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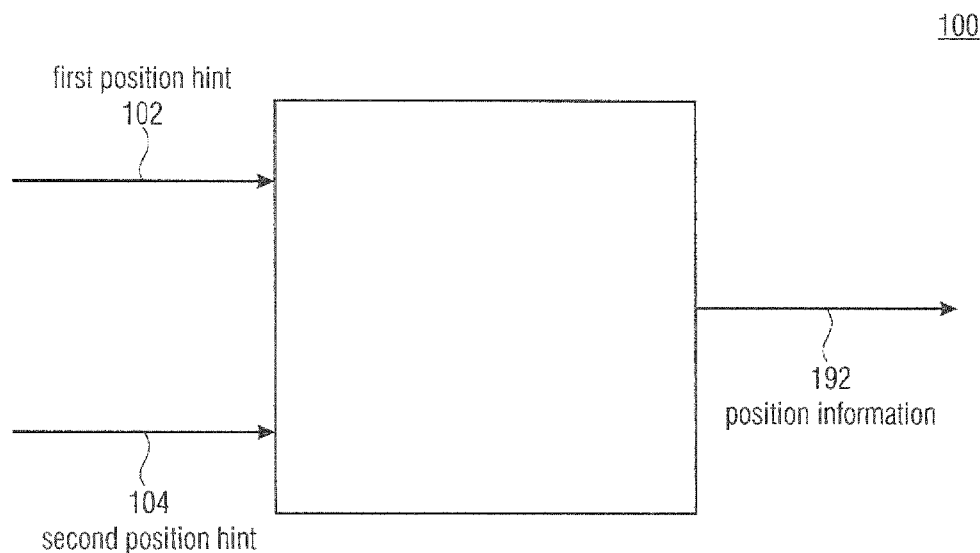


Fig. 1

(57) Abstract: An apparatus for determining a position of a device, wherein the apparatus is configured to obtain a first position and a second position, wherein the position hints each comprise an information about a position and shape of a respective multidimensional geometric region and an information about a presence of the device in the respective multi-dimensional geometric region. The apparatus is configured to provide a position information of the device based on the first position hint and the second position hint.



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Apparatus and Method for Determining a Position of a Device

Description

Embodiments of the present invention relate to apparatuses and methods for determining a position of a device

Background of the Invention

Contextual information is envisioned to play a key role in all layers of the communication stack [1] [2] [3]. In particular, many proposals for the optimization of networks with respect to the latency, the throughput, and the robustness of wireless links are increasingly assuming the availability of information about the position of network elements (e.g., base stations and user equipment) [2]. As a result, algorithms for node localization have received a great deal of attention in recent years [4].

In the literature, localization schemes typically produce estimates of the position of a network element by using the following assumptions:

- (i) there is only one type of signal (e.g., a wireless reference signal);
- (ii) sensors are homogenous (e.g., radio signals impinge on antennas of the same type); and
- (iii) estimates are computed with a particular algorithm (e.g., a maximum likelihood algorithm).

However, with the recent advances in computational power and sensor technology, schemes based on the above assumptions do not exploit the full potential of current and future networks. In particular, one of the major limitations of the sole use of single-sensor single-signal schemes is that the uncertainty of estimates can be too high if the signal used for localization is too weak because of, for example, noise or the vagaries of wireless channels.

For example, the LTE positioning protocol (LPP) and the signaling schemes described in [9] rely on different approaches such as OTDOA, A-GNSS, E-CID, barometric sensors, WLAN, and bluetooth signals, but the LPP message exchange (a.k.a. LPP transaction) is defined only between a location server and a target device, as depicted in Figure 6.

In view of the above, there exists a desire for an improved concept to determine a position of a device.

Summary of the Invention

An embodiment according to the invention creates an apparatus for determining a position of a device. The apparatus is configured to obtain a first position hint and a second position hint (or multiple position hints). The position hints each comprise an information about a position and shape of a respective multi-dimensional geometric region and an information about a presence of the device in the respective multi-dimensional geometric region. In other words, the first position hint comprises an information about a position and shape of a multi-dimensional geometric region and an information about a presence of the device in the multi-dimensional geometric region. Furthermore, the second position hint comprises an information about a position and shape of a multi-dimensional region and an information about a presence of the device in the multi-dimensional geometric region. The multi-dimensional geometric region as described by the first position hint and the second position hint may be different multi-dimensional geometric regions. Furthermore, the apparatus is configured to provide a position information of the device based on the first position hint and the second position hint.

The embodiment is based on the idea that a position of a device can be determined more effectively, e.g. with a higher precision, using at least two position hints. Moreover, the apparatus may for example use an overlap of the geometric regions described by the position hints to determine the position of the device. Furthermore, using multi-dimensional geometric regions a high degree of flexibility is provided, e.g. if using a geometric region describing a three-dimensional space and a geometric region describing a two-dimensional region, to determine the position of the device. Moreover, the multi-dimensional geometric region may have four dimensions, e.g. 3 spatial dimensions and a fourth time dimension. Thereby, the described embodiment enables an efficient and precise determination of the position of the device, in e.g. three-dimensional coordinates.

In embodiments, the multi-dimensional geometric region may be a three-dimensional geometric region. The described embodiment is beneficial as it allows to localize the device not only on a plane, but also adding for example height/altitude information, such that the device can be localized vertically.

In embodiments, the apparatus may be configured to determine an overlap region of the multi-dimensional geometric regions and to determine the position of the device based on the overlap region. Using an overlap reduces an area in which the device is potentially localized. Thereby, the determination of the position achieves a higher position.

In embodiments, the apparatus may be configured to determine the position of the device by finding a position x^* by choosing x^* from $C = \bigcap_{i=1}^N C_i$. The set C is a multi-dimensional candidate region, C_i is a multi-dimensional geometric region associated with the i -th position hint and N is a number of obtained position hints. Using the described formula allows for a simple determination of the overlap. Based on the overlap, the position of the device can be easily determined.

In embodiments, the apparatus may be configured to iteratively determine the position of the device according to $x_{n+1} = P_1(\dots P_{C_{N-1}}(P_{C_N}(x_n)))$, wherein n is an iteration index, $P_{C_i}(x_n)$ denotes a projection of a previous position estimate x_n onto the multi-dimensional geometric region C_i , where i denotes to which position hint the multi-dimensional geometric region is associated and N denotes a number of multi-dimensional regions associated to a number of position hints. The described embodiment allows for an efficient determination of the position using only little computational resources.

In embodiments, the apparatus may be configured to determine the position of the device by minimizing overall candidate positions x

$$\sum_{i=1}^N w_i \|x - P_{C_i}(x)\|,$$

wherein i denotes association to the i -th position hint, N is a number of obtained position hints, $w_i \in [0,1]$ are weights and $P_{C_i}(\cdot)$ denotes a projection of a candidate position x onto the multi-dimensional geometric region C_i . Determining the position x of the device according to the above mentioned formula allows for a reliable determination of the position of the device in the presence of inconsistent sets (i.e., sets that do not overlap because of the presence of noise in sensor readings, for example).

In embodiments, the apparatus may be configured to determine a reliability of the presence of the device in a corresponding multi-dimensional geometric region C_i , and to choose the weights w_i to be close to 1 if the device is determined to be with a high reliability in the multi-dimensional region C_i . Alternatively, the apparatus is configured to choose the weights w_i to

be close to 0 if the device is determined to be with a low reliability in the multi-dimensional region C_i . Alternatively, the apparatus is configured to determine the weights w_i to be uniform, if no reliability or uncertainty information can be determined, e.g. obtained from the position hint. The described embodiment can flexibly choose to incorporate reliability information either obtained from the position hints or from unknown weights by choosing them to uniform. Thereby, a high precision of the determination of the position of the device can be achieved.

In embodiments, the apparatus may be configured to obtain weights indicating a certainty of the device being in a multi-dimensional region described by the position hint from the position hint. Obtaining the weights from the position hint, allows the apparatus to use the weights to improve a localization estimation of the device. Thereby, a reliability of the position estimate of the device can be improved.

In embodiments, a multi-dimensional region, described by the first position hint and/or the second position hint may be convex. Using multi-dimensional regions with convex shapes allows for reliable localization of the device with simple methods. In other words, multi-dimensional regions of convex shape allow for determination of the position with low computational complexity.

In embodiments, the apparatus may be configured to determine the position of the device using convex optimization. By convex optimization, the device can be localized with high reliability and low computational complexity.

In embodiments, a shape of the multi-dimensional region described by the first position hint may be different from a shape of a multi-dimensional region described by the second position hint. The described embodiment allows a flexible use of various multi-dimensional regions for determining the position of the device.

In embodiments, the multi-dimensional region described by the first position hint and/or the second position hint may be plane-shaped or line-shaped. The described multi-dimensional regions allow the use of simple localization algorithms for determining the position of the device.

In embodiments, the multi-dimensional region described by the first position hint and/or the second position hint may be cone-shaped, sphere-shaped, box-shaped, or ellipsoidal, among other possible shapes. The described embodiment allows the flexible use of three-

dimensional shapes which can for example be provided by a camera, a mobile phone or a base station.

In embodiments, the apparatus may be configured to obtain the position hint and/or the second position hint through usage of a camera. Moreover, the multi-dimensional region described by the first position hint and/or the second position hint is cone-shaped and corresponds to a field of view of the camera. The described embodiment is beneficial as it allows to use a camera for obtaining information about the location of the device. Fused with other multi-dimensional regions, the described cone-shaped region can be used to precisely determine the location of the device.

In embodiments, the apparatus may be configured to provide an uncertainty information accompanied by the position information, which describes the position of the device, wherein the uncertainty information is configured to indicate a reliability of the position information. Alternatively, the uncertainty information may also indicate a possible deviation of the device from the determined position information. The described embodiment is advantageous as it not only provides a position of the device, but also indicates how reliable the provided position information is.

In embodiments, the apparatus may be configured to transmit a request to neighboring devices. Upon reception of the request by the neighboring devices, the neighboring devices are configured to transmit a position hint. The described embodiment allows the apparatus to request a position of a device by requesting the neighboring devices to transmit position hints. The neighboring devices thereby can deliver information about a searched device. The described embodiment therefore flexibly enables to localize a device at any time necessary.

In embodiments, the position hint may comprise probability information which indicates the probability of a presence of a device in the described multi-dimensional region. Having probability information in the position hint allows to more precisely and reliably determining the position of the device.

In embodiments, the apparatus may be configured to broadcast a position hint upon reception of a localization request. Moreover, the apparatus is configured to selectively not transmit a position hint, when a probability information indicates that the device is not in a multi-dimensional region surveilled by the apparatus. Thereby, the described apparatus saves energy by not transmitting if the transmission is of little use for localization of the device. For example, another device may want to localize a second device and therefore

transmits the localization request to the apparatus which upon reception of the localization request does not transmit a position hint to the device if the second device is not in the multi-dimensional geometric region surveilled by the apparatus.

Embodiments of the invention provide for a method for determining a position of a device. The method comprises obtaining a first position hint and a second position hint, wherein the position each comprise an information about a position and shape of a respective multi-dimensional geometric region and the information about a presence of the device in the respective multi-dimensional geometric region. Moreover, the method comprises providing a position information of the device based on the first position hint and the second position hint.

The described method can be supplemented by any of the features and functionalities which are herein described with respect to the apparatus, either individually or in combination.

Embodiments according to the invention provide a computer program with a program code for performing the method, when the computer program runs on a computer or a micro-controller.

Brief Description of the Figures

In the following, embodiments of the present invention will be explained with reference to the accompanying drawings, in which:

- Fig. 1 shows a schematic block diagram of an embodiment of the invention;
- Fig. 2 shows a schematic block diagram of an embodiment of the invention;
- Fig. 3 shows a localization scenario according to embodiments of the invention;
- Fig. 4 shows the localization scenario of Fig. 3 after a localization process according to embodiments of the invention;
- Fig. 5 shows a flow chart of a method according to embodiments of the invention;
- Fig. 6 shows a concept for localization as used in LTE.

Detailed Description of the Embodiments

Fig. 1 depicts a flow chart of an apparatus 100 for determining a position of a device. The apparatus 100 is configured to obtain a first position hint 102 and a second position hint 104. The position hints 102 and 104 each comprise an information about a position and shape of a respective multi-dimensional geometric region and an information about the presence of the device in the respective multi-dimensional geometric region. Furthermore, the apparatus 100 is configured to provide a position information 192 of the device based on the first position hint 102 and the second position hint 104.

The described embodiment can flexibly and precisely determine the position of the device based on the first position hint 102 and the second position hint 104. For example, the apparatus 100 may choose to use an overlap of geometric regions described by the first position hint and the second position hint, to thereby obtain an overlap region, in which the device is located with a high probability. Thereby, an area in which the device resides is narrowed down and therefore a position at which the device is located can be determined more precisely.

In the following, similar reference signs indicate similar features and functionalities. Furthermore, the described apparatus 100 can be supplemented by any features and functionalities described with embodiments herein.

Fig. 2 depicts a flow chart of an apparatus 200 according to an embodiment of the invention for determining a position of device.

The apparatus 200 comprises an overlap determiner 210, a weights obtainer 220, a position information determiner 230, a position determiner 240, a localization request transmitter 250, a localization request receiver 260, and a position hint provider 270.

Similar to apparatus 100, the apparatus 200 obtains a first position hint 202 and a second position hint 204. The overlap determiner 210 may determine an overlap based on geometric regions provided by the first position hint 202 and the second 204 or additional position hints. An overlap information 212 is then provided to the position information determiner 230. Furthermore, the weights obtainer may obtain weights 222 based on the first position hint 202 and the second position hint 204 or by initializing them to be uniform. The weights 222 may then also be provided to the position information determiner 230. The position information determiner 230 can then flexibly either use the first position hint 202, the second position hint 204, the overlap 212 or the weights 222 in any combination to provide a position

estimate 232 and reliability information 234. The reliability information 234 can be optional and the position estimate 232 can also be interpreted as the position information. The position estimate 232 and the reliability information 234 can then be fed to the position determiner 240, which can provide a high precision position 296 of the device. Furthermore, the apparatus 200 can provide based on the position estimate 232 a position information 292 and the reliability information 234.

Moreover, the apparatus 200 may also transmit a location request via location request transmitter 250, to request position hints from nearby devices, to determine a position of a device. Furthermore, the apparatus 200 may receive a location request through location request receiver 260 and upon reception of the localization request provide a position hint using position hint provider 270 to assist in locating a device through another device. Therefore, the position hint provider 270 can provide the position hint 272.

Fig. 3 shows a typical localization scenario according to embodiments of the invention in which a base station 310, a camera 320, and a one-bit sensor 330 are used to localize a wireless node 340.

The base station may provide a position hint describing a geometric region C_3 which is sphere-shaped, and in which the wireless node 340 is present. Furthermore, the camera 320 may provide a cone-shaped multi-dimensional region with a further position hint in which the wireless node 340 is present. Moreover, the one-bit sensor 330 may provide a box-shaped multi-dimensional region C_1 in which the wireless node 340 is residing. The regions C_1 , C_2 , C_3 will be described in the position hints of the individual devices, i.e. base station 310, camera 320, and one-bit sensor 330.

Fig. 4 shows a localization result of the scenario depicted in Fig. 3, which is obtained by overlap of the regions C_1 , C_2 , and C_3 . The region 410 in which the wireless node 340 is most likely to be found has been narrowed down compared to the regions C_1 , C_2 , or C_3 , allowing for precise localization of the wireless node 340. Furthermore a mathematical set notation is given with which the overlap region 410 may be obtained.

Fig. 5 shows a flow chart of a method 500 according to embodiments of the invention. The method 500 comprises obtaining 510 a first position hint and a second position hint, wherein the position hints each comprise an information about a position and shape of a respective multi-dimensional geometric region and an information about a presence of the device in the respective multi-dimensional geometric region. Moreover, the method 500 comprises

providing 520 a position information of the device based on the first position hint and the second position hint.

The described method can be supplemented by any features and functionalities described herein with respect to apparatuses either individually or in combination.

Fig. 6 shows a conventional localization concept.

Further Aspects

Features and functionalities described in the following can be incorporated either individually or in combination with the apparatuses and methods described herein.

Embodiments of the invention describe Sensor-Agnostic Localization which may employ an information fusion.

Conventional schemes are not designed to incorporate side information gained from other types of sensors (e.g. sensors in 310, 320 and/or 330) and algorithms present in the network, and it is noted that networks are becoming widely diverse with respect to localization schemes. Techniques for position estimation based on completely unexpected sensor measurements and algorithmic approaches are constantly being developed and deployed (e.g., temperature, barometric sensors, images from cameras, and steering vectors from beamformers, to name a few).

Algorithms able to combine information from heterogeneous sensors, with the intent to obtain a final location estimate that is more accurate than any of the individual estimates being fused, have a long history in the academia [5] [6] [7] [8]. In particular, these algorithms for information fusion are relatively easy to implement if sensors are able to report geometrical shapes representing the uncertainty region of the location of a network element (e.g. in the first position hint or the second position hint). For these information fusion algorithms, the type of the sensor or the scheme used to generate the uncertainty regions is not a matter of primary concern.

Despite the theoretical advances on information fusion algorithms, current 3GPP communication protocols have very limited support for them. An option for supporting information fusion between more general classes of devices is currently missing. Furthermore, the (convex) geographic shapes currently available in standards (TS 36.355,

TS 23.032) are somewhat limited. For instance, there is no clear support for the so-called ice-cream cone in convex analysis, and this shape can be particularly useful to report information about the position of network elements gained from angle-of-arrival estimators (e.g. the camera 320). Furthermore, many shapes in the standard are two-dimensional [9, 10], with no simple way to incorporate information about an additional dimension if available.

In the following a rich collection of geometrical constructs are proposed to report uncertainty regions (e.g. in the first position hint and or the second position hint) and also signaling schemes to exchange and fuse location information from multiple network elements. The proposed mechanisms will enable the use of set-theoretic methods and other information fusion algorithms.

Embodiments according to the invention describe:

- Novel localization protocols with a rich collection of convex shapes representing uncertainty regions. An objective underlying embodiments is to enable localization algorithms, such as those based on set-theoretic methods that fuse information gained from heterogeneous sensors spread throughout the network.
- Novel protocols to request convex shapes from different devices with information about the location about a node in the network.
- The protocols for exchanging information about the location of devices can be used by any combination of network elements (user terminals, base stations, elements in the core network, etc.)

In the following the particular scenario depicted in Figure 3 is considered. Figure 3 describes an uncertainty region provided by different nodes 310, 320 and 330 in a network. The network tries to estimate the two-dimensional coordinates of a wireless node 340 by fusing information from three heterogeneous sources of information:

- (i) a camera 320 that is only able to provide information about the bearing;
- (ii) a 1-bit sensor 330 that is only able to inform whether a given node is within a rectangular region; and
- (iii) a base station 310 that is able to estimate its distance from the node to be located (e.g., by measuring the received signal strength).

As illustrated in Figure 3, the uncertainty region of each sensor is represented by closed convex sets denoted by $C_i \subset \mathbb{R}^2$, $i \in \{1,2,3\}$, where C_1 is a rectangular region obtained by the 1-bit sensor 330, C_2 is the convex cone obtained by the camera 320, and C_3 is the 2D sphere obtained by the base station 310. Individually, no sensor is able to estimate accurately the coordinates of the node. The uncertainty region of each individual network element is too large. However, in this particular example, a reliable estimate can be obtained by solving the following convex feasibility problem, which, in simple words, computes a coordinate consistent with all reported uncertainty regions:

Problem 1: Find $x^* \in C = \bigcap_{i=1}^3 C_i$.

If Problem 1 has a solution, it is not necessarily unique, but any solution can be a good estimate of the sensor location (e.g. wireless node 340) if the sets are appropriately constructed, as illustrated in Figure 4. Moreover, Fig. 4 describes an uncertainty region obtained by fusing the information from different sensors. This uncertainty region is the set of solutions to Problem 1. For the moment, it is assumed that Problem 1 has a solution. Later it is shown how to deal with inconsistent sets by using existing algorithms.

Convex feasibility problems such as those exemplified above can be solved (optimally and with low complexity) with existing solvers [8, 11, 12, 7, 5, 6]. For completeness, approaches that have convergence guarantees will be briefly reviewed, and later techniques are described that can cope with infeasible problems (i.e., when $C = \emptyset$).

According to embodiments the projection-onto-closed-convex-sets (POCS) algorithm [13, 14, 12] can be used, which is also known as the algebraic reconstruction technique in some scientific circles. The algorithm works as follows. Starting from an arbitrary vector x_1 in the Euclidean space, the simplest version of the POCS algorithm produces a sequence $(x_n)_{n \in \mathbb{N}}$ according to (for concreteness, here the POCS algorithm is used, applied to the specific example in Figure 3):

$$x_{n+1} = P_{C_3} \circ P_{C_2} \circ P_{C_1}(x_n),$$

where, for each $i \in \{1,2,3\}$, the projection $P_{C_i}: \mathbb{R}^2 \rightarrow \mathbb{R}^2$ is given by $P_{C_i}(x) = y^*$, y^* is the uniquely existing vector satisfying $\|x - y^*\|_2 \leq \|x - u\|_2$ for every $u \in C_i$ (all sets are closed

convex sets), and $\|\cdot\|_2$ denotes the standard Euclidean norm. In finite dimensional spaces such as those in the example considered here, the sequence $(x_n)_{n \in \mathbb{N}}$ generated as above satisfies $\lim_{n \rightarrow \infty} x_n = x^*$ for an unspecified $x^* \in C$. This algorithm can be easily extended to arbitrary (separable) Hilbert spaces and arbitrary closed convex sets, but it is noted that projection-based methods are mostly suitable to solve feasibility problems constructed with sets onto which the projection is easy to compute. Extensions considering different operators such as relaxed and generalized projections with nonconvex sets have also been reported in the literature [14, pp. 181-202].

An important point to notice in the above example is that, irrespective of the algorithm being used to solve Problem 1, no need for any information about the schemes that produce the uncertainty regions is necessary. The proposed mechanism for node localization is sensor agnostic.

So far, it was assumed that Problem 1 is feasible, which may not happen in practice very often because of the presence of heavy outliers in the measurements used to create the convex sets. To address this challenge, convex feasibility problems can be seen from the viewpoint of convex optimization problems. More precisely, Problem 1 can be reformulated as:

Problem 2: Minimize $\sum_{i=1}^3 w_i \|x - P_{C_i}(x)\|$,

where $(w_i)_{i \in \{1,2,3\}} \subset [0,1]$ are weights indicating the reliability of the corresponding closed convex sets (uniform weights can be used if information about reliability is not available).

With convex uncertainty regions, Problem 2 is a convex optimization problem, so, in principle, it can be solved with off-the-shelf solvers. If the number of sets is sufficiently large, then a solution to Problem 2 can be seen as a point that is consistent with most sets. In particular, if Problem 1 is feasible, then the set of solutions to Problem 1 and Problem 2 coincide. As mentioned above, the approaches described here for the very particular scenario depicted in Figure 3 can be straightforwardly generalized to higher dimensional

spaces and other closed convex sets. The use of nonconvex sets are not ruled out in the protocols described in the next sections, but it is noted that, with nonconvex sets, the resulting optimization problems are typically hard to solve, in the sense that there is no known algorithm able to solve every problem instance both fast and optimally.

In the following a proposed mechanism according to embodiments is discussed.

According to embodiments each node in the network has its own unique identification number (ID). The mechanism starts with a network entity querying other network elements about the possible location of a node (NOTE: a node can request information about its own location). For example, if the network entity requiring information about a node is an access point, it may broadcast a signal with the desired node ID. Requests can also be sent to specific network elements using, for example, the X2 interface or wireless control channels. Upon reception of the request messages, network elements with information about the location of the desired node report convex sets (possibly in a compressed message) with the approximate location of the desired node. Examples of these sets include, but are not limited to, spheres, boxes, ellipsoids, planes, and cones, to cite a few. To each convex set, network elements can also associate a number from zero to one indicating the probability of finding the desired node within the reported convex set. Information of this type is particularly useful in set-theoretical approaches that are able to provide weights to sets, with the intent to obtain final estimates that are close to reliable sets in case Problem 1 has no solution. Furthermore, in the request message, the prescribed confidence level can also be reported, so that network elements only report shapes having at least a given probability of finding the desired node.

As an example of the mechanism described above, the scenario illustrated in Figure 3 is used. To carry out a localization of the wireless node at the base station 310, network elements can exchange the following messages:

1. The base station 310 wants to obtain information about the position of the wireless node, so it sends a special broadcast localization message with the wireless node's 340 ID. For example in LTE, this request can be done either by issuing requests to each node in the cell separately (e.g., by using the PDSCH), or by using a multicast channel, such as the PMCH.

2. The network entity equipped with the camera 320 in Figure 3 responds with a dedicated message (in LTE, by using, for example, the PUSCH) conveying the information about the cone C_2 . This information may contain, for example, the coordinates of the camera 340, a central direction vector, and an angle corresponding to the uncertainty of the estimate at a given confidence level.
3. The sensor node 330 in Figure 3 transmits information about whether the wireless node is within the rectangular region C_1 in Figure 3 (which is the case). This information can also be transmitted to the base station by using regular uplink data channels (for example, the PUSCH in LTE).
4. By assuming that the base station 310 can estimate the distance to the wireless node 340, this knowledge can be represented by a sphere, which is illustrated by the shape C_3 . In the example, this information is already available at the base station, so it does not need to be transmitted.
5. The base station 310 can now employ a state-of-the-art information fusion algorithm to obtain an accurate estimate on the position of the wireless node 340 shown in Figure 3.

Note that, instead of transmitting regions directly to the base station 310, each node can also use a broadcast communication channel to transmit the information to all nodes within communication range. This scheme would enable the application of distributed localization approaches such as those in [5].

In the following benefits of embodiments of the invention are listed:

- There is no need to define novel protocols for sensor localization if novel localization techniques become available. The possible region where a node is located may be reported as a convex set.

- Easy means of fusing information from heterogeneous sensors available anywhere in the network (e.g., from access points, from the node to be located, etc.)
- The algorithm for information fusion is not standardized. Operators are free to use existing methods (e.g., existing set-theoretic approaches) or to develop new algorithms.
- Information about the location can be exchanged between any nodes. Additional privacy or security protocols can also be considered.

List of Acronyms and Symbols

A-GNSS	Assisted global navigation satellite system
E-CID	Enhanced cell identity
E-UTRAN	Evolved universal terrestrial radio access network
LPP	LTE positioning protocol
LTE	Long term evolution
OTDOA	Observed time difference of arrival
POCS	Projection onto convex sets
WLAN	Wireless local area network

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Claims

1. An apparatus (100; 200; 340) for determining a position of a device (340),
 wherein the apparatus is configured to obtain a first position hint (102; 202) and a second position hint (104; 204), wherein the position hints (102; 202; 104; 204) each comprise an information about a position and shape of a respective multi-dimensional geometric region and an information about a presence of the device (340) in the respective multi-dimensional geometric region,
 wherein the apparatus is configured to provide a position information (192; 292) of the device based on the first position hint and the second position hint.
2. An apparatus according to claim 1, wherein the multi-dimensional geometric region is a three-dimensional geometric region.
3. An apparatus according to claim 1 or 2, wherein the apparatus is configured to determine an overlap region of the multi-dimensional geometric regions, and to determine the position of the device based on the overlap region.
4. An apparatus according to one of the claims 1 to 3, wherein the apparatus is configured to determine the position of the device by finding a position x^* of the device by choosing x^* from

$$C = \bigcap_{i=1}^N C_i,$$

wherein C is a multi-dimensional candidate region, C_i is a multi-dimensional geometric region associated with the i -th position hint, and wherein N is a number of obtained position hints.

5. An Apparatus according to one of the claims 1 to 4, wherein the apparatus is configured to iteratively determine the position of the device according to

$$x_{n+1} = P_1(\dots P_{C_{N-1}}(P_{C_N}(x_n))),$$

wherein n is an iteration index, $P_{C_i}(x_n)$ denotes a projection of a previous position estimate x_n onto the multi-dimensional geometric region C_i , where i denotes to which position hint the multi-dimensional geometric region is associated and N denotes a number of multi-dimensional regions associated to a number of position hints.

6. An apparatus according to one of the claims 1 to 5, wherein the apparatus is configured to determine the position of the device by minimizing over all candidate positions x

$$\sum_{i=1}^N w_i \|x - P_{C_i}(x)\|,$$

wherein i denotes association to the i -th position hint, N is a number of obtained position hints, $w_i \in [0,1]$ are weights and $P_{C_i}(\cdot)$ denotes a projection of a candidate position x onto the multi-dimensional geometric region C_i .

7. An apparatus according to claim 6, wherein the apparatus is configured to determine a reliability of the presence of the device in a corresponding multi-dimensional geometric region C_i , and to choose the weights w_i to be close to 1 if the device is determined to be with a high reliability in the multi-dimensional region C_i , and to choose the weights w_i to be close to 0 if the device is determined to be with a low reliability in the multi-dimensional region C_i , or

wherein the apparatus is configured to determine the weights w_i to be uniform, if no reliability or uncertainty information can be determined.

8. An apparatus according to one of the claims 1 to 7, wherein the apparatus is configured to obtain weights indicating a certainty of the device being in a multi-dimensional region described by the position hint from the position hint.
9. An apparatus according to one of the claims 1 to 8, wherein a multi-dimensional region, described by the first position hint and/or the second position hint, is convex.

10. An apparatus according to one of the claims 1 to 9, wherein the apparatus is configured to determine the position of the device using convex optimization.
11. An apparatus according to claim 1 to 10, wherein a shape of the multi-dimensional region described by the first position hint is different from a shape of the multi-dimensional region described by the second position hint.
12. An apparatus according to one of the claims 1 to 11, wherein the multi-dimensional region described by the first position hint and/or the second position hint is plane-shaped or line-shaped.
13. An apparatus according to one of the claims 1 to 12, wherein the multi-dimensional region described by the first position hint and/or the second position hint is cone-shaped, sphere-shaped, box-shaped or ellipsoidal.
14. An apparatus according to one of the claims 1 to 13, wherein the apparatus is configured to obtain the first position hint and/or the second position hint through usage of a camera (320), and wherein the multi-dimensional region described by the first position hint and/or the second position hint is cone-shaped and corresponds to a field of view of the camera.
15. An apparatus according to one of the claims 1 to 14, wherein the apparatus is configured to provide an uncertainty information (234) accompanied by the position information (192; 292), wherein the uncertainty information is configured to indicate a reliability of the position information, and/or wherein the uncertainty information is configured to indicate a possible deviation of the device from the determined position information.
16. An apparatus according to one of the claims 1 to 15, wherein the apparatus is configured to transmit a request to neighboring devices,

whereupon reception of the request, the neighboring devices are configured to transmit a position hint.

17. An apparatus according to claim 16, wherein the position hint comprises probability information which indicates a probability of a presence of the device in the described multi-dimensional region.
18. An apparatus according to one of the claims 1 to 17, wherein the apparatus is configured to broadcast a position hint upon reception of a localization request, and wherein the apparatus is configured to selectively not transmit a position hint, when a probability information indicates that the device is not in a multi-dimensional geometric region surveilled by the apparatus.
19. Method for determining a position of a device,

obtaining a first position hint and second position hint, wherein the position hints each comprise an information about a position and shape of a respective multi-dimensional geometric region and an information about a presence of the device in the respective multi-dimensional geometric region,

providing a position information of the device based on the first position hint and the second position hint.
20. Computer program with a program code for performing the method according to claim 19, when the computer program runs on a computer or a microcontroller.

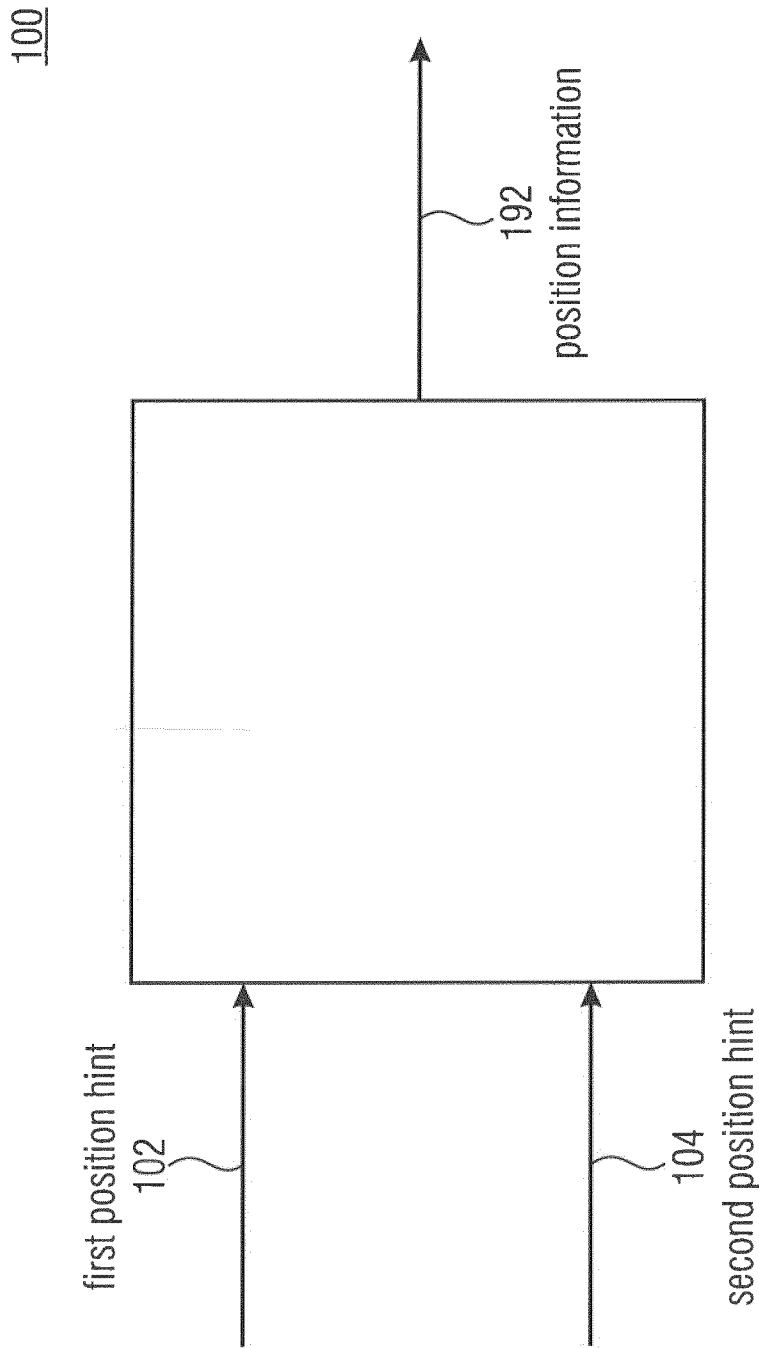


Fig. 1

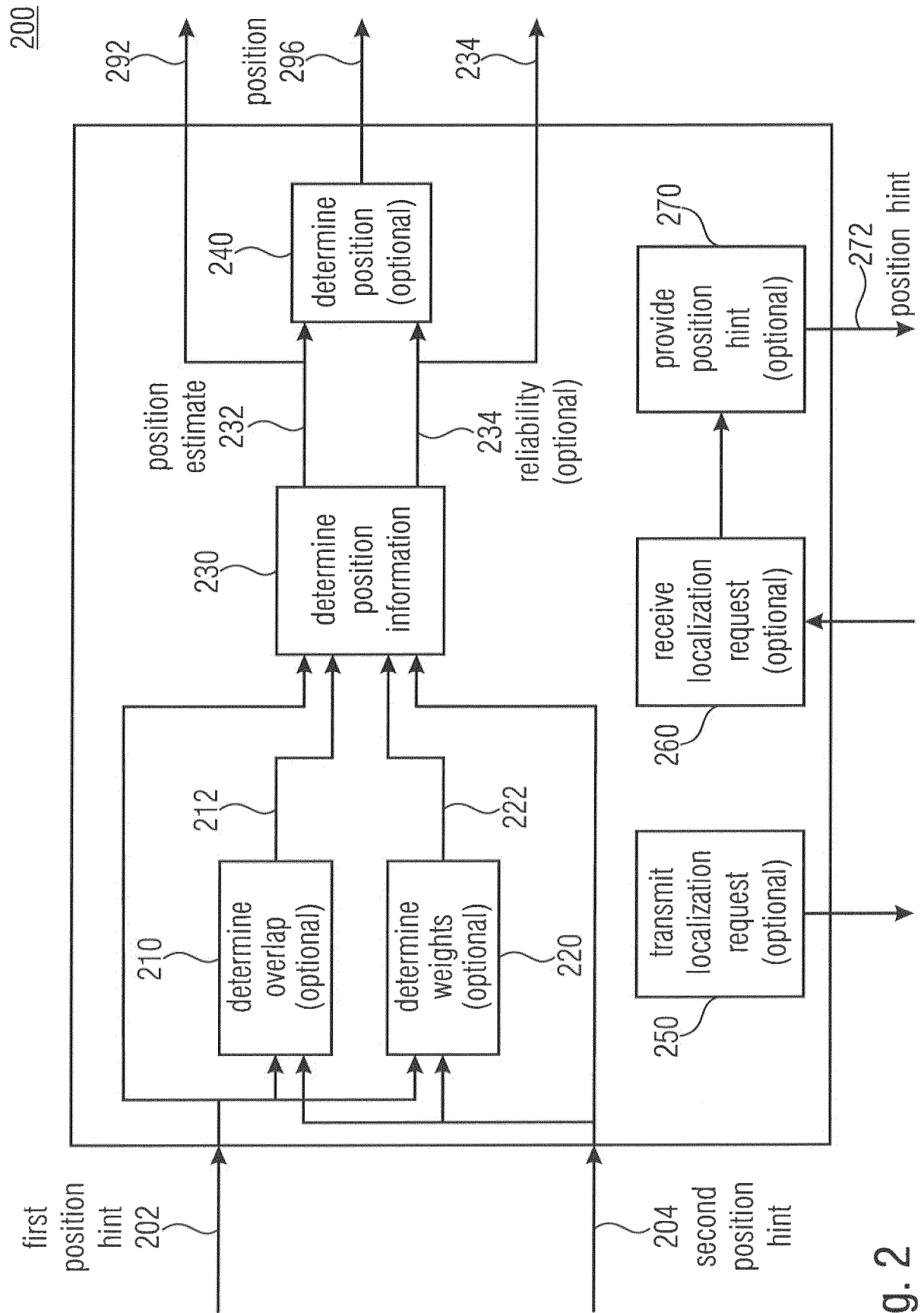


Fig. 2

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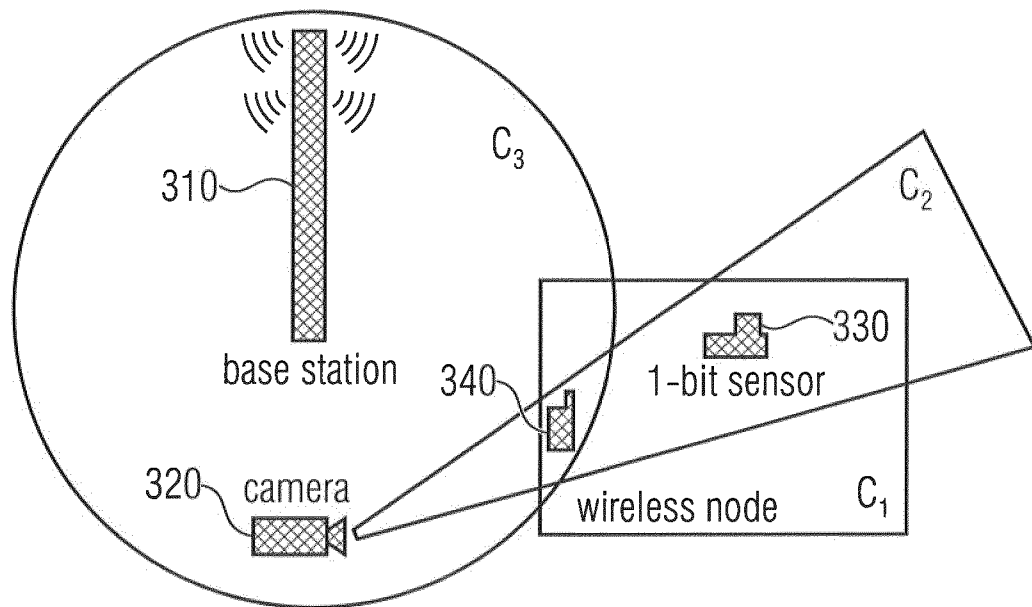


Fig. 3

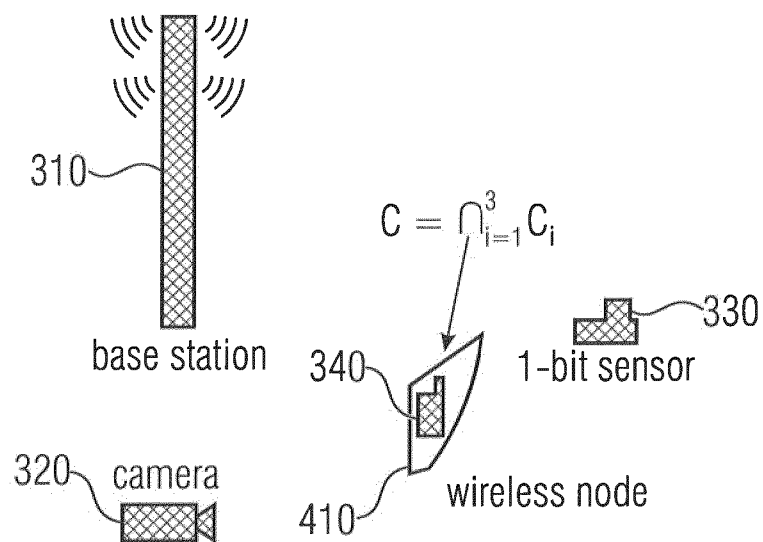


Fig. 4

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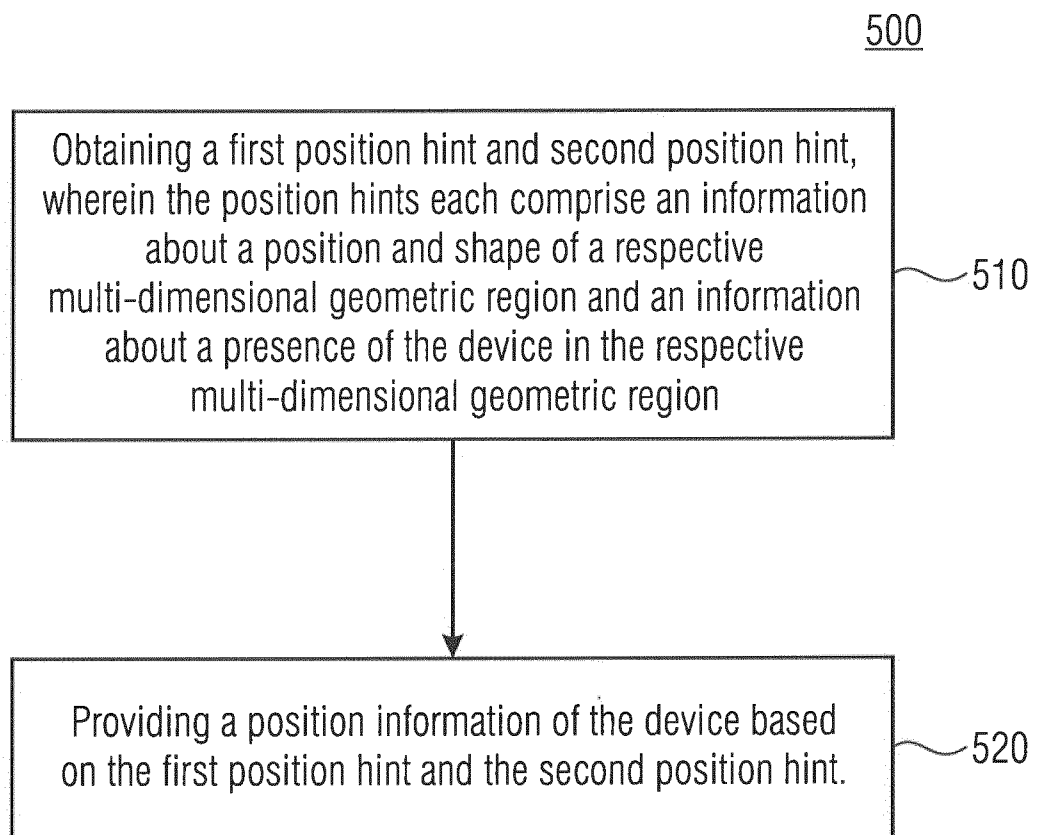


Fig. 5

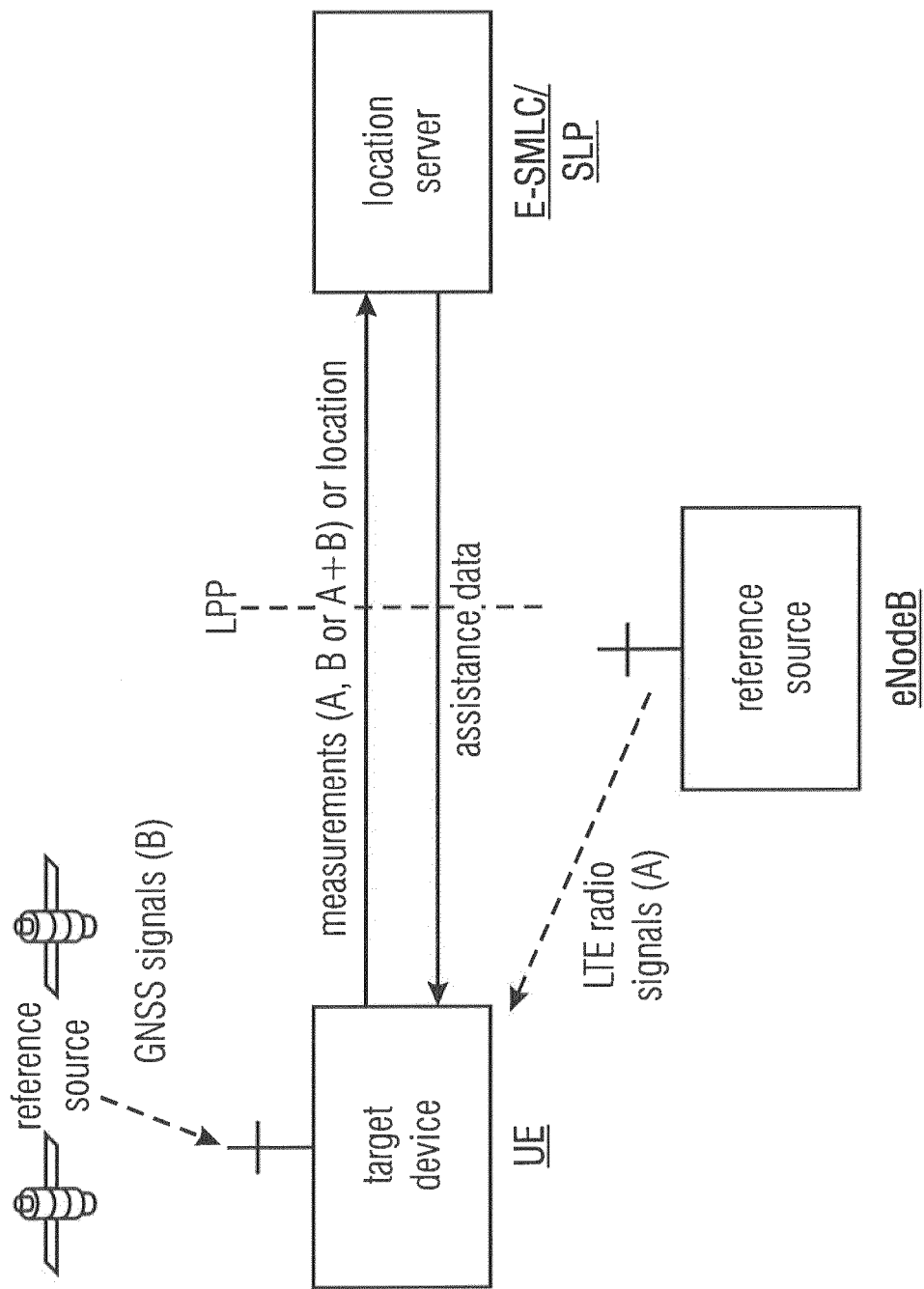


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/068777A. CLASSIFICATION OF SUBJECT MATTER
INV. G06F17/11 H04W64/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F H04W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MOHAMMAD REZA GHOLAMI ET AL: "Wireless network positioning as a convex feasibility problem", EURASIP JOURNAL ON WIRELESS COMMUNICATIONS AND NETWORKING, vol. 2011, no. 1, 10 November 2011 (2011-11-10), XP055522372, New York, NY, US ISSN: 1687-1472, DOI: 10.1186/1687-1499-2011-161 page 2 - page 4 ----- -/--	1-20



Further documents are listed in the continuation of Box C.



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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search

9 November 2018

Date of mailing of the international search report

21/11/2018

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Huguet Serra, G

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2018/068777

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MOHAMMAD REZA GHOLAMI ET AL: "On Geometric Upper Bounds for Positioning Algorithms in Wireless Sensor Networks", ARXIV.ORG, CORNELL UNIVERSITY LIBRARY, 201 OLIN LIBRARY CORNELL UNIVERSITY ITHACA, NY 14853, 12 January 2012 (2012-01-12), XP080557705, section IV -----	1-20
X	Mohammad Reza Gholami: "Positioning algorithms for wireless sensor networks", Degree Thesis, 2011, pages 1-56, XP055522377, Gothenburg, Sweden Retrieved from the Internet: URL: https://pdfs.semanticscholar.org/620b/5946dc253044bffa7ff97bb83fbcf3493db3.pdf [retrieved on 2018-11-09] Chapter 4, section 3. -----	1-20
X	MOHAMMAD REZA GHOLAMI ET AL: "Robust distributed positioning algorithms for cooperative networks", 2011 IEEE 12TH WORKSHOP ON SIGNAL PROCESSING ADVANCES IN WIRELESS COMMUNICATIONS (SPAWC 2011) IEEE PISCATAWAY, NJ, USA, IEEE, PISCATAWAY, NJ, USA, 26 June 2011 (2011-06-26), pages 156-160, XP032035716, DOI: 10.1109/SPAWC.2011.5990384 ISBN: 978-1-4244-9333-3 section 3.2 -----	1-20
X	GHOLAMI MOHAMMAD REZA ET AL: "Cooperative Wireless Sensor Network Positioning via Implicit Convex Feasibility", IEEE TRANSACTIONS ON SIGNAL PROCESSING, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 61, no. 23, December 2013 (2013-12), pages 5830-5840, XP011535735, ISSN: 1053-587X, DOI: 10.1109/TSP.2013.2279770 [retrieved on 2013-10-28] sections II and III -----	1-20