US 20030114115A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2003/0114115 A1

Overy et al. (43) Pub. Date: Jun. 19, 2003

(54) POSITIONING

(76) Inventors: **Michael Overy**, Hants (GB); **Natividade Lobo**, Berks (GB)

Correspondence Address:
ANTONELLI TERRY STOUT AND KRAUS
SUITE 1800
1300 NORTH SEVENTEENTH STREET
ARLINGTON, VA 22209

(21) Appl. No.: **10/182,615**

(22) PCT Filed: **Feb. 2, 2001**

(86) PCT No.: **PCT/GB01/00440**

(30) **Foreign Application Priority Data**

Feb. 2, 2000 (GB) 0002404.2
Aug. 7, 2000 (GB) 0019366.4

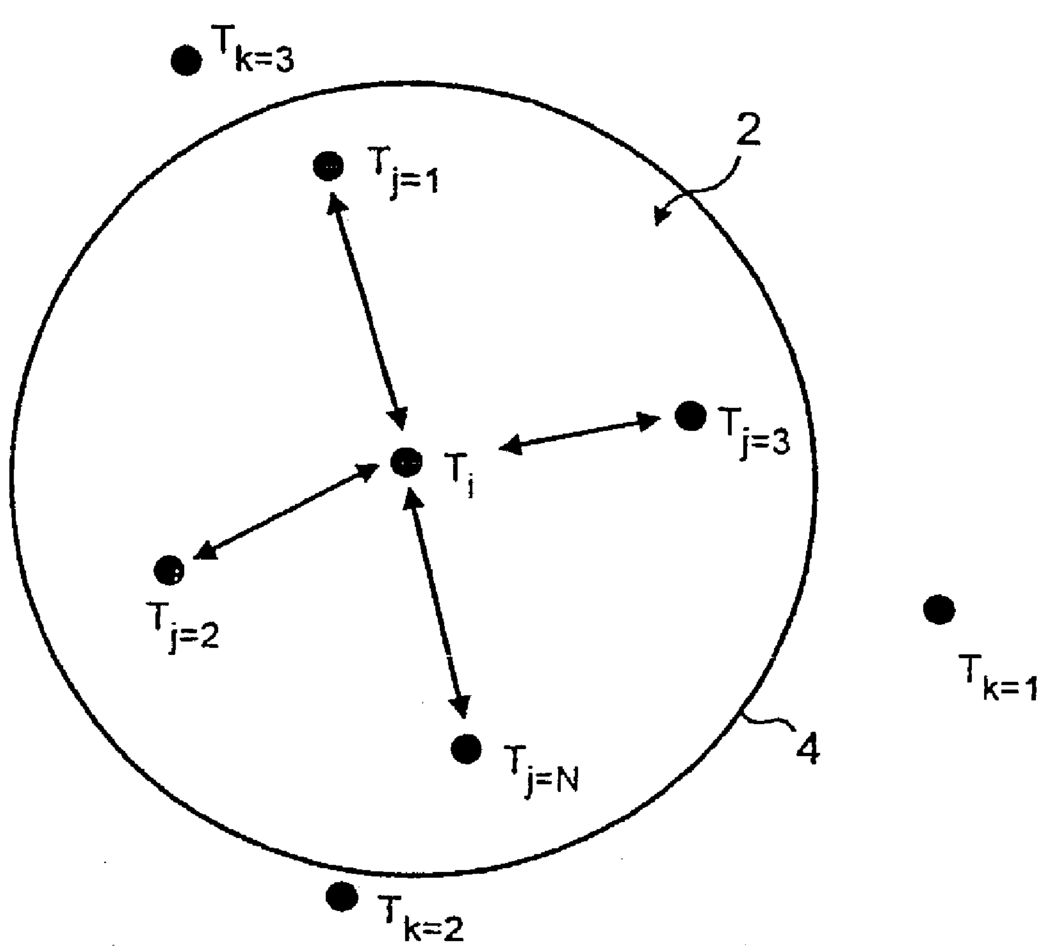
Publication Classification

(51) **Int. Cl.**[7] **G01S 3/02**; H04B 1/38

(52) **U.S. Cl.** **455/73**; 342/463; 455/41

(57) **ABSTRACT**

A receiver for calculating its position according to a first transmitter, having a processor arranged to convolve: the probability density function representing the position of the first transmitter, sent by the first transmitter to the receiver; with the probability density function representing the likelihood that a transmission from the first transmitter will be successfully received at the receiver.



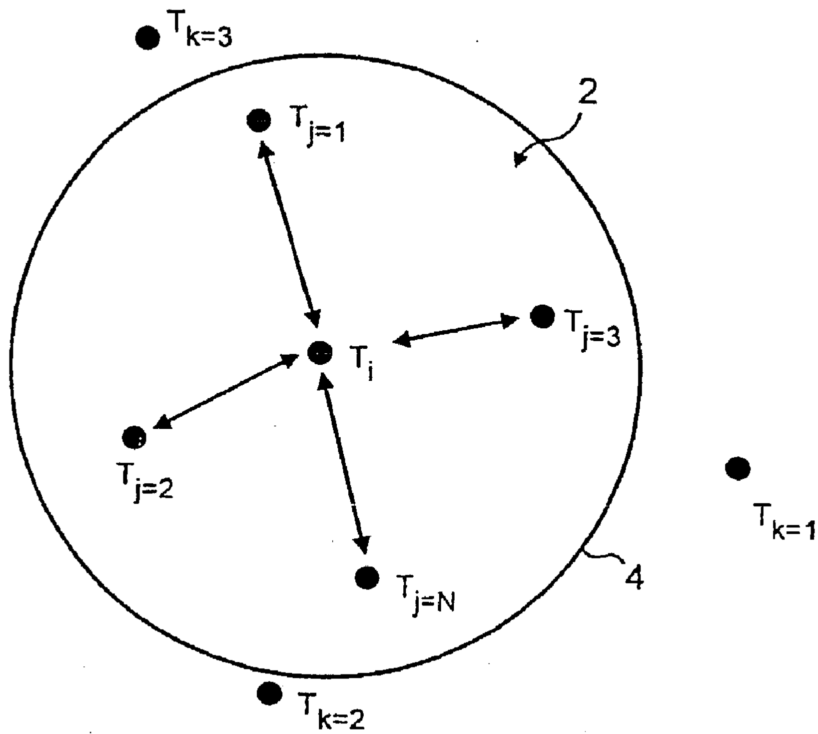

T k=3
T j=1
2
T j=3
T i
T j=2
T k=1
T j=N
4
T k=2

FIG. 1

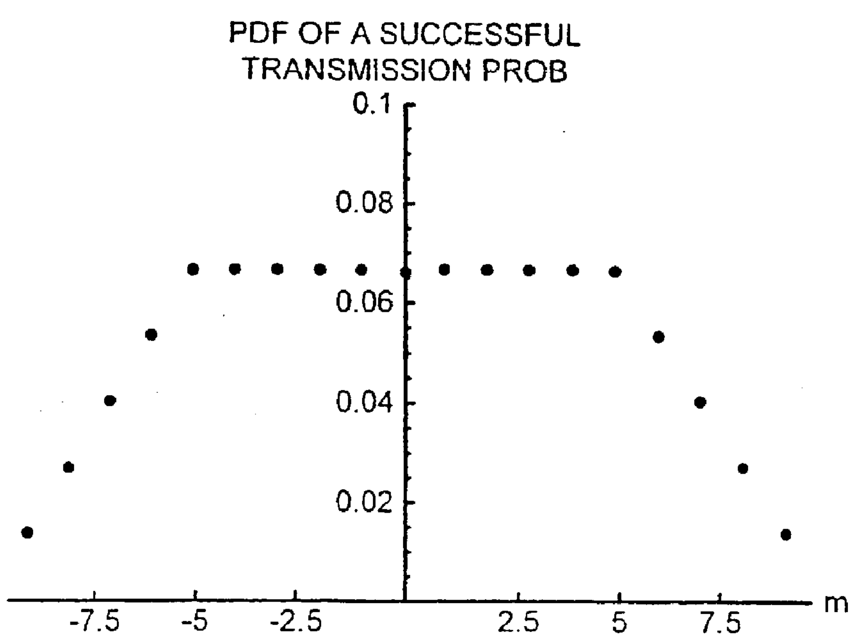

PDF OF A SUCCESSFUL
TRANSMISSION PROB
0.1
0.08
0.06
0.04
0.02
-7.5
-5
-2.5
2.5
5
7.5
m

FIG. 2

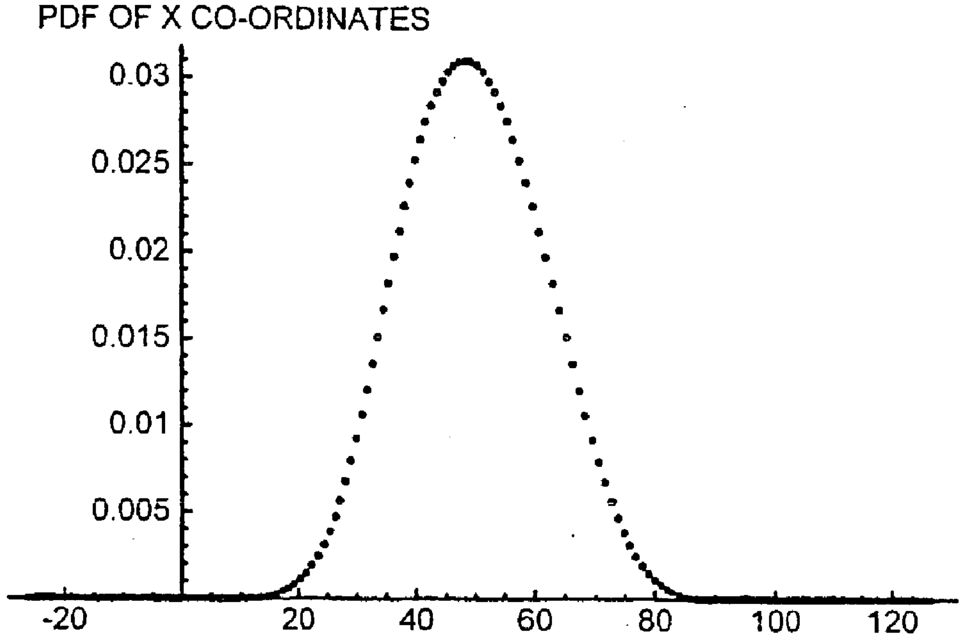

PDF OF X CO-ORDINATES
0.03
0.025
0.02
0.015
0.01
0.005
-20
20
40
60
80
100
120

FIG. 3

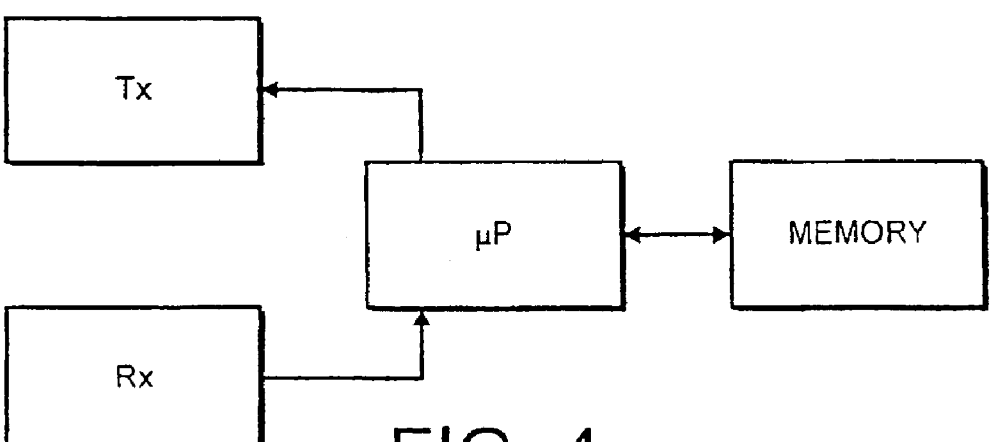

Tx
μP
MEMORY
Rx

FIG. 4

POSITIONING

[0001] The present invention relates to the positioning of a transceiver using other transceivers. It has particular application to the positioning of a transceiver by forming an ad hoc network of transceivers without the use of a dedicated infrastructure.

[0002] It is often desirable to be able to determine one's position or to determine the position of another person or device. The Global position system (GPS) allows the location of specialist receivers to be positioned on the surface of the earth. GPS uses a fixed network of satellite transmitters orbiting the earth to transmit to and thereby locate the receiver. Cellular positioning systems have also been proposed in which the existing network of fixed base station transceivers is used to locate a mobile phone. The unchanging position and identity of the fixed base stations and the distance of the mobile phone from the base stations is used to estimate the phones location. Both of these systems operate over large distances exceeding many kilometres.

[0003] It would be desirable to provide a system by which the location of persons or objects can be determined wirelessly but without having to invest in a dedicated fixed network of radio receivers.

[0004] It would be desirable to re-use existing wireless technology, which may be provided for a different purpose, to allow position determination.

[0005] For a better understanding of the present invention and to understand how the same may be brought into effect reference will now be made by way of example only to the accompanying drawings in which:

[0006] **FIG. 1** illustrates a distribution of transceivers T;

[0007] **FIG. 2** illustrates an exemplary probability density function representing the chances of successful transmission between transmitter and receiver as the distance between transmitter and receiver varies;

[0008] **FIG. 3** illustrates an exemplary probability density function representing the probable location of a transceiver on the x-axis; and

[0009] **FIG. 4** illustrates a transceiver.

[0010] **FIG. 1** illustrates a transceiver Ti which is capable of forming an ad hoc network **2** via radio communications with the transceivers Tj. The network may be formed by Ti acting as a Master with the transceivers Tj functioning as Slaves. Preferably the transceivers are Bluetooth transceivers and the network is a piconet. When the transceiver Ti acquires its position it forms a network with neighbouring transceivers Tj which have already acquired their positions. The communication range of transceiver Ti is illustrated by the circle **4**. There are a number of transceivers Tj which are outside the range **4** and cannot participate in the network **2**.

[0011] The transceiver Ti, once it has acquired its position it can participate as a Slave in a different network formed by another transceiver to acquire its position. Each of the transceivers T are the same. Each acts as a Master to form a network with Slave transceivers to acquire a position and then it can participate as a Slave in a different network formed by another transceiver to acquire its position. The transceivers T are not infrastructure. They are preferably integrated into host devices such as mobile phones, desk telephones, computers etc. The transceivers which are available to participate in a network may therefore vary as transceivers move into and out of range of the Master transceiver.

[0012] Referring to **FIG. 1**, the transceiver Ti is attempting to determine its position. It forms a network with N transceivers Tj where j=1, 2, 3 . . . N.

[0013] The probability that a transceiver Tj can transmit successfully to the transceiver Ti when separated by distance y is given by $prob_{TransSuccessful.ji}[y]$. The probability density function representing the probability a transceiver j can transmit successfully to the Transceiver Ti is given by $pdf_{TransSuccessful.ji}[y]$

[0014] where

$$pdf_{TransSuccessful..ji}[y]=\frac{prob_{TransSuccessful\text{-}ji}[y]}{\int_{-\infty}^{\infty}prob_{TransSuccessful\text{-}ji}[y]dy}$$

[0015] If all transmitters Tj are equal, $prob_{TransSuccessful.ji}[y]$ may be replaced by $prob_{TransSuccessful}[y]$ which represents the probability that any one of the transceivers Tj can transmit successfully to the transceiver Ti when separated by distance y. The probability density function representing the probability a transceiver j can transmit successfully to any one of the Transceiver Ti is given by $Pdf_{TransSuccessful.ji}[y]$ where

$$pdf_{TransSuccessful}[y]=\frac{prob_{TransSuccessful}[y]}{\int_{-\infty}^{\infty}prob_{TransSuccessful}[y]dy}$$

[0016] **FIG. 2** illustrates an exemplary probability density function representing the chances of successful transmission between a transmitter and receiver Ti as the distance between transmitter and receiver varies. The probability density function may be based on measurements for example by sounding the communication channel between transmitter and receiver. The probability density function may be an approximation, chosen to ease subsequent calculations. The illustrated probability density function is an approximation which eases subsequent calculations. It assumes that within a certain range of the transmitter the chances of reception are good and constant, but at a certain threshold distance from the transmitter the chances of reception decrease proportionally with the distance travelled from the threshold.

[0017] The transceivers T are preferably positioned in three dimensions with respect to three orthogonal linear axes. Although this is not essential, it provides advantages because the positioning of a transceiver with respect to one of the axes is independent of the positioning with respect to the other two axes. The transceiver is therefore positioned in three dimensions by positioning it separately with respect to each axes. In the following description the positioning of a transceiver Ti with respect to one axes is described. Analogous procedures are carried out for the remaining axes.

[0018] Each transceiver is positioned with respect to the linear axis using a probability density function. The transceiver Tj is positioned with respect to the linear axis by $pdf_j[z]$ where the argument indicates a position of the transceiver Tj from an origin common to the transceivers Tj . The function $pdf_j[z]$ varies as the argument varies having a maximal value at where the most likely acquired position for transceiver Tj is. The transceiver Ti will acquire its position by calculating a probability density function $pdf_i[z]$ for itself.

[0019] **FIG. 3** illustrates an exemplary probability density function $pdf_i[z]$ representing the probable location of a transceiver on the x-axis, where z represents a distance along the x-axis.

[0020] When the transceiver Ti is acquiring its position, it receives $pdf_j[z]$ from each of the N transceiver Tj where j=1, 2, 3 . . . N. That is it receives $pdf_1[z]$ from T**1**, $pdf_2[z]$ from T**2**, $pdf_3[z]$ from T**3**, etc.

[0021] If all transmitters Tj are equal, there is no necessity for each of the transmitters j to send $prob_{TransSuccessful.ji}[y]$. The values of $prob_{TransSuccessful}[y]$ may be stored in Ti. However, if the transmitters Tj have different transmission characteristics such as different transmission power levels then it may be appropriate for each of the transceivers Tj to transmit $prob_{TransSuccessful.ji}[y]$ to the transceiver Ti.

[0022] On the basis of this information the transceiver Ti can calculate its position according to a first order calculation. This first order calculation takes into account, the transceivers Tj with which the transceiver Ti can directly communicate. The calculation determines where the transceiver Ti could be because it can communicate with the transceivers Tj.

[0023] The transceiver Ti can calculate its position density function $pdf_i[z]$, which takes into account all the transceivers Tj, by combining the intermediate probability density functions $pdf_{ij}[y]$ calculated because the particular Transceiver Tj can communicate with Ti, for all j.

[0024] The intermediate probability density functions pdf_{ij} [y] calculated because the particular Transceiver Tj can communicate with Ti is given by:

$$pdf_{ij}[y] = \frac{\left(\int_{-\infty}^{\infty} pdf_j[z]prob_{TransSuccessful\cdot ji}[y-z]dz\right)}{\int_{-\infty}^{\infty}\left(\int_{-\infty}^{\infty} pdf_j[z]prob_{TransSuccessful\cdot ji}[y-z]dz\right)dy}$$

[0025] This can be converted using mathematics to:

$$pdf_{ij}[y] = \int_{-\infty}^{\infty} pdf_j[z]pdf_{TransSuccessful\cdot ji}[y-z]dz$$

[0026] The probability density function representing the position of the receiver Ti is therefore given by the convolution of the probability density function representing the position of the transmitter Tj with the probability density function representing the likelihood of successful transmission from the transmitter to receiver.

[0027] The transceiver Ti can calculate its position density function $pdf_i[z]$, which takes into account all the transceivers Tj, by combining the intermediate probability density functions $pdf_{ij}[y]$ calculated because the particular Transceiver Tj can communicate with Ti as follows:

$$pdf_i[y] = \frac{\prod_{j=1}^{N} \alpha_j pdf_{ij}[y]}{\sum_{y'}\left(\prod_{j=1}^{N} \alpha_j pdf_{ij}[y']\right)} \qquad \text{where } \sum_{j=1}^{N} \alpha_j = 1$$

[0028] where α_j is a parameter which represents how trustworthy the Transceiver Tj is. For example, if the transceiver Tj is a reference station it will have a high value, whereas if the transceiver Tj is very mobile it will have a low value. It should be appreciated that the values α_j may be transmitted by transceiver Tj to transceiver Ti (although renormalisation will be required such that $\Sigma\alpha_j=1$) , or the values of α_j may be calculated by Ti on the basis of information received from the transceivers Tj such as other indications of their trustworthiness.

[0029] The use of trustworthiness in the calculation can be disabled by setting $\alpha_j=1$ for all j.

[0030] The above calculation of $pdf_i[z]$ effectively determines the renormalised overlap of the probability density functions $pdf_{ij}[z]$ (taking into account their trustworthiness if appropriate) for all j. A problem, however, arises if the probability density functions $pdf_{ij}[z]$ do not overlap.

[0031] A preferred method of combining the intermediate probability density functions $pdf_{ij}[y]$ takes into account that the intermediate probability density functions $pdf_{ij}[y]$ may not all overlap. The method combines the intermediate probability density functions in a pair-wise fashion. If the pair of probability density functions which are to be combined do overlap the method calculates the renormalised overlap of the two intermediate probability density functions. However, if the pair of probability density functions which are to be combined do not overlap, the method calculates a weighted sum of the two probability density functions.

[0032] One manner of implementing the preferred method will now be described. In this preferred method the transceiver Ti, before it has acquired its new position, may have no current position or may have a position which has expired. If the current position has expired the variable $pdf_{i(old)}[y]$ is set equal to the current expired value of $pdf_i[y]$. If there is no current position the variable $pdf_{i(old)}[y]$ is set equal to 0. A temporary variable $pdf_{iTemp.j}[y]$ is assigned for use in the calculation. It is initially set for j=0, equal to $pdf_{i(old)}[y]$. The temporary variable $pdf_{iTemp.j-1}[y]$, is combined in a pair-wise fashion with $pdf_{i.j}[y]$, starting with the pair-wise combination of variable $pdf_{iTemp.0}[y]$ with $pdf_{i.1}$ [y] to produce $pdf_{iTemp.1}[y]$, then the pair-wise combination of $pdf_{iTemp.1}[y]$ with $pdf_{i.2}[y]$ to produce $pdf_{iTemp.2}[y]$, etc., ending with the pair-wise combination of $pdf_{iTemp.N-1}[y]$

with $pdf_{i.N}[y]$ to produce $pdf_{iTemp.2}[y]$ which is the position of Ti ($pdf_i[y]$)) taking into account only the first order transceivers Tj, for j=1, 2, 3 . . . N.

[0033] The method can be coded as follows:

[0034] Start Code:

[0035] Initial condition: $pdf_{iTemp.0}[y]=pdf_{i(old)}[y]$

[0036] Body of the loop started with j=1 and exited at j=N

[0037] {

[0038] (Test for overlap between $pdf_{iTemp.j-1}[y]$ & $pdf_{ij}[y]$)

$$\text{If } \sum_{y'} pdf_{iTempj}-1[y']pdf_{ij}[y'] \neq 0 \quad \text{then}$$

[0039] (If there is overlap, calculate the renormalised overlap)

$$pdf_{iTempj} = \frac{pdf_{iTempj}-1\lfloor y\rfloor \alpha_j pdf_{ij}\lfloor y\rfloor}{\sum_{y'} (pdf_{iTempj}-1[y']pdf_{ij}[y'])}$$

[0040] else

[0041] (If there is no overlap, calculate a weighted sum)

[0042] $pdf_{iTempj}[y]=pdf_{iTempj-1}[y]+\alpha_j pdf_{ij}[y]$

[0043] }End of loop

[0044] Final result: $pdf_i[y]=pdf_{iTemp.N}[y]$

[0045] End Code

[0046] Thus far the value of $pdf_i[y]$ representing the position of the transceiver Ti, takes into account only the transceivers Tj{j=1,2, . . . N}, which can communicate directly with the transceiver Ti. Each of the transceivers Tj may be able to directly communicate directly with transceivers with which the transceiver Ti is unable to directly communicate. Such transceivers are second order transceivers as the transceiver Ti which is acquiring its position cannot communicate to them directly but can receive information about them from the transceivers it can communicate with. Information about the second order transceivers can be used to additionally refine $pdf_i[y]$ so that it takes account not only of where the transceiver Ti could be because it can directly communicate with transceivers Tj but also where it could not be because it cannot communicate with the second order transceivers.

[0047] Let each of the second order transceivers be designated by Tk, where k≠j and k≠i, k=1,2 . . . M.

[0048] In the above coding, the loop is directly followed and the "Final result" is directly preceded by the coding:

[0049] Body of the loop started with k=1 and exited at k=M

$$\left\{ prob_{noreception\cdot ki}[y] = \right.$$

$$\sum_z pdf_k[z](1 - prob_{TransSuccessful\cdot ki}[y-z])pdf_{iTempk} =$$

$$\frac{pdf_{iTempN}\lfloor y\rfloor \cdot prob_{noreception\cdot ki}\lfloor y\rfloor}{\sum_{y'} (pdf_{iTempN}[y] \cdot prob_{noreception\cdot ki}[y])} pdf_{iTemp\cdot N}[y] =$$

$$\left. pdf_{iTemp\cdot k}[y] \right\} \text{end of loop}$$

[0050] It will be necessary for the transceiver to receive the values of $pdf_k[y]$ via the first order transceivers which are in communication with the second order transceivers.

[0051] Likewise $prob_{TransSuccessful.ki}[y]$ should also be transmitted to Ti via the first order transceivers Tj. However, if all the second order transceivers are the same then $prob_{TransSuccessful.ki}[y]$ will be a constant and can be stored. According to a one embodiment, the approximate value $prob_{TransSuccessful}[y]$ which was used in the first order calculations is also used in the second order calculations.

[0052] The probability density function representing a position of a transceiver will normally have a normal distribution as illustrated in **FIG. 3**. Advantages can be achieved by assuming such pdfs have a normal distribution. The completed information required to define a normal distribution is the mean and the standard deviation. Consequently the probability density function representing the position of a transceiver can be transmitted using only two parameters—the mean and standard deviation.

[0053] **FIG. 4** illustrates a transceiver suitable for carrying out the invention. It comprises transmitter circuitry, receiver circuitry, a processor and a memory. The memory stores the above described algorithm. The processor executes the algorithm. The parameters used as input to the algorithm are stored in the memory and the result of the algorithm, the position of the transceiver, is also stored in the memory. When the transceiver operates as a receiver, to acquire its position, it receives the parameters it requires for the algorithm from the transceivers it is in communication with and stores them in the memory. When the transceiver operates as a transmitter, it is operable to transmit its stored position to the receiving transceiver using its transmission circuitry. The algorithm may be transported for transfer to a transceiver using a carrier such as a CD-ROM or floppy disc.

[0054] Although the present invention has been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications and variations to the examples given can be made without departing from the spirit and scope of the invention.

1. A receiver for calculating its position according to a first transmitter, having a processor arranged to convolve:

(i) the probability density function representing the position of the first transmitter, sent by the first transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from the first transmitter will be successfully received at the receiver.

2. A receiver as claimed in claim 1 for calculating its position according to a second transmitter, having a processor arranged to convolve:

(i) the probability density function representing the position of the second transmitter, sent by the second transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from the second transmitter will be successfully received at the receiver.

3. A receiver as claimed in any preceding claim wherein the probability density function representing the likelihood that a transmission from the first transmitter will be successfully received at the receiver is an approximation which simplifies processing.

4. A receiver as claimed in claim 2 or **3**, wherein the probability density function representing the likelihood that a transmission from the first transmitter will be successfully received at the receiver is the same as the probability density function representing the likelihood that a transmission from the second transmitter will be successfully received at the receiver.

5. A receiver as claimed in claim 1 for calculating its position according to a plurality of transmitters, having a processor arranged to calculate a probability density function for each of said plurality of transmitters by the convolution of

(i) the probability density function representing the position of one of the plurality of said transmitters, sent by said one transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from said one transmitter will be successfully received at the receiver

and arranged to combine the resultant plurality of probability density functions.

6. A receiver as claimed in claim 5 wherein the combination of the resultant probability density functions involves pair-wise combination of probability density functions.

7. A receiver as claimed in claim 6 wherein the pair-wise combination involves the multiplication of one probability density function with another.

8. A receiver as claimed in claim 5 wherein the pair-wise combination involves the addition of one probability density function with another.

9. A receiver as claimed in claim 7 or **8**, wherein the combination is a weighted combination.

10. A receiver as claimed in claim 9 wherein the weighted combination increases the contribution made from probability density functions derived from trusted transmitters.

11. A receiver as claimed in any preceding claim wherein the transmitters are not permanent infrastructure.

12. A method of calculating the position of a receiver by communication with a plurality of transceivers comprising the steps of, for each of said plurality of transmitters, convolving

(i) the probability density function representing the position of a transmitter, sent by the transmitter to the receiver; with

(ii) the probability density function representing the likelihood that a transmission from the transmitter will be successfully received at the receiver

and combining the plurality of convolution products.

13. A method as claimed in claim 12 wherein the receiver is the Master transceiver in an ad-hoc network of Bluetooth transceivers and the plurality of transmitters are Slave transceivers in that Bluetooth network.

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