructions executable by one or more computers which, upon such executions, causes the one or more computers to perform the method of embodiments of the invention.

Examples of computer-readable media include both volatile and non-volatile media, removable and non-removable media, and include, but are not limited to: solid state memories; removable disks; hard disk drives; magnetic media; and optical disks. In general, the computer-readable media include any type of medium suitable for storing, encoding, or carrying a series of instructions executable by one or more computers to perform any one or more of the processes and features described herein.

Many further variations and modifications will suggest themselves to those versed in the art upon making reference to the foregoing illustrative embodiments, which are given by way of example only, and which are not intended to limit the scope of the invention, that being determined by the appended claims.

Claims

1. A system for determining location correction information for correcting GNSS data, the system comprising:

a communication interface to receive correction GNSS data from a plurality of mobile devices;

a storage unit to store the correction GNSS data from the plurality of mobile devices, to store an indication that each correction GNSS data was obtained at a reference location in a first geographical area, and to store reference GNSS information for each reference location; and

a processor arranged to determine location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location.

2. A system according to claim 1, wherein the reference GPS information comprises information for enabling the processor to calculate a set of reference pseudo range values for each satellite at the reference location at a given time, and wherein the correction GNSS data from each mobile device comprises a set of measured pseudo range values;

wherein the processor is arranged to, for each satellite, use the measured pseudo range values and the corresponding reference pseudo range value to calculate the location correction information, wherein the location correction information comprises location correction values for each satellite.

3. A system according to claim 1 or 2, wherein the processor is arranged to, for each satellite, determine an average of the measured pseudo range values, and wherein the processor is arranged to determine the location correction information using the average of the measured pseudo range values and the corresponding reference pseudo range value.

4. A system according to any one of claims 1 to 3, wherein the processor is arranged to, for each satellite, determine a predetermined percentage of the largest values and a predetermined percentage of the smallest values of the measured pseudo range values, and to discard them from the calculation of the location correction information.

5. A system according to any preceding claim, wherein the first geographical area comprises a single reference location, and the location correction information is determined using the correction GNSS data and the reference GNSS information for the reference location.

6. A system according to any one of claims 1 to 5, wherein the first geographical area comprises a plurality of reference locations, wherein the processor is arranged to determine the location correction information for the first geographical area using the location correction information for each reference location.

7. A system according to any one of claims 1 to 6, wherein the processor is arranged to use a statistical model with the correction GNSS data to determine the location correction information.

8. A system according to any one of claims 1 to 7, wherein the processor is arranged to discard from the determination of the location correction information any correction GNSS data that differs from the other correction GNSS data by more than a predetermined amount.

9. A system according to any one of claims 1 to 8, wherein the processor is arranged to discard from the determination of the location correction information any correction GNSS data that was received more than a predetermined time ago.

10. A system according to any one of claims 1 to 9, wherein the communication interface is arranged to receive the correction GNSS data along with an indication from each of the plurality of mobile devices that the correction GNSS data was obtained at a reference location.

11. A system according to claim 10, wherein each mobile device is arranged to determine that the correction GNSS data was obtained at a reference location on the basis of a user indication received at said mobile device.

12. A system according to claim 11, wherein each mobile device is arranged to determine that the correction GNSS data was obtained at a reference location on the basis of the reception of a beacon signal from a beacon located at said reference location.

13. A system according to claim 12, wherein the system further comprises the beacon located at the reference location, the beacon being arranged to provide the beacon signal to mobile devices at said reference location.

14. A system according to any one of claims 1 to 12, wherein the communication interface is arranged to receive GNSS data from mobile devices located at a plurality of different locations in the first geographical area;

wherein the processor is arranged to determine that certain GNSS data for a mobile device was obtained at a reference location on the basis of a comparison of the GNSS data for that mobile device at different locations within the first geographical area and at least one of user path information and map information.

15. A system according to any one of claims 1 to 14, wherein the communication interface is arranged to send information related to the location correction information for the first geographical area to a mobile device in the first geographical area to enable that mobile device to use the location correction information to correct GNSS data received at that mobile device.

16. A system according to any one of claims 1 to 15, wherein the communication interface is arranged to receive GNSS data from a mobile device in the first geographical area;

wherein the processor is arranged to use the location correction information for the first geographical area to correct the received GNSS data from that mobile device; and

wherein the communication interface is arranged to send corrected GNSS data to that mobile device.

17. A system according to any one of claims 1 to 16, wherein the first geographical area is determined on the basis of being within a predetermined distance from a reference location.

18. A system according to any one of claims 1 to 17, wherein the storage unit is arranged to store reference GNSS information for a plurality of reference locations each associated with a different geographical area;

wherein the communication interface is arranged to receive a plurality of sets of correction GNSS data from mobile devices in different geographical areas, and wherein the storage unit is arranged to store indications that each set of received correction GNSS data was obtained at a corresponding reference location;

wherein the processor is arranged to determine location correction information for each geographical area using the correction GNSS data and the reference GNSS information for the corresponding reference location.

19. A system according to claim 18,

wherein the system is arranged to receive GNSS data from a plurality mobile devices located in the different geographical areas, and is arranged to determine the corresponding location correction information for each mobile device based on which one of the different geographical areas each mobile device is located in.

20. A system according to any one of claims 1 to 19, comprising a server mobile device including the communication interface, the storage unit, and the processor.

21. A system according to any one of claims 1 to 19, comprising:

a plurality of mobile devices;

a server comprising the communication interface, the storage unit, and the processor.

22. A computer-implemented method for determining location correction information for correcting GNSS data, the method comprising:

receiving correction GNSS data from a plurality of mobile devices;

storing the correction GNSS data from the plurality of mobile devices and an indication that each correction GNSS data was obtained at a reference location in a first geographical area;

storing reference GNSS information for each reference location;

determining location correction information using the correction GNSS data and the reference GNSS information for the corresponding reference location.

23. A non-transitory computer-readable medium storing software comprising instructions executable by one or more computers which, upon such executions, causes the one or more computers to perform the method of claim 22.

Intellectual Property Office

Application No:	GB1802902.5	**Examiner:**	Mr Henry Nevell
Claims searched:	1-23	**Date of search:**	11 July 2018

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-3, 5-7, 10, 14-23	WO00/65367 A1 (GLOBAL LOCATE) See particularly page 25 lines 5-28
X	1-3, 5-7, 10, 14-23	WO2004/036240 A2 (QUALCOMM) See particularly end of paragraph 1024
X	1-3, 5-7, 10, 14-23	US6014101 A1 (LOOMIS) See particularly col 8 lines 52-66

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G01S; H04W

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC, Patent Fulltext

International Classification:

Subclass	Subgroup	Valid From
None		