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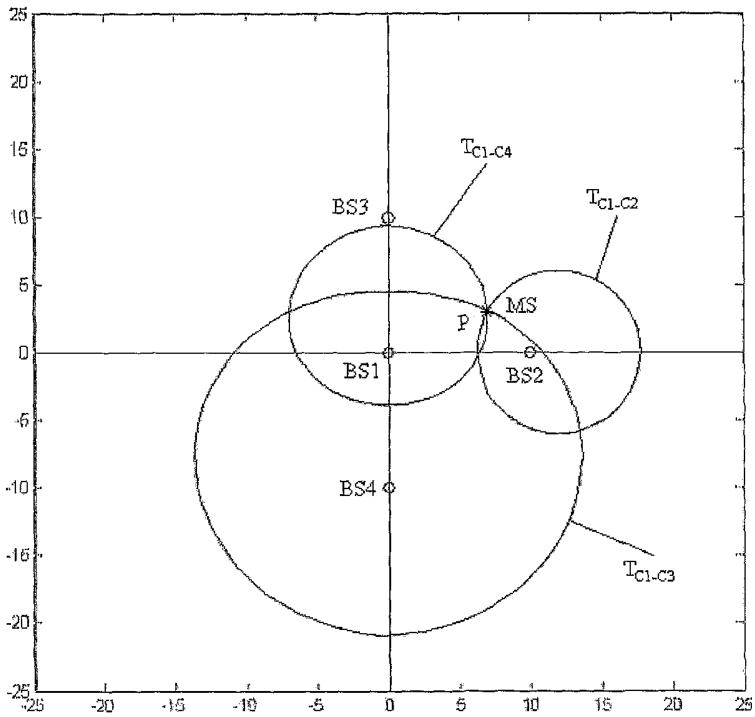
(54) Title: POSITION LOCATION VIA GEOMETRIC LOCI CONSTRUCTION



(57) Abstract: The invention falls into the field of wireless communications and electromagnetic waves propagation. More specifically, part of the invention falls into the field of position location, or estimation of the location of a wireless device. The invention solves the problem of categorizing transmitters with contiguous propagation attenuation factors to a wireless device. The invention estimates the values of these factors, and also estimates the position of the wireless device - or "locates" the device. This problem is affronted by proper geometric loci construction. At the same time, an internal criterion is calculated in order to evaluate the results of the location procedure. The invention comes at the desiring results with minimum input: the positions of the transmitters and the Received Signal Strength (R.S.S.) from each transmitter at the position of the wireless device (and also supplemental information, such as the gain of the transmitters' and receiver's antenna etc.). The invention may be employed to any wireless network, since it may be incorporated into existing and inexpensive network equipment. Therefore, the invention may be employed to either new or already existing and running networks. It is especially suited for operation in unknown environments, since topographical maps are not needed. The costly and sometimes impracticable procedure of on-the-field pre-measurements is avoided. Additionally, expensive equipment, such as directional or switched-beam or adaptive antenna arrays, is not required. The invention overcomes most of these problems, which are characteristic of existing location methods, as presented in the "Description" part.

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DESCRIPTION

Position Location via Geometric Loci Construction.

The scientific field of the invention is wireless communications and electromagnetic waves propagation. More specifically, part of the invention falls into the field of position location, or estimation of the location of a wireless device.

The calculation of the propagation attenuation factor, in relative research, is usually performed as part of a larger procedure, related to propagation modeling. In the literature, there are a large number of relative papers, such as in [1]-[8]. In these papers, the positions of both transmitter and receiver are known, and the object of research is the extraction of a law of propagation, and/or the calculation of the propagation attenuation factor, which determines the loss of signal strength with respect to the transmitter-receiver distance.

Location of a wireless unit is also subject of extended research during the last years. As an example, consider the development of Global Positioning System (GPS). In GPS, an extra component, known as GPS receiver, is needed at the user's side, in order for the system to work. This means extra cost and size for the wireless unit. Furthermore, GPS suffers in indoor environments, due to large loss of signal strength during penetration of concrete walls, which means that GPS can not be used in indoor LANs.

There are a number of advanced position location (PL) techniques, alternative to GPS, for wireless device positioning. These techniques are known as Radio-Frequency (RF) or network-based techniques, and are categorized as Direction Finding systems (DF systems) and Range Based systems (RB systems) [9]. DF techniques estimate the position location of a mobile station (MS) by measuring the Angle-Of-Arrival (AOA) of the incoming signal, from the MS to a sufficient number of Base Stations (BSs). (Hereinafter, the term BS will generally refer to a fixed transceiver, with known position, and not only to cellular systems BSs.) On the other hand, RB techniques estimate the position of a MS by measuring the distance between the MS and a sufficient number of BSs. RB techniques may be further categorized as ranging, range-sum or range difference, if range estimates are based on Time-Of-Arrival (TOA), Time-Sum-Of-Arrival (TSOA) or Time-Difference-Of-Arrival (TDOA) measurements of the incoming signal, respectively. Furthermore, distance measurements may be implemented based on the signal strength of the incoming signal.

DF techniques are used in macrocell networks, such as cellular telephony networks, where BSs and the MS are located at large distances, and there is also a large difference between the heights of the antennas of the BSs and that of the MS. Advanced AOA measurement techniques, such as MUSIC or ESPRIT are used [9]-[11]. A major disadvantage of these techniques is the need for expensive equipment and hardware for the AOA estimation [12], such as accurately calibrated antenna arrays etc. Furthermore, in microcells, BSs may be placed at heights below building rooftops. This case also occurs in indoor networks (such as WLANs). In this and other cases, multipath propagation strongly affects AOA techniques, because multiple replicas of the signal arrive at the receiver from different directions [12]. Therefore, DF systems may not perform accurately in such cases.

RB techniques based on TOA measurements are also widespread. These techniques also suffer from multipath propagation, because multiple replicas of the signal arrive at the receiver at different times of arrival. Furthermore, in Non-Line-Of-Sight (NLOS) conditions, only reflected and scattered replicas of the signal arrive at the receiver, making TOA measurements and position location even more inaccurate. Finally, these techniques also need expensive and accurately synchronized hardware (clocks) at the BSs.

RB techniques, which utilize signal strength measurements, have the advantage that they do not need expensive hardware, because signal strength measurement is implemented using inexpensive off-the-shelf components. These systems use either models of propagation and topographical maps of the area of coverage, or in-situ signal strength measurements in selected locations. In the literature, these systems are used in outdoor [13] and indoor environments [14]-[18]. The disadvantage of these techniques is exactly the need for topographical maps or in-situ measurements. Using a statistical propagation model only, yields large inaccuracies, due to the large-scale fading phenomenon. Large-scale fading is caused by shadowing effects of large buildings or natural features [19]-[21]. Even when topographical maps are available, the achieved accuracy is usually not adequate. Furthermore, in-situ measurements are an extremely expensive procedure, and are not always applicable, such as in emergency situations.

The invention, with minimum input the positions of a sufficient number of BSs, and the signal strength from each BS at the MS's position, determines which of the BSs have the same (or contiguous) attenuation factor to the MS, calculates these factors and estimates the MS's position. This is accomplished by using propagation laws and constructing proper geometric loci. The core of the invention is the construction of the geometric loci, as well as a method for revealing the values of the attenuation factors and the position of the MS.

The invention may be incorporated into any wireless network (cellular networks, wireless local area networks, sensor networks etc.), since it may be embodied into existing and inexpensive network equipment (e.g. 802.11 standard mandates on received signal strength indicators [RSSI]). Furthermore, the invention may be incorporated to already existing and functional networks. It is especially suited for operation in unknown environments (e.g. sensor networks), since topographical maps are not needed. The costly and sometimes impracticable procedure of on-the-field pre-measurements is avoided. Additionally, expensive equipment, such as directional, or switched-beam, or adaptive antenna arrays, is no longer required. The invention overcomes most of these problems, which are characteristic of existing location methods, as aforementioned. For these reasons, the invention offers the possibility of locating a wireless unit with minimum prerequisites and inexpensive equipment.

Attached figures present the principles of the invention, and offer an intuitive understanding.

In figure 1, an example of two Base Stations (BSs), namely BS1, BS2, with the same attenuation factor to a Mobile Station (MS) is presented.

The example of figure 1 is further analyzed in figure 2. If an arbitrary attenuation factor is presumed, then, by measuring the received signal strength by the MS from each BS, two circles will be created. The MS must lie on these circles. Therefore, for this arbitrary attenuation factor, the MS must lie on either of the two intersection points, P1, P2, of these circles (see figure 2). If no intersection point exists, then the presumed attenuation factor is a priori rejected.

In figure 3, the evolution of the case study presented in figure 2 is illustrated. If the arbitrary attenuation factor scans an (arbitrary) interval, then, two circle groups, $C1, C2$, are constructed. The circles of these groups are centered at the fixed positions of BS1 and BS2 respectively, and their radii are calculated using the instantaneous hypothetical value of the attenuation factor (similarly to figure 2 description). The geometric locus of the *intersection points* of the groups $C1, C2$ is denoted by T_{C1-C2} in figure 2. The MS must lie on this locus, and the locus represents all possible locations of the MS.

In figure 4, the case study becomes a little more complicated. Let there be a third BS, namely BS3, with the same attenuation factor to the MS as BS1 and BS2. Then, similarly as aforementioned, a third circle group, namely $C3$, is constructed. In figure 4, the geometric loci T_{C1-C2}, T_{C1-C3} of the intersection points of the groups $C1$-$C2$ and $C1$-$C3$ respectively are illustrated. The locus T_{C2-C3} of the intersection points of the groups $C2$-$C3$ is not illustrated for clarity, since it bears no further information on the location of the MS. The MS must lie on the intersection points between the loci T_{C1-C2}, T_{C1-C3}, T_{C1-C3}, which are illustrated in figure 4 as P1 and P2. The reason why T_{C2-C3} bears no further information, is because the intersection points between the loci are not further restricted if T_{C2-C3} is used instead of T_{C1-C2} or T_{C1-C3}.

The case of a fourth BS, namely BS4, with the same attenuation factor to the MS as BS1, BS2 and BS3, is presented in figure 5. Similarly, the circle group $C4$ is constructed. Figure 5 presents the geometric loci T_{C1-C2}, T_{C1-C3}, T_{C1-C4}. The locus T_{C1-C4} corresponds to the intersection points of the groups $C1$-$C4$. The MS possible location is restricted to an unambiguous location, namely the joint intersection point of the loci T_{C1-C2}, T_{C1-C3}, T_{C1-C4}. This point is denoted as P in figure 5.

The case of four BSs, which have similar (contiguous) but not equal attenuation factors to the MS, is presented in figure 6. The geometric loci T_{C1-C2}, T_{C1-C3}, T_{C1-C4} do not have a joint intersection point, as they did in figure 5. But, as the invention scans the estimator of the contiguous attenuation factors, there is a value of the estimator for which the sum of distances between the loci is minimal. This value may be used as the estimate of the contiguous attenuation factors, and the position of the device may be estimated as the average of the points P1, P2 and P3 of figure 6. The points P1, P2 and P3 are the points of the geometric loci which correspond to the minimum sum of distances between these loci. The real MS position is not displayed for clarity.

In figure 7, another case study is presented. In this study, there are five BSs, namely BS1, BS2, BS3, BS4, BS5. Let BS1, BS2 and BS3 have contiguous attenuation factors to the MS. Let BS4 and BS5 have contiguous attenuation factors to the MS, but not contiguous to the ones of BS1, BS2 and BS3. The invention scans all possible values of the two estimators of these factors. Thus, the circle groups $C1, C2, C3, C4, C5$ and the geometric loci T_{C1-C2}, T_{C1-C3}, T_{C4-C5} are constructed, in a way similar to the one aforementioned. The locus T_{C4-C5} corresponds to the intersection points between the groups $C4$-$C5$. The values of the estimators which correspond to the minimum sum of distances between the respective points of the loci, are used as the estimates of the real attenuation factors. The location of the device is estimated as the average of the point P1, P2 and P3 of figure 7. These points correspond to the estimates of the real attenuation factors. The real location of the MS is not displayed for clarity.

The case of six BSs, namely BS1, BS2, BS3, BS4, BS5, BS6, is presented in figure 8. Let BS1 and BS2 have contiguous attenuation factors to the MS. Let BS3 and BS4 have contiguous attenuation factors to the MS, but not contiguous to the ones of BS1 and BS2. Finally, let BS5 and BS6 have contiguous attenuation factors to the MS, but not contiguous to the ones of BS1, BS2, BS3 and BS4. Similarly as in the four and five BSs cases, the circle groups $C1, C2, C3, C4, C5, C6$ and the loci T_{C1-C2}, T_{C3-C4}, T_{C5-C6} are constructed. Again, the values of the attenuation factors estimators, which correspond to the minimum sum of distances between the loci, are used as the estimates of the real attenuation factors. The location of the device is estimated as the average of the points P1, P2 and P3 of figure 8. These points correspond to the estimates of the real attenuation factors. The real location of the MS is not displayed for clarity.

Hereinafter, it is assumed that there are a number of fixed transmitters, referred to as BSs, and a mobile receiver or wireless device/unit, referred to as MS. The terms BS and MS will generally refer to a transmitter and receiver, respectively, and should not be confused with cellular networks terminology. A number of assumptions need to be made prior to the presentation of the invention.

The MS is assumed to be placed at the unknown position (x_{MS}, y_{MS}), in an arbitrary, but known, coordinates system. The MS can sense signals from a maximum number of BSs, namely $N_{BS,MAX}$. Let $N_{BS,MAX} \in \mathrm{N}$ and $N_{BS,MAX} \geq 4$. The received signal strength measurement from each BS can be performed by the MS, since most current MSs have the capability of signal strength indication. However, this is not a prerequisite for the invention.

Let $i \in \{1,\ldots,N_{BS,MAX}\}$, and let the i-th transmitter be placed at the known position $(x_{BS,i}, y_{BS,i})$, of the same coordinates system to the MS (the i-th transmitter's position can be provided by the network administrator). Consequently, the unknown distance d_i between the MS and the i-th transmitter will be given by $d_i = \sqrt{(x_{BS,i} - x_{MS})^2 + (y_{BS,i} - y_{MS})^2}$.

The BSs transmit to a known output power (easily provided by the network administrator). The antennas of the BSs and the MS are considered to be omnidirectional and their respective gains are considered to be known. Therefore, the reference power level, that the MS theoretically receives at 1m distance from each BS, is known and denoted by $P_{0,i}$. The received signal strength at the MS's position, from each BS, is denoted by P_i.

The invention selects a number of BSs, namely N_{BS}, which will be used for the position location of the MS. The selection of the specific N_{BS} transmitters is based on criteria that are irrelevant to the algorithm of the invention. The main reason for restricting the number of BSs to be taken into account is computational burden, which means more time needed for the algorithm to be executed. On the other hand, a more accurate result is expected as N_{BS} increases. The user of the invention will determine the value of N_{BS}. A possible criterion for selecting transmitters is to select those transmitters with the strongest signal strength received by the MS, up to a maximum of e.g. nine transmitters (the maximum depends on the computational power available to the user of the invention).

Furthermore, it should be noted, that the attenuation factor between the MS and the i-th transmitter, namely n_i, ranges vastly, depending on the propagation channel. Evidently, $n_i \in [n_{\min}, n_{\max}]$. Determining the bounds of n_i is irrelevant to the invention, and should be performed by the user of the invention. In practical cases, $n_{\min}$ will be around 2, and $n_{\max}$ will be around 7 to 8, or more.

Based on the assumptions made above, consider the simple case of two BSs, namely BS1 and BS2, placed at (x_{BS1}, y_{BS1}) and (x_{BS2}, y_{BS2}) respectively, and a MS placed at (x_{MS}, y_{MS}), as illustrated in figure 1. The positions of BS1 and BS2 are considered known, while the position of the MS is considered unknown. The distance between the MS and BS1, BS2, is denoted by d_1, d_2 respectively, and given by:

$$d_1 = \sqrt{(x_{BS1} - x_{MS})^2 + (y_{BS1} - y_{MS})^2} \quad (1)$$

$$d_2 = \sqrt{(x_{BS2} - x_{MS})^2 + (y_{BS2} - y_{MS})^2} \quad (2)$$

Hereinafter, the theoretical received signal strength by the MS, at 1m distance by *any* BS, will be assumed to be equal to P_o, without loss of generality. The received signal strength from BS1 and BS2, is denoted by P_1, P_2 respectively, and given by [19]:

$$P_1 = \frac{P_0}{d_1^{n1}} \quad (3)$$

$$P_2 = \frac{P_0}{d_2^{n2}} \quad (4)$$

From equations (3) and (4), it is shown that the received power is inversely proportional to the distance raised by an exponent. This exponent is the attenuation factor, and is denoted by n_1, n_2 for BS1,BS2 respectively. The received signal strength exhibits large scale and small scale fading [19], which will be discussed further below.

The factors n_1, n_2 and the distances d_1, d_2 are unknown. Let n_1, n_2 be equal to each other, i.e. $n_1 = n_2 = n$. By using the equations (3) and (4), estimates for d_1, d_2 can be obtained, for any arbitrary value of the estimator $\bar{n}$ of n. The estimates of d_1, d_2, for an arbitrary value of $\bar{n}$, are denoted by $\bar{d}_1(\bar{n}), \bar{d}_2(\bar{n})$ and given by:

$$\bar{d}_1(\bar{n}) = \left(\frac{P_0}{P_1}\right)^{1/\bar{n}} \quad (5)$$

$$\bar{d}_2(\bar{n}) = \left(\frac{P_0}{P_2}\right)^{1/\bar{n}} \quad (6)$$

As the estimator $\bar{n}$ scans the interval $[n_{\min}, n_{\max}]$ with step n_{step}, the estimates $\bar{d}_1(\bar{n}), \bar{d}_2(\bar{n})$ are calculated by equations (5) and (6).

(The value of n_{step} is irrelevant to the algorithms of the invention. Evidently, a larger value of n_{step} implies faster execution of the algorithm and a less accurate result. On the other hand, a smaller value of n_{step} implies more accurate results with the cost of increased execution time. Determining the value of n_{step} should take into account the computational power available to the user of the invention.)

The estimates $\bar{d}_1(\bar{n}), \bar{d}_2(\bar{n})$ define circle groups, centered at the BSs locations. These groups are denoted by $C_1(x_{BS1}, y_{BS1}, \bar{d}_1(\bar{n})), C_2(x_{BS2}, y_{BS2}, \bar{d}_2(\bar{n}))$, i.e. by their respective centers and radii. The MS must lie on the intersection points of these circles. This is illustrated in figure 2, where an arbitrary value of $\bar{n}$ is selected (different to the real value of n). The intersection points P1 and P2 constrain the possible MS locations, for the specific value of $\bar{n}$. If for a value of $\bar{n}$ the corresponding circles do not intersect each other, then this value is discarded. If the circles are adjacent, there is only one "intersection" point and one possible MS location.

The set of all intersection points, so far defined, for all values of $\bar{n} \in [n_{\min}, n_{\max}]$, determines a geometric locus. This locus, displayed in figure 3, is denoted by T_{C1-C2}. The geometric locus is a closed curve, definitely passes by the MS location, and encloses one BS. The BS enclosed is the one closest to the MS. Note that figure 3 displays a geometric locus and not a circle centered at BS2. Evidently, the MS location lies on the locus T_{C1-C2}.

Let there be a third BS, namely BS3, placed at (x_{BS3}, y_{BS3}), at a distance d_3 from the MS, transmitting at the same power level as BS1 and BS2. Let the attenuation factor of BS3 to the MS be n, equal to the ones of BS1 and BS2. The power P_3 that the MS receives from BS3 is given by:

$$P_3 = \frac{P_0}{d_3^n} \quad (7)$$

while the estimate of the distance d_3 for an arbitrary value of the estimator $\bar{n} \in [n_{\min}, n_{\max}]$, is denoted by $\bar{d}_3(\bar{n})$ and given by:

$$\bar{d}_3(\bar{n}) = \left(\frac{P_0}{P_3}\right)^{1/\bar{n}} \tag{8}$$

Similarly to the aforementioned analysis, a circle group $C_3(x_{BS3}, y_{BS3}, \bar{d}_3(\bar{n}))$ is constructed. Furthermore, the geometric locus T_{C1-C3} of the intersection points between $C_1(x_{BS1}, y_{BS1}, \bar{d}_1(\bar{n}))$ and $C_3(x_{BS3}, y_{BS3}, \bar{d}_3(\bar{n}))$, as well as the geometric locus T_{C2-C3} of the intersection points between $C_2(x_{BS2}, y_{BS2}, \bar{d}_2(\bar{n}))$ and $C_3(x_{BS3}, y_{BS3}, \bar{d}_3(\bar{n}))$ are constructed. The loci T_{C1-C2} and T_{C1-C3} are displayed in figure 4. The locus T_{C2-C3} is not displayed for clarity. The locus T_{C1-C3} is a closed curve, enclosing BS1, since BS1 is closer to the MS than BS3. The intersection points of the two loci, denoted by P1 and P2, are also displayed in figure 4. The points P1 and P2 of figure 4, are the only possible locations of the MS. Thus, the location of the MS and the value of $\bar{n}$ are significantly restricted. It should be noted that the locus T_{C2-C3} is also a closed curve, enclosing BS2. However, the locus T_{C2-C3} will have the same intersection points P1 and P2 with the other two loci. Therefore, the locus T_{C2-C3} does not bare any further information on the MS location or the attenuation factor value, and is not displayed in figure 4 for clarity.

Let there be a fourth BS, namely BS4, placed at (x_{BS4}, y_{BS4}), at a distance d_4 from the MS, and let the attenuation factor between BS4 and the MS be also n. The received power by the MS, from BS4, is denoted by P_4 and given by:

$$P_4 = \frac{P_0}{d_4^n} \tag{9}$$

while the estimate of the distance between the MS and BS4, for a value of the estimator $\bar{n} \in [n_{\min}, n_{\max}]$, is given by:

$$\bar{d}_4(\bar{n}) = \left(\frac{P_0}{P_4}\right)^{1/\bar{n}} \tag{10}$$

Similarly, the circle group $C_4(x_{BS4}, y_{BS4}, \bar{d}_4(\bar{n}))$ is created, and the geometric locus T_{C1-C4} of the intersection points between the groups $C_1(x_{BS1}, y_{BS1}, \bar{d}_1(\bar{n}))$ and $C_4(x_{BS4}, y_{BS4}, \bar{d}_4(\bar{n}))$ is constructed. The geometric loci T_{C2-C3}, T_{C2-C4}, T_{C3-C4} may also be constructed. Figure 5 displays the loci T_{C1-C2}, T_{C1-C3}, T_{C1-C4}. Evidently, these loci have a joint intersection point, which is denoted by P in figure 5. The loci T_{C2-C3}, T_{C2-C4}, T_{C3-C4} do not bear additional information on the MS's location, and are not displayed in figure 5, for clarity. Consequently, the only possible location of the MS is the joint intersection point P, and the only possible attenuation factor value, is the estimate that corresponds to this point. Thus, an estimate of the attenuation factor n, and also an estimate of the MS's position, are specified. The existence of more than four BSs with the same attenuation factor to the MS, will not improve the estimation of the MS's location.

The invention can also estimate the attenuation factors between four BSs and the MS, in the case where these factors are contiguous to one another instead of equal. In this case, the received signal strength from each BS is given by:

$$P_1 = \frac{P_0}{d_1^{n1}} \tag{11}$$

$$P_2 = \frac{P_0}{d_2^{n2}} \tag{12}$$

$$P_3 = \frac{P_0}{d_3^{n3}} \tag{13}$$

$$P_4 = \frac{P_0}{d_4^{n4}} \tag{14}$$

where n_1, n_2, n_3, n_4 are the attenuation factors between the MS and BS1, BS2, BS3 and BS4 respectively. In this case, a common estimator $\bar{n} \in [n_{\min}, n_{\max}]$ of n_1, n_2, n_3, n_4 is generated. For each value of $\bar{n} \in [n_{\min}, n_{\max}]$, the estimates $\bar{d}_1(\bar{n})$, $\bar{d}_2(\bar{n})$, $\bar{d}_3(\bar{n})$, $\bar{d}_4(\bar{n})$ of the distances d_1, d_2, d_3, d_4 respectively are calculated:

$$\bar{d}_1(\bar{n}) = \left(\frac{P_0}{P_1}\right)^{1/\bar{n}} \tag{15}$$

$$\bar{d}_2(\bar{n}) = \left(\frac{P_0}{P_2}\right)^{1/\bar{n}} \tag{16}$$

$$\bar{d}_3(\bar{n}) = \left(\frac{P_0}{P_3}\right)^{1/\bar{n}} \quad (17)$$

$$\bar{d}_4(\bar{n}) = \left(\frac{P_0}{P_4}\right)^{1/\bar{n}} \quad (18)$$

In this case, the constructed loci $T_{C1-C2}, T_{C1-C3}, T_{C1-C4}$ do not present a joint intersection point. However, as $\bar{n}$ scans $[n_{\min}, n_{\max}]$ with step n_{step}, there are up to two corresponding points on each locus. Therefore, the distance between two loci, for a value of $\bar{n}$, is defined as the minimum distance between the points of these loci, for this value of $\bar{n}$. If for a value $\bar{n}_{val,1} \in [n_{\min}, n_{\max}]$ the corresponding points on locus 1 are A and B, and for a value $\bar{n}_{val,2} \in [n_{\min}, n_{\max}]$ the corresponding points on locus 2 are C and D, the distance between these two loci, for the specific values of attenuation factor estimators, is the minimum among the distances A-C, A-D, B-C and B-D, i.e. the distance given by:

$$Distance(\bar{n}_{val,1}, \bar{n}_{val,2}) = \min\{d(\mathrm{A},\mathrm{C}), d(\mathrm{A},\mathrm{D}), d(\mathrm{B},\mathrm{C}), d(\mathrm{B},\mathrm{D})\} \quad (19)$$

where $d(\mathrm{X},\mathrm{Y})$ denotes the distance between the points X and Y. Hereinafter, the term distance between two loci will refer to the distance defined by equation (19).

Consequently, the loci $T_{C1-C2}, T_{C1-C3}, T_{C1-C4}$ are characterized by a distance between each other, which is a function of $\bar{n}$. The sum of these distances is also a function of $\bar{n}$. The minimum distant points of the loci $T_{C1-C2}, T_{C1-C3}, T_{C1-C4}$, as $\bar{n}$ scans $[n_{\min}, n_{\max}]$, are used for the estimation of the MS's location. The term "minimum distant points" means that the **sum of distances** between the loci $T_{C1-C2}, T_{C1-C3}, T_{C1-C4}$ is minimum. The corresponding value of the estimator $\bar{n} \in [n_{\min}, n_{\max}]$ is the estimate of the contiguous factors n_1, n_2, n_3, n_4. Furthermore, the MS's location is estimated by the average of the corresponding "minimum distant" points of the loci $T_{C1-C2}, T_{Ci-C3}, T_{C1-C4}$. This case is illustrated in figure 6, where the "minimum distant points" are denoted by P1, P2 and P3. Thereby, the estimate of the MS's location is (x, y), where x and y are given by:

$$x = \frac{x_1 + x_2 + x_3}{3} \quad (20)$$

$$y = \frac{y_1 + y_2 + y_3}{3} \qquad (21)$$

where (x_1, y_1), (x_2, y_2), (x_3, y_3) are the coordinates of the points P1, P2, P3 in figure 6, respectively.

It should be noted that in figure 6, the loci intersect. In another case study, the loci will possibly not intersect, but the attenuation factors and the MS's location are estimated using the minimum sum of distances between the geometric loci in any case. If one or more of the loci T_{C2-C3}, T_{C2-C4}, T_{C3-C4} are used alternatively, the estimation outcome may be slightly different.

The invention uses an internal criterion in order to estimate the accuracy of the attenuation factor and the MS's position estimation procedure. Evidently, this criterion cannot be the true accuracy of position location, since the position of the MS is unknown. Thereby, it should be noted that when the attenuation factors n_1, n_2, n_3, n_4 are equal to one another, there is only one joint intersection point, while the same is not true when the factors n_1, n_2, n_3, n_4 are contiguous. The minimum sum of distances between the "minimum distant points" will be larger for more dissimilar attenuation factors. Therefore, the *Measure of Applicability* (*MA*) is defined as:

$$MA = \frac{1}{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} + \sqrt{(x_1 - x_3)^2 + (y_1 - y_3)^2} + \sqrt{(x_2 - x_3)^2 + (y_2 - y_3)^2}} \qquad (22)$$

where (x_1, y_1), (x_2, y_2), (x_3, y_3) are the coordinates of the "minimum distant points" (e.g. the points P1, P2, P3 in figure 6, respectively). The *Measure of Applicability* is an alternative to the real accuracy and can be used in order to evaluate the result of the overall estimation procedure. Evidently, the *MA* in equation (22) is the inverse of the minimum sum of distances between the geometric loci. A larger *MA* corresponds to a more accurate estimation.

The invention, described so far, is able of revealing the MS's location, in the case where there are four BSs, as long as these BSs are characterized by similar attenuation factors to the MS. In the case where more than four BSs are available, the invention is able to categorize BSs with contiguous attenuation factors, estimate these factors, and also estimate the MS's position. The cases of 5, 6 or more BSs are now described.

Let there be five BSs, namely BS1, BS2, BS3, BS4, BS5, characterized by the attenuation factors n_1, n_2, n_3, n_4, n_5 to the MS, at a distance of d_1, d_2, d_3, d_4, d_5 away from the MS, placed at $(x_{BS1}, y_{BS1}), (x_{BS2}, y_{BS2}), (x_{BS3}, y_{BS3}), (x_{BS4}, y_{BS4}), (x_{BS5}, y_{BS5})$ respectively. The received power by the MS, from each BS, is given by:

$$P_1 = \frac{P_0}{d_1^{n1}},\ P_2 = \frac{P_0}{d_2^{n2}},\ P_3 = \frac{P_0}{d_3^{n3}},\ P_4 = \frac{P_0}{d_4^{n4}},\ P_5 = \frac{P_0}{d_5^{n5}} \quad (23)$$

Let the factors n_1, n_2, n_3 be contiguous to each other, and the factors n_4, n_5 be contiguous to each other, but not contiguous to n_1, n_2, n_3. The estimator $n_A \in [n_{\min}, n_{\max}]$ of n_1, n_2, n_3, and the estimator $n_B \in [n_{\min}, n_{\max}]$ of n_4, n_5 are generated. Using the method that was described for the case of three BSs (refer to figure 4), the geometric loci T_{C1-C2}, T_{C1-C3} are constructed. Then, the method that was used in the case of two BSs (refer to figure 3) is applied, and the locus T_{C4-C5} is constructed. Thus, three loci are constructed, which ideally should have a joint intersection point. Practically, as n_A scans $[n_{\min}, n_{\max}]$ with step n_{step}, and n_B scans $[n_{\min}, n_{\max}]$ with step n_{step}, there is a value for n_A and a value for n_B, for which the sum of distances between the loci is minimum. These values are the estimates of the attenuation factors. It should be noted, that the sum of distances is now a function of n_A and n_B. The case study is illustrated in figure 7, where the points P1, P2 and P3, of the loci $T_{C1-C2}, T_{C1-C3}, T_{C4-C5}$, corresponding to the minimum sum of distances, are displayed. The MS's position is estimated as the average of P1, P2 and P3, as defined by equations (20) and (21). Finally, the *MA* of the specific triplet-pair combination is calculated.

The invention is functional even in the case where it is not known which exactly of the five BSs are characterized by contiguous attenuation factors. In this case, all possible combinations of five BSs taken three at a time are configured (the order of selection is immaterial). Then, the *MA* is calculated for each triplet-pair combination. The combination corresponding to the optimum (maximum) *MA*, among the configured triplet-pair combinations, is the dominant combination, and is used in order to estimate the MS's position.

Let there be 6 BSs, namely BS1, BS2, BS3, BS4, BS5, BS6, with attenuation factors n_1, n_2, n_3, n_4, n_5, n_6, at a distance d_1, d_2, d_3, d_4, d_5, d_6 away from the MS, placed at $(x_{BS1}, y_{BS1}), (x_{BS2}, y_{BS2}), (x_{BS3}, y_{BS3}), (x_{BS4}, y_{BS4}), (x_{BS5}, y_{BS5}), (x_{BS6}, y_{BS6})$ respectively. The received power by the MS, from each BS, is given by:

$$P_1 = \frac{P_0}{d_1^{n1}},\ P_2 = \frac{P_0}{d_2^{n2}},\ P_3 = \frac{P_0}{d_3^{n3}},\ P_4 = \frac{P_0}{d_4^{n4}},\ P_5 = \frac{P_0}{d_5^{n5}},\ P_6 = \frac{P_0}{d_6^{n6}} \quad (24)$$

Let the factors n_1, n_2 be contiguous to each other, the factors n_3, n_4 be contiguous to each other but not contiguous to n_1, n_2, and the factors n_5, n_6 be contiguous to each other, but not contiguous to n_1, n_2, n_3, n_4. The estimator $n_A \in [n_{\min}, n_{\max}]$ of n_1, n_2, the estimator $n_B \in [n_{\min}, n_{\max}]$ of n_3, n_4 and the estimator $n_C \in [n_{\min}, n_{\max}]$ of n_5, n_6 are generated. Similarly to the case of two BSs (refer to figure 3), the geometric loci T_{C1-C2}, T_{C3-C4}, T_{C5-C6} are constructed. Thus, three loci are constructed, which ideally should have a joint intersection point. Practically, as n_A scans $[n_{\min}, n_{\max}]$ with step n_{step}, n_B scans $[n_{\min}, n_{\max}]$ with step n_{step}, and n_C scans $[n_{\min}, n_{\max}]$ with step n_{step}, there is a value for n_A, a value for n_B and a value for n_C, for which the sum of distances between the loci is minimum. These values are the estimates of the attenuation factors. It should be noted, that the sum of distances is now a function of n_A, n_B and n_C. This case is illustrated in figure 8, where the points P1, P2 and P3 of the loci T_{C1-C2}, T_{C3-C4}, T_{C5-C6} correspond to the minimum sum of distances. The MS's position is estimated as the average of P1, P2 and P3, as defined by equations (20) and (21). Finally, the *MA* of the specific pair-pair-pair combination is calculated.

The invention is functional even in the case where it is not known which exactly of the six BSs are characterized by contiguous attenuation factors. In this case, all possible combinations of six BSs taken two at a time are configured (the order of selection is immaterial). Thus, a pair and a remaining quadruplet are configured. Then, all possible combinations of the remaining four BSs, taken two at a time, are configured (the order of selection is immaterial). Thus, all possible combinations of the type pair-pair-pair are formed, and the *MA* is calculated for each one of them. The combination corresponding to the optimum (maximum) *MA*, among the configured pair-pair-pair combinations, is the dominant combination, and is used in order to estimate the MS's position.

Evidently, the invention may be developed, in order to categorize any number of BSs (greater than six) with respect to the propagation attenuation factor to the MS. Based on the analysis of four, five and six BSs, all combinations of the BSs, taken four, five or six at a time are configured (the order of selection is immaterial). Each combination is scrutinized, properly analyzed, if needed, to triplet-pair and pair-pair-pair combinations (in the case of pentad or hexads, respectively). The invention measures the *MA* of each sub-combination, and determines the optimum group of BSs. Thus, the unknown attenuation factors are estimated, and the MS position is located. The residual attenuation factors, after the MS is located, are calculated, using the equation:

$$n_i = \frac{\log(P_0) - \log(P_i)}{\log(d_i)} \tag{25}$$

where n_i is the attenuation factor of the i-th BS to the MS, and d_i is calculated considering the estimated MS position and the known position of the i-th BS.

Finally, a discussion follows, regarding technical issues that may arise during the employment of the invention to real-world problems, and ways of overcoming these issues.

If the number of BSs that the MS can sense is too large, the execution of the algorithm may significantly delay. A number of BSs needs to be selected, in order to provide proper input to the algorithm. A smaller number of BSs means less accuracy but smaller execution time, while a larger number of BSs improves accuracy but execution time delays significantly. A possible criterion for BS selecting, is to select those BSs whose received signal is strongest. Another criterion is to select those BSs, whose signal strength fluctuation, as measured by the MS, is minimum. Actually, the criterion that the user of the invention will adopt is irrelevant to the algorithm of the invention.

Small-scale fading refers to the rapid fluctuations of the received signal in space, time and frequency, and is caused by the signal scattering off objects between the transmitter and receiver [19], [20], [21], [22]. The large signal fluctuation introduced by small-scale fading means that the instantaneous value of the received signal strength may be very different than the local mean, and that this value changes rapidly with time and with movement of the order of wavelength. Performance degradation of the proposed algorithm may appear under strong fading conditions. In order to mitigate the consequences of small-scale fading, antenna diversity may be utilized at the transmitter, receiver, or both. Furthermore, a large number of signal samples from all BS's may be collected by the MS, in order to affront time-varying fading. Also, a large number of signal samples may be collected while moving slightly the MS, at distances of the order of wavelength. The invention can be used together with any of the techniques of small-scale fading mitigation described herein.

Large-scale fading or shadowing is caused by buildings or natural features and is determined by the local mean of a small-scale fading signal [19], [20], [21]. Large-scale fading means that the mean signal strength value varies from the value predicted by path loss slope [23]. In other words, large-scale fading describes the effect which occurs over a large number of measurement locations, which have the same transmitter-receiver separation, but have different levels of clutter on the propagation path. Consequently, even after mitigating small-scale fading using the techniques described above, the local mean signal strength may be measured to be different than predicted by the slope of the path loss diagram. However, large-scale fading does not need to be resolved when using the invention method. Rather, the invention dynamically resolves any changes to the effective attenuation factors by anew estimating the MS location.

When the transmitted power by each BS is not constant, the invention uses the information of the theoretical received power at 1m transmitter-receiver separation (provided by the administrator of the network), in order to categorize the BSs and locate the MS. The equations (3) to (18), and (23) to (25) are used with no modification other than the power received at 1m distance.

In some cases there is prior information on the position of the MS. As an example, consider the case of cellular systems, where the MS position is restricted into the cell of the associated BS. In a case like this, this information may be combined with the MS location provided by the invention, in order to ameliorate the accuracy of the location system.

If the orientation of the MS user affects the received power, the invention may sample the received power for different user orientations. This case is relevant to space-selective fading. In any case, the orientation with the optimum *MA* is selected.

The resolution of the estimator $\bar{n}$ *may also be an issue.* The computational burden of the algorithm increases as the value of n_{step} decreases. Consequently, there is a trade off between the precision of the estimated attenuation factors and execution time. The selection of n_{step} values should be performed by the invention user, and is irrelevant to the algorithm of the invention.

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CLAIMS

1.

A method for the determination and categorization of transmitters, with the same or contiguous propagation attenuation factors with respect to a wireless device, estimation of these attenuation factors and estimation of the wireless device's position.

The position of the *i*-th transmitter is considered to be known, and is denoted by $(x_{BS,i}, y_{BS,i})$, while the position of the wireless device is unknown and is denoted by (x_{MS}, y_{MS}). The unknown distance between the *i*-th transmitter and the device is denoted by d_i and is given by $d_i = \sqrt{(x_{BS,i} - x_{MS})^2 + (y_{BS,i} - y_{MS})^2}$. The attenuation factor between the *i*-th transmitter and the device is unknown and is assumed to lie within $[n_{\min}, n_{\max}]$. The theoretical signal strength (in Watts) that the device receives at a distance of $1\,\mathrm{m}$ from the *i*-th transmitter is denoted by $P_{0,i}$ and is considered to be known. The antennas of the transmitters and the device are assumed to be omnidirectional with known gain(s).

Hereinafter, a reference to a step signifies a step of the specific claim. A reference to a sub-step signifies a sub-step of the specific step of the specific claim. A reference to a step or sub-step of another claim will be explicitly stated.

The method is characterized by the steps of:

I. The device, placed at the unknown location (x_{MS}, y_{MS}), measures the local mean signal strength received from all transmitters (let there be a total of $N_{BS,MAX}$ transmitters). The local mean signal strength is calculated as the average of a sample of measures. The size of the sample is arbitrarily determined by the network administrator (or the user of the invention). The local mean signal strength is denoted by P_i.

II. A number $N_{BS} \leq N_{BS,MAX}$ of transmitters are selected. The number N_{BS} and the selected transmitters are determined by the network administrator (or the user of the invention). Definitely, the number of selected transmitters, N_{BS}, shall be greater than or equal to 4, i.e. $N_{BS} \geq 4$.

III. Given the N_{BS} transmitters, four of them are selected in all possible ways (i.e. all combinations of N_{BS} transmitters taken four at a time - the order of selection is immaterial). Then, *for each one of these quadruplets*, the following *sub-steps* are executed:

(i) It is assumed that the transmitters of the quadruplet are characterized by a common –and unknown – attenuation factor to the device, denoted by n_1.

(ii) One transmitter is randomly selected, and is named "central".

(iii) All three pairs between the central and the other transmitters are formed.

(iv) The estimator $\bar{n}_A$ of the common attenuation factor n_1 is generated. The estimator $\bar{n}_A$ scans $[n_{\min}, n_{\max}]$ with step n_{step}. The value of n_{step} is determined by the network administrator (or the user of the invention).

(v) For each value of $\bar{n}_A \in [n_{\min}, n_{\max}]$, and for each pair of transmitters i and j constructed in (iii), (indexes i and j correspond to transmitters): The estimates of the distances between the transmitters i, j and the device, denoted by $\bar{d}_i(\bar{n}_A), \bar{d}_j(\bar{n}_A)$ respectively, are calculated using:

$$\bar{d}_i(\bar{n}_A) = \left(\frac{P_{0,i}}{P_i}\right)^{1/\bar{n}_A}, \bar{d}_j(\bar{n}_A) = \left(\frac{P_{0,j}}{P_j}\right)^{1/\bar{n}_A} \quad (1)$$

(vi) For each value of $\bar{n}_A \in [n_{\min}, n_{\max}]$, and for each pair of transmitters i and j constructed in (iii), (indexes i and j correspond to transmitters): The intersection points of the circles, with centers $(x_{BS,i}, y_{BS,i})$ and $(x_{BS,j}, y_{BS,j})$, and radii the estimates $\bar{d}_i(\bar{n}_A), \bar{d}_j(\bar{n}_A)$ respectively, are calculated. The intersection points will be at most two. However, there may be one, or even none intersection point between the two circles.

(vii) As $\bar{n}_A$ scans $[n_{\min}, n_{\max}]$, and for each pair of transmitters i and j constructed in (iii), (indexes i and j correspond to transmitters), the corresponding geometric locus of the intersection points defined in (vi) is constructed. Thus, a total of three geometric loci are constructed, corresponding to the three transmitters pairs (the wireless device must lie on these loci).

(viii) For each value of $\bar{n}_A \in [n_{\min}, n_{\max}]$, the **sum** of the corresponding distances between the geometric loci is calculated, as a function of $\bar{n}_A$. The distance between two geometric loci is calculated using the following definition: If for a value $\bar{n}_{val,1} \in [n_{\min}, n_{\max}]$ the corresponding points on locus 1 are A and B, and for a value $\bar{n}_{val,2} \in [n_{\min}, n_{\max}]$ the corresponding points on locus 2 are C and D, the distance between these two loci, for the specific values of attenuation factor estimators, is the minimum among the distances A-C, A-D, B-C and B-D, i.e. the distance given by:

$$Distance(\bar{n}_{val,1}, \bar{n}_{val,2}) = \min\{d(\mathrm{A},\mathrm{C}), d(\mathrm{A},\mathrm{D}), d(\mathrm{B},\mathrm{C}), d(\mathrm{B},\mathrm{D})\} \quad (2)$$

where $d(\mathrm{X},\mathrm{Y})$ is the distance between the points X and Y.

(ix) The minimum value of the function of the **sum** of distances between the geometric loci is calculated. The value $\bar{n}_{A,opt}$ of $\bar{n}_A$ which minimizes the sum of distances is also found. The inverse of the minimum value of the function of sum, is *the measure of applicability of the specific quadruplet of transmitters*. Furthermore, the three points on the geometric loci, which correspond to the minimum value of the function of sum and the measure of applicability, are determined.

IV. All significant data are stored, i.e.: All quadruplets (as combinations of transmitters), the measure of applicability of each quadruplet, the value $\bar{n}_{A,opt}$ which corresponds to the measure of applicability of each quadruplet, and the points of the geometric loci which correspond to the measure of applicability of each quadruplet.

2.

A method for the determination and categorization of transmitters, with the same or contiguous propagation attenuation factors with respect to a wireless device, estimation of these attenuation factors and estimation of the wireless device's position, according to claim 1, where, after the step IV of claim 1, and when the number N_{BS} is greater than or equal to 5 (i.e. $N_{BS} \geq 5$), the following steps are also executed:

I. Given the N_{BS} transmitters, five of them are selected in all possible ways (i.e. all combinations of N_{BS} transmitters taken five at a time - the order of selection is immaterial).

II. *For each one pentad,* three transmitters are selected in all possible ways (i.e. all combinations of five transmitters taken three at a time – the order of selection is immaterial). Thus, all possible combinations of a triplet and a pair are configured. *For each triplet-pair combination,* the following sub-steps are executed:

(i) *For the triplet,* it is assumed that the corresponding transmitters are characterized by a common –and unknown – attenuation factor to the device, denoted by n_1.

(ii) From the triplet, one transmitter is randomly selected, and is named "central".

(iii) From the triplet, the two pairs between the central and the other two transmitters are formed.

(iv) For the triplet, the estimator $\bar{n}_A$ of n_1 is generated. The estimator $\bar{n}_A$ scans $[n_{\min}, n_{\max}]$ with step n_{step}.

(v) For each value of $\bar{n}_A \in [n_{\min}, n_{\max}]$, and for each pair of transmitters i and j constructed in (iii), (indexes i and j correspond to transmitters): The estimates of the distances between the transmitters i, j and the device, denoted by $\bar{d}_i(\bar{n}_A), \bar{d}_j(\bar{n}_A)$ respectively, are calculated using:

$$\bar{d}_i(\bar{n}_A) = \left(\frac{P_{0,i}}{P_i}\right)^{1/\bar{n}_A}, \bar{d}_j(\bar{n}_A) = \left(\frac{P_{0,j}}{P_j}\right)^{1/\bar{n}_A} \qquad (3)$$

(vi) For each value of $\bar{n}_A \in [n_{\min}, n_{\max}]$, and for each pair of transmitters i and j constructed in (iii), (indexes i and j correspond to transmitters): The intersection points of the circles, with centers $(x_{BS,i}, y_{BS,i})$ and $(x_{BS,j}, y_{BS,j})$, and radii the estimates $\bar{d}_i(\bar{n}_A), \bar{d}_j(\bar{n}_A)$ respectively, are calculated. The intersection points will be at most two. However, there may be one, or even none intersection point between the two circles.

(vii) As $\bar{n}_A$ scans $[n_{\min}, n_{\max}]$, and for each pair i and j constructed in (iii), (indexes i and j correspond to transmitters), the corresponding geometric locus of the intersection points defined in (vi) is constructed. Thus, a total of two geometric loci are constructed, corresponding to the two transmitters pairs (the wireless device must lie on these loci).

(viii) *For the pair of the pentad* (rest two transmitters), it is assumed that the corresponding transmitters are characterized by a common –and unknown – attenuation factor to the device, denoted by n_2. The transmitters of this pair are denoted by *k* and *m*, for clarity.

(ix) For this pair, the estimator $\bar{n}_B$ of n_2 is generated. The estimator $\bar{n}_B$ scans $[n_{\min}, n_{\max}]$ with step n_{step}.

(x) For each value of $\bar{n}_B \in [n_{\min}, n_{\max}]$, and for the transmitters *k* and *m*, the estimates of the distances between the transmitters k,m and the device, denoted by $\bar{d}_k(\bar{n}_B)$, $\bar{d}_m(\bar{n}_B)$ respectively, are calculated using:

$$\bar{d}_k(\bar{n}_B) = \left(\frac{P_{0,k}}{P_k}\right)^{1/\bar{n}_B}, \bar{d}_m(\bar{n}_B) = \left(\frac{P_{0,m}}{P_m}\right)^{1/\bar{n}_B} \quad (4)$$

(xi) For each value of $\bar{n}_B \in [n_{\min}, n_{\max}]$, and for the transmitters *k* and *m*, the intersection points of the circles, with centers $(x_{BS,k}, y_{BS,k})$ and $(x_{BS,m}, y_{BS,m})$, and radii the estimates $\bar{d}_k(\bar{n}_B), \bar{d}_m(\bar{n}_B)$ respectively, are calculated. The intersection points will be at most two. However, there may be one, or even none intersection point between the two circles.

(xii) As $\bar{n}_B$ scans $[n_{\min}, n_{\max}]$, and for the transmitters *k* and *m*, the corresponding geometric locus of the intersection points defined in (xi) is constructed. Thus, one geometric locus is constructed, corresponding to the transmitters pair *k* and *m* (the wireless device must lie on this locus).

(xiii) For each value of $\bar{n}_A$ and for each value of $\bar{n}_B$, the **sum** of the corresponding distances between the geometric loci of sub-steps (vii) and (xii), is calculated. The sum of distances is a function of $\bar{n}_A$ and $\bar{n}_B$.

(xiv) The minimum value of the function of the **sum** of distances between the geometric loci is calculated. The values $\bar{n}_{A,opt}, \bar{n}_{B,opt}$ of $\bar{n}_A$ and $\bar{n}_B$ respectively, which minimize the sum of distances are also found. The inverse of the minimum value of the function of sum, is *the measure of applicability of the specific triplet-pair combination of transmitters*. Furthermore, the three points on the geometric loci, which correspond to the minimum value of the function of sum and the measure of applicability, are determined.

III. All significant data are stored, i.e.: All pentads, all triplet-pair combinations (as combinations of transmitters), the measure of applicability of each triplet-pair combination, the values $\bar{n}_{A,opt}, \bar{n}_{B,opt}$ which correspond to the measure of applicability of each triplet-pair combination, and the points of the geometric loci which correspond to the measure of applicability of each triplet-pair combination.

3.

A method for the determination and categorization of transmitters, with the same or contiguous propagation attenuation factors with respect to a wireless device, estimation of these attenuation factors and estimation of the wireless device's position, according to claim 2, where, after the step III of claim 2, and when the number N_{BS} is greater than or equal to 6 (i.e. $N_{BS} \geq 6$), the following steps are also executed:

I. Given the N_{BS} transmitters, six of them are selected in all possible ways (i.e. all combinations of N_{BS} transmitters taken six at a time - the order of selection is immaterial).

II. *For each one hexad*, two transmitters are selected in all possible ways (i.e. all combinations of six transmitters taken two at a time – the order of selection is immaterial).

III. For each pair of II, there is a corresponding quadruplet, which is the rest of the transmitters of the hexad. For this quadruplet, two transmitters are selected in all possible ways (i.e. all combinations of four transmitters taken two at a time – the order of selection is immaterial). Thus, for each hexad, all possible combinations of the type pair-pair-pair are constructed. *For each pair-pair-pair combination*, the following sub-steps are executed:

(i) *For the first pair of transmitters*, denoted by *i* and *j*, it is assumed that they are characterized by a common –and unknown – attenuation factor to the device, denoted by n_1.

(ii) For the first pair, the estimator $\bar{n}_A$ of n_1 is generated. The estimator $\bar{n}_A$ scans $[n_{\min}, n_{\max}]$ with step n_{step}.

(iii) For each value of $\bar{n}_A \in [n_{\min}, n_{\max}]$, and for the transmitters i and j, the estimates of the distances between the transmitters i, j and the device, denoted by $\bar{d}_i(\bar{n}_A), \bar{d}_j(\bar{n}_A)$ respectively, are calculated using:

$$\bar{d}_i(\bar{n}_A) = \left(\frac{P_{0,i}}{P_i}\right)^{1/\bar{n}_A}, \bar{d}_j(\bar{n}_A) = \left(\frac{P_{0,j}}{P_j}\right)^{1/\bar{n}_A} \quad (5)$$

(iv) For each value of $\bar{n}_A \in [n_{\min}, n_{\max}]$, and for the transmitters *i* and *j*, the intersection points of the circles, with centers $(x_{BS,i}, y_{BS,i})$ and $(x_{BS,j}, y_{BS,j})$, and radii the estimates $\bar{d}_i(\bar{n}_A), \bar{d}_j(\bar{n}_A)$ respectively, are calculated. The intersection points will be at most two. However, there may be one, or even none intersection point between the two circles.

(v) As $\bar{n}_A$ scans $[n_{\min}, n_{\max}]$, and for the transmitters *i* and *j*, the corresponding geometric locus of the intersection points defined in (iv) is constructed. Thus, one geometric locus is constructed, corresponding to the transmitters pair *i* and *j* (the wireless device must lie on this locus).

(vi) *For the second pair of transmitters*, denoted by *k* and *m*, it is assumed that they are characterized by a common –and unknown – attenuation factor to the device, denoted by n_2.

(vii) For the second pair, the estimator $\bar{n}_B$ of n_2 is generated. The estimator $\bar{n}_B$ scans $[n_{\min}, n_{\max}]$ with step n_{step}.

(viii) For each value of $\bar{n}_B \in [n_{\min}, n_{\max}]$, and for the transmitters *k* and *m*, the estimates of the distances between the transmitters k, m and the device, denoted by $\bar{d}_k(\bar{n}_B), \bar{d}_m(\bar{n}_B)$ respectively, are calculated using:

$$\bar{d}_k(\bar{n}_B) = \left(\frac{P_{0,k}}{P_k}\right)^{1/\bar{n}_B}, \bar{d}_m(\bar{n}_B) = \left(\frac{P_{0,m}}{P_m}\right)^{1/\bar{n}_B} \quad (6)$$

(ix) For each value of $\bar{n}_B \in [n_{\min}, n_{\max}]$, and for the transmitters *k* and *m*, the intersection points of the circles, with centers $(x_{BS,k}, y_{BS,k})$ and $(x_{BS,m}, y_{BS,m})$, and radii the estimates $\bar{d}_k(\bar{n}_B), \bar{d}_m(\bar{n}_B)$ respectively, are calculated. The intersection points will be at most two. However, there may be one, or even none intersection point between the two circles.

(x) As $\bar{n}_B$ scans $[n_{\min}, n_{\max}]$, and for the transmitters *k* and *m*, the corresponding geometric locus of the intersection points defined in (ix) is constructed. Thus, one geometric locus is constructed, corresponding to the transmitters pair k and m (the wireless device must lie on this locus).

(xi) *For the third pair of transmitters*, denoted by p and q, it is assumed that they are characterized by a common –and unknown – attenuation factor to the device, denoted by n_3.

(xii) For the third pair, the estimator $\bar{n}_C$ of n_3 is generated. The estimator $\bar{n}_C$ scans $[n_{\min}, n'_{\max}]$ with step n_{step}

(xiii) For each value of $\bar{n}_C \in [n_{\min}, n_{\max}]$, and for the transmitters p and q, the estimates of the distances between the transmitters p, q and the device, denoted by $\bar{d}_p(\bar{n}_C), \bar{d}_q(\bar{n}_C)$ respectively, are calculated using:

$$\bar{d}_p(\bar{n}_C) = \left(\frac{P_{0,p}}{P_p}\right)^{1/\bar{n}_C}, \bar{d}_q(\bar{n}_C) = \left(\frac{P_{0,q}}{P_q}\right)^{1/\bar{n}_C} \quad (7)$$

(xiv) For each value of $\bar{n}_C \in [n_{\min}, n_{\max}]$, and for the transmitters p and q, the intersection points of the circles, with centers $(x_{BS,p}, y_{BS,p})$ and $(x_{BS,q}, y_{BS,q})$, and radii the estimates $\bar{d}_p(\bar{n}_C), \bar{d}_q(\bar{n}_C)$ respectively, are calculated. The intersection points will be at most two. However, there may be one, or even none intersection point between the two circles.

(xv) As $\bar{n}_C$ scans $[n_{\min}, n_{\max}]$, and for the transmitters p and q, the corresponding geometric locus of the intersection points defined in (xiv) is constructed. Thus, one geometric locus is constructed, corresponding to the transmitters pair p and q (the wireless device must lie on this locus).

(xvi) For each value of $\bar{n}_A$, $\bar{n}_B$, and $\bar{n}_C$, the **sum** of the corresponding distances between the geometric loci of sub-steps (v), (x), and (xv), is calculated. The sum of distances is a function of $\bar{n}_A$, $\bar{n}_B$ and $\bar{n}_C$.

(xvii) The minimum value of the function of the **sum** of distances between the geometric loci is calculated. The values $\bar{n}_{A,opt}, \bar{n}_{B,opt}, \bar{n}_{C,opt}$ of $\bar{n}_A, \bar{n}_B$ and $\bar{n}_C$ respectively, which minimize the sum of distances, are also found. The inverse of the minimum value of the function of sum, is *the measure of applicability of the specific pair-pair-pair combination of transmitters*. Furthermore, the three points on the geometric loci, which correspond to the minimum value of the function of sum and the measure of applicability, are determined.

IV. All significant data are stored, i.e.: All hexads, all pair-pair-pair combinations (as combinations of transmitters), the measure of applicability of each pair-pair-pair combination, the values $\bar{n}_{A,opt}, \bar{n}_{B,opt}, \bar{n}_{C,opt}$ which correspond to the measure of applicability of each pair-pair-pair combination, and the points of the geometric loci which correspond to the measure of applicability of each pair-pair-pair combination.

4.

A method for the determination and categorization of transmitters, with the same or contiguous propagation attenuation factors with respect to a wireless device, estimation of these attenuation factors and estimation of the wireless device's position, according to claim 1 or 2 or 3, where, after the act of storage (step IV of claim 1, step III of claim 2, or step IV of claim 3), the following steps are also executed:

I. From all examined combinations (quadruplets, triplet-pair combinations, and pair-pair-pair combinations) the one with the *optimum (maximum) measure of applicability* is selected. This combination is named "dominant" combination.

II. The position of the wireless device is estimated as the average of the three geometric loci points which correspond to the measure of applicability of the dominant combination. The average (x, y) of three points, $(x_1, y_1), (x_2, y_2)$, (x_3, y_3) respectively, is calculated using:

$$x = \frac{x_1 + x_2 + x_3}{3}, y = \frac{y_1 + y_2 + y_3}{3} \quad (8)$$

III. Those attenuation factors, from transmitters to the wireless device, which are not determined during the described procedure, are calculated using $n_i = \frac{\log(P_{0,i}) - \log(P_i)}{\log(d_i)}$, n_i being the attenuation factor of the i-th transmitter, d_i being the distance between the i-th transmitter and the wireless device, and d_i being estimated using the location produced by step II, equation (8).

Figure 1/8

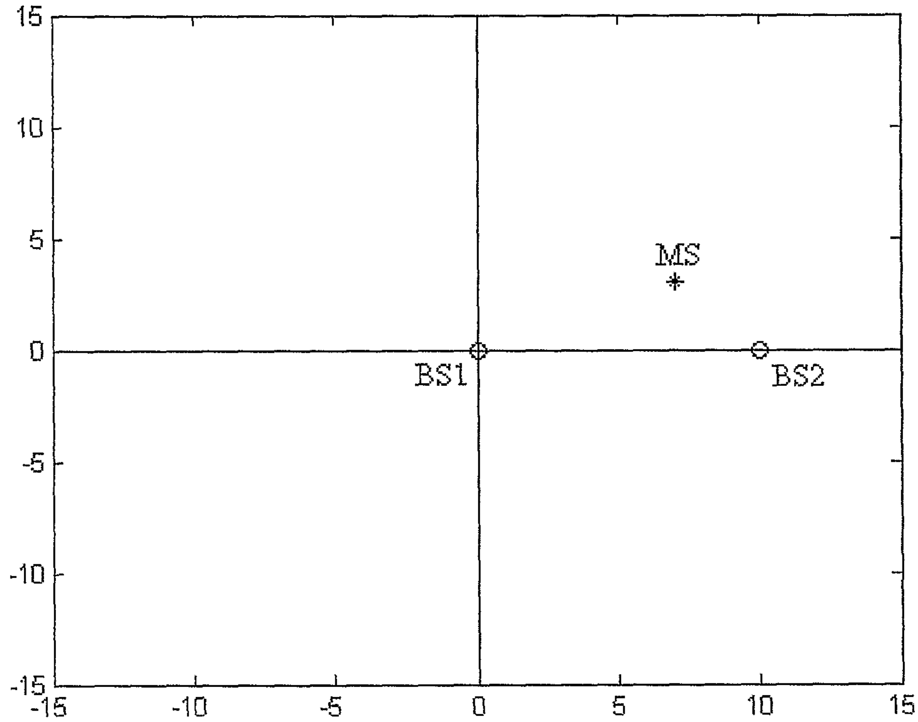
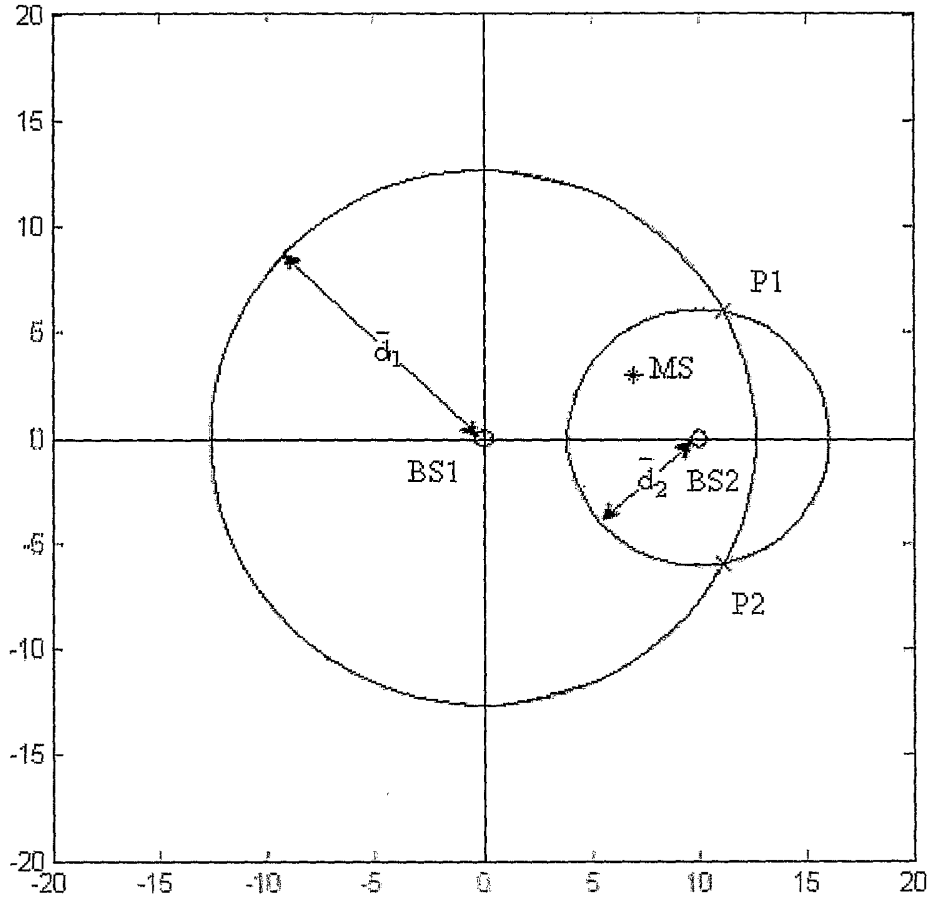


Figure 2/8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BS2
P2
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20

Figure 3/8

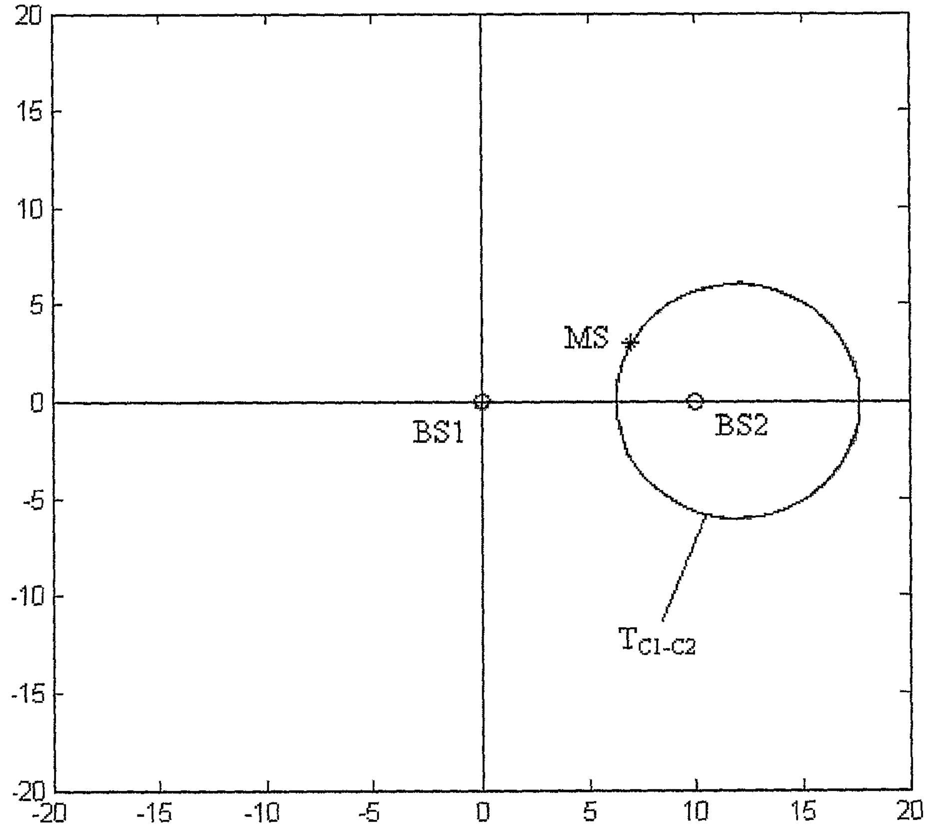
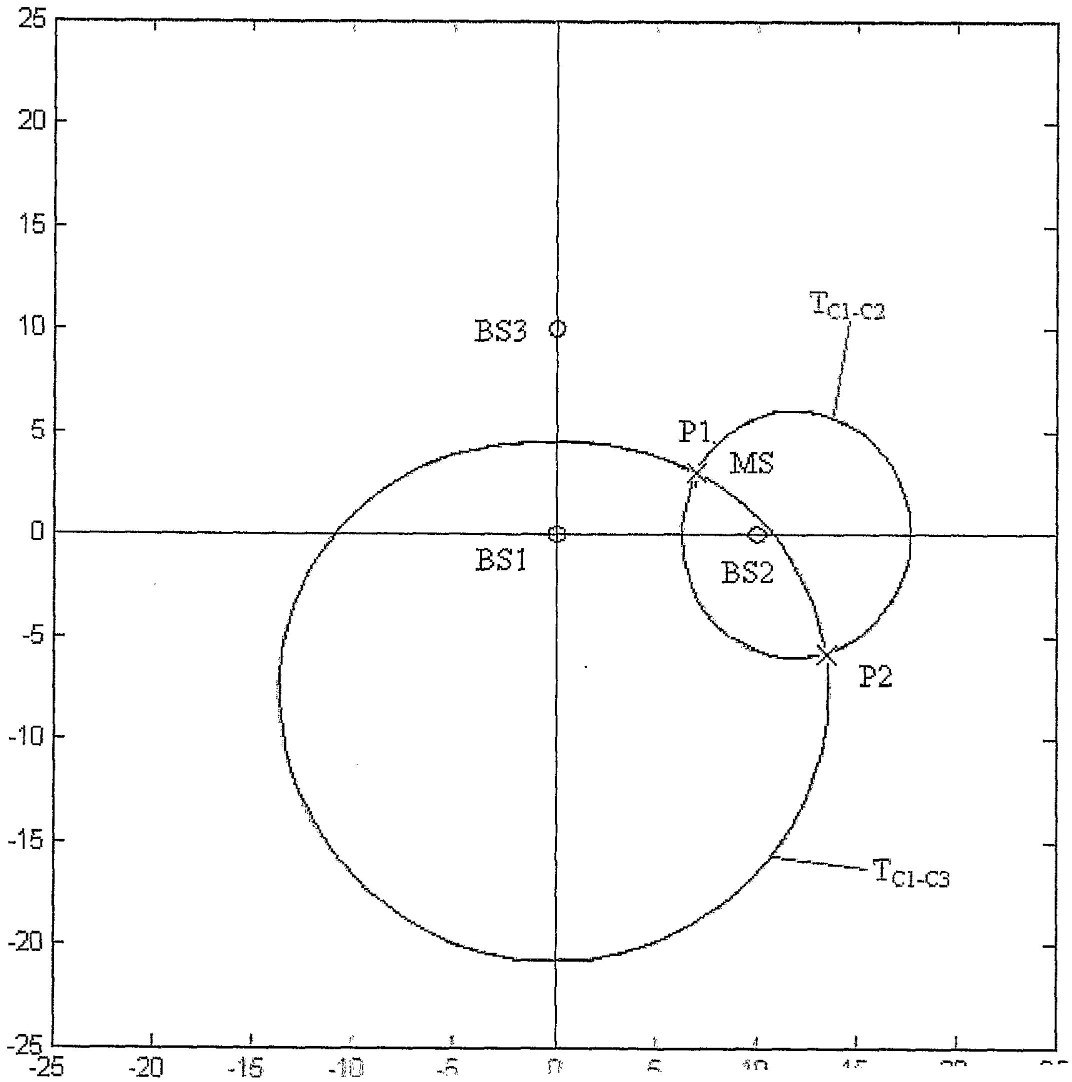


Figure 4/8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BS2
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-10
-5

Figure 5/8

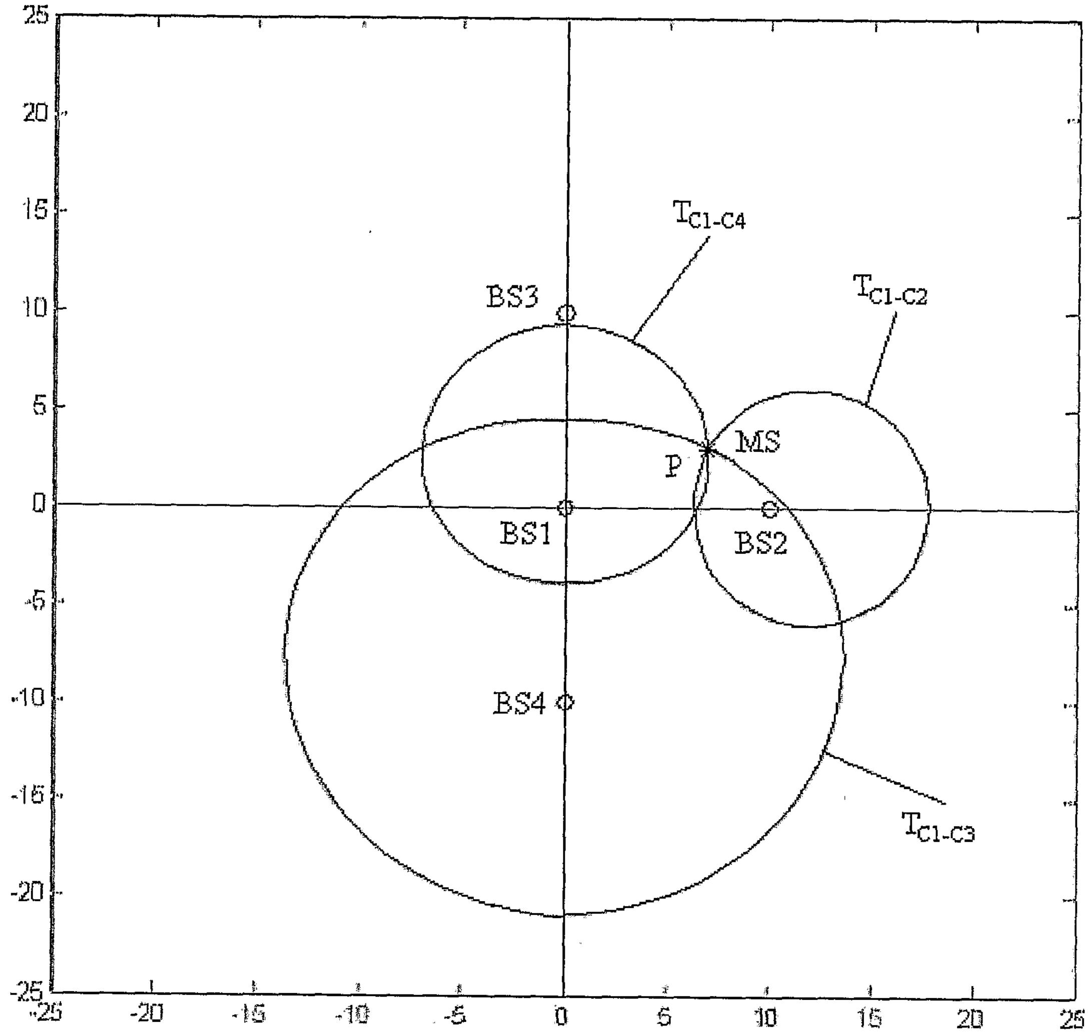
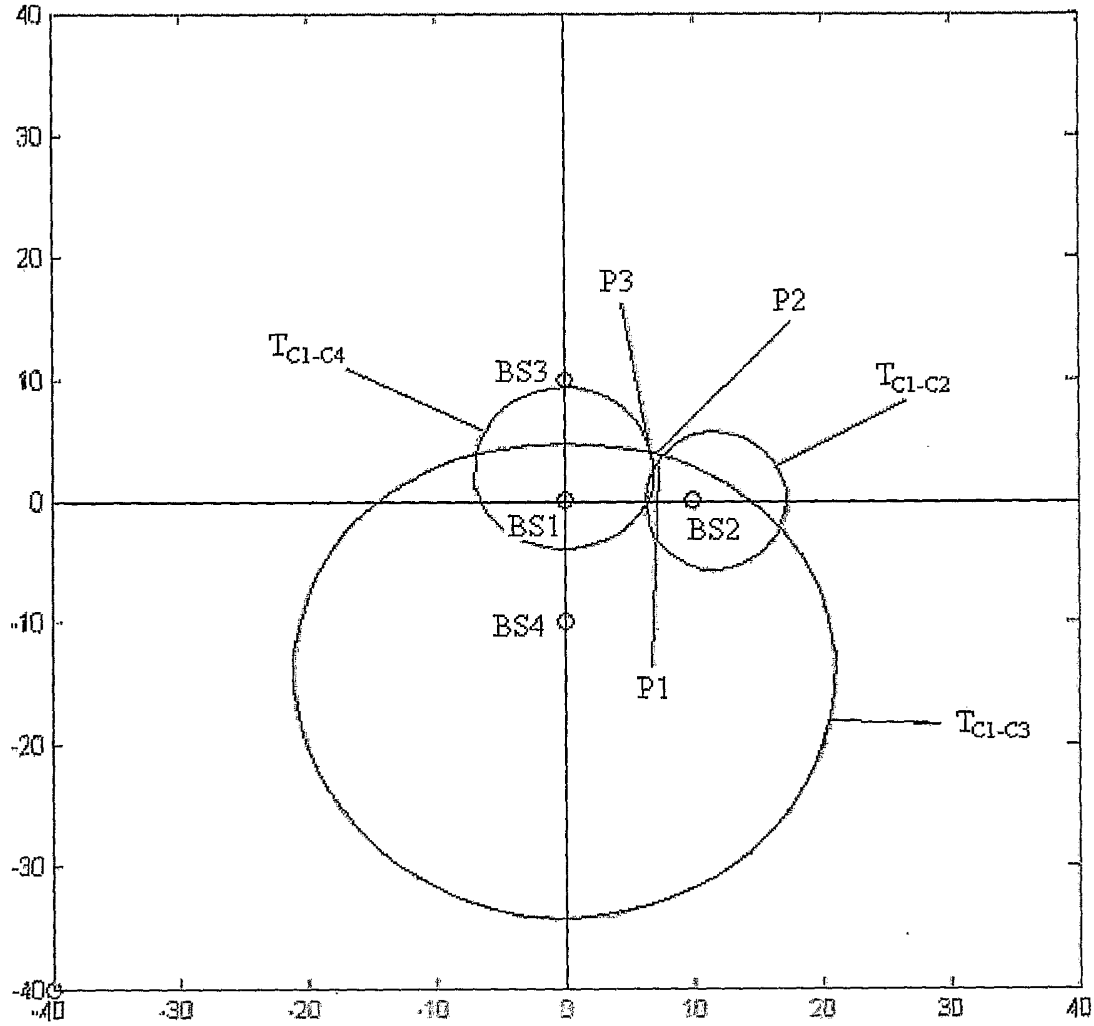


Figure 6/8



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P2
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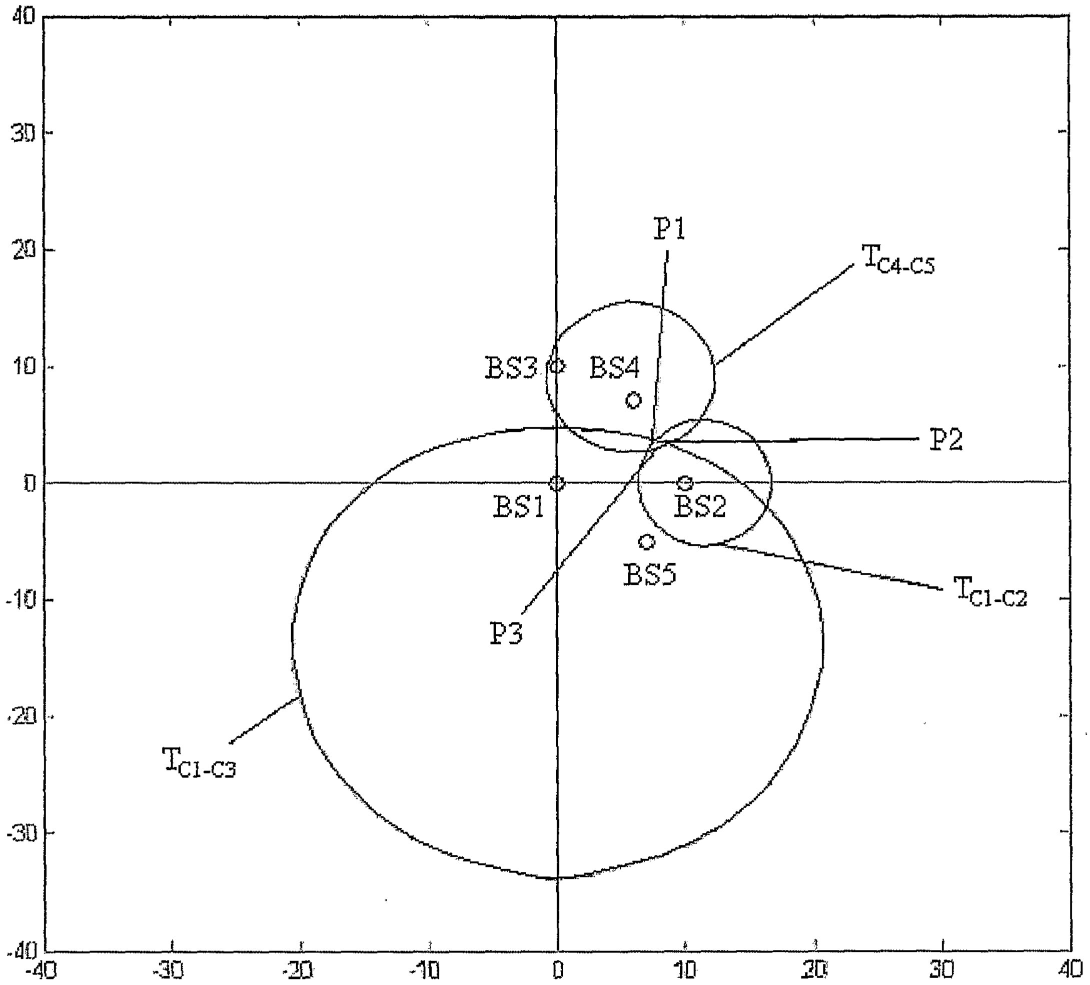
BS3
T C1-C2
BS1
BS2
BS4
P1
T C1-C3

Figure 7/8



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BS4
P2
BS1
BS2
BS5
T_{C1-C2}
P3
T_{C1-C3}
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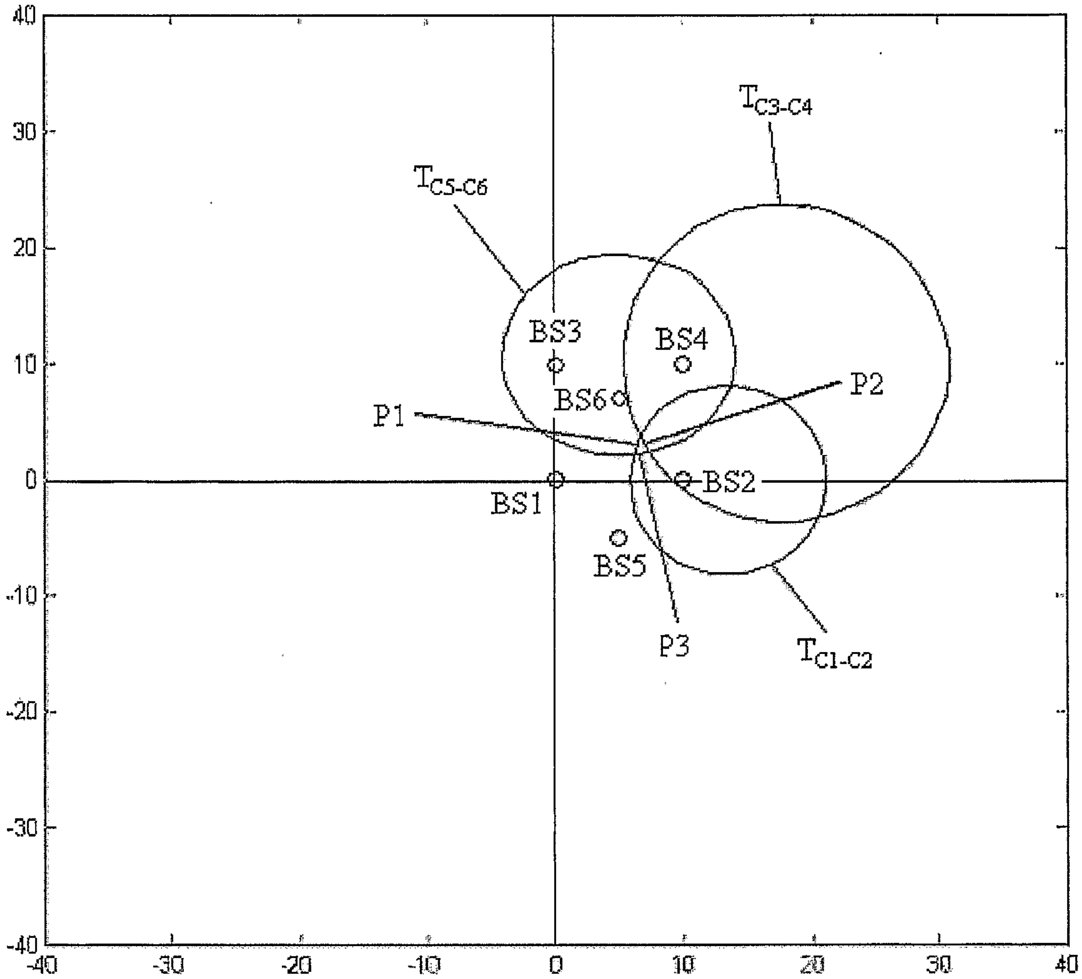
Figure 8/8



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INTERNATIONAL SEARCH REPORT

International application No
PCT/GR2005/000036

A. CLASSIFICATION OF SUBJECT MATTER
H04Q7/38 G01S5/10 G01S5/14

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)
H04Q G01S

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 practical, search terms used)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DING-BING LIN ET AL: "Mobile location estimation based on differences of signal attenuations for gsm systems" IEEE ANTENNAS AND PROPAGATION SOCIETY INTERNATIONAL SYMPOSIUM. 2003 DIGEST. APS. COLUMBUS, OH, JUNE 22 - 27, 2003, NEW YORK, NY : IEEE, US, vol. VOL. 4 OF 4, 22 June 2003 (2003-06-22), pages 77-80, XP010649678 ISBN: 0-7803-7846-6 paragraph ‘0002! abstract ----- -/--	1-4

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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

"P" document published prior to the international filing date but later than the priority date claimed

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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 February 2006	09/03/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Bösch, M

INTERNATIONAL SEARCH REPORT

International application No
PCT/GR2005/000036

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/203904 A1 (GWON YOUNGJUNE LEE ET AL) 14 October 2004 (2004-10-14) paragraphs '0033!, '0035!, '0038! paragraphs '0039!, '0042! paragraph '0046! - paragraph '0050! paragraph '0055! - paragraph '0058! paragraph '0064! - paragraph '0080! paragraph '0107! - paragraph '0163! -----	1-4
A	WO 03/071303 A (TELIA AB ; SOMMER, MAGNUS) 28 August 2003 (2003-08-28) page 12, line 26 - page 13, line 32 page 15, line 34 - page 16, line 12 page 16, line 37 - page 21, line 10 -----	1-4
A	US 5 293 642 A (LO ET AL) 8 March 1994 (1994-03-08) column 2, line 14 - line 60 column 4, line 33 - column 5, line 50 column 6, line 65 - column 7, line 37 -----	1-4

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GR2005/000036

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			EP	1481259	A1	01-12-2004
			SE	524493	C2	17-08-2004
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