Hybrid Pattern Matching/TDOA Positioning Method for CDMA Networks

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***Abstract*—In this paper hybrid pattern matching (PM) and time difference of arrival (TDOA) positioning method is proposed to improve a position accuracy of mobile station (MS) in CDMA networks where GPS is not satisfactory. Iterative TDOA method is used for its high accuracy and good robustness. Since the performance of iteration method depends highly on the initial estimation, the proposed method uses the location information from PM to estimate initial value. There is no need to change the hardware of MS. PM's results and other data such as received signal value, time delay are measured by using diagnostic monitoring (DM) software in real environment. The results show that proposed method can provide a better accuracy than conventional PM algorithm.**

***Index Terms*—gpsOne, positioning, pCell, iterative TDOA**

I. Introduction

Location is of increasing importance for safety, gaming, and commercial services. In all cases, position location accuracy and availability are very much important. The most possible and already deployed methods, especially in CDMA system are global positioning system (GPS), cell-ID, angle of arrival (AOA), time based location techniques such as time of arrival (TOA), TDOA and PM.

GPS delivers very accurate position information for good environmental condition. gpsOne can be used to improve position service availability in CDMA system [1]. But nevertheless, the performance loss in urban or indoor areas can be dramatic and its accuracy can be severely degraded by multipath reflections.

Cell-ID positioning is simple and economic and it does not require any upgrade of MSs or network equipments, but since the MS can be anywhere within a cell, accuracy depends on cell size [2].

AOA schemes require only two BSs minimum for a location estimate [3]. However, it is highly range dependent. A small error in the angle measurement will results in large location error when the MS is far away from any BSs involved.

CDMA systems are particularly good at maintaining very precise timing synchronization between BSs [4], which is the key requirement for determining location using TOA and TDOA. However, TOA method requires the MS to act as a transponder in which processing delays and non line of sight (NLOS) propagation can introduce error [3]. To overcome these limitations, time difference measurements rather than absolute time measurements can be used [3]. This method is often called the TDOA method.

Positioning can also be realized by pattern matching. The main principle here is to observe the site (or scene) where positioning is to be applied and to draw conclusions about the position of target from these observations. In PM, some physical quantities are taken into account. A popular method is to detect a position from the propagation characteristics of radio signals which MS experiences at a certain position on a site. In this case, pattern matching is also known as fingerprinting [5] and it can be used for CDMA network [7]. Nowadays, SK Telecom, the largest Korean cellular operator having 19 million subscribers, uses network-based PM pCell algorithm for positioning in cdma2000 1x networks [6]. cdma2000 1x cellular system uses gpsOne solution which combines global positioning system (GPS) cellular network. Then, sending the information to position determination entity (PDE) where the measurements are combined to produce a position [8]. In cellular networks, the location technique based on TDOA measurement is easy to implement in the real CDMA system, because the synchronization between BS and MS is not required and synchronization among the BSs which participate in the measurement has been accomplished. This technique does not require any special type of antennas, it is cheaper to put in place than the AOA finding methods. In this respect, it is superior to AOA and TOA methods. Non iterative and iterative TDOA methods are used.

Non iterative methods for positioning are straightforward as they provide the position estimate in just one step [9]-[11]. Non iterative positioning methods may not yield satisfactory position estimate for situations where a highly accurate position estimate is required.

To achieve high accuracy requirements, iterative methods are used. Many iterative methods are proposed for cellular networks [12]-[14]. Some of them such as the Gauss-Newton method which fails to converge for certain geometric constellations and thus, it is not suitable for a general solution in cellular networks [14]. Another one is the Steepest Descent method which has a slow convergence in the final iteration steps. Among the iterative methods the Levenberg-Marquardt is suitable to estimate MS location with high accuracy and low complexity [14].

However, these iteration algorithms require an initial location guess and may suffer from the convergence problem if the initial guess is not accurate enough. Non iterative algorithm may provide a good initial position [15] or mean value of the positions of all involved BSs can be used [14].

An iteration method can superior the pCell algorithm when initial guess position is estimated accurately. For this purpose, we use MS position obtained from pCell algorithm as a good initial position.

In this paper, we propose such a hybrid positioning algorithm which combines both, pCell and iterative TDOA methods to improve the accuracy of pCell algorithm in indoor environment.

This paper is organized as follow: In section II, we briefly discuss the PM and TDOA methods. In Section III, we explain our proposed scheme and how it results in a better accuracy. The performance of the proposed scheme is evaluated via computer simulation using real environment data in Section IV. In Section V concluding remarks will be given.

II. CONVENTIONAL METHODS

A. Pattern Matching

Every location in the radio environment has a unique signature, based on observed signal strength and cell identifications, along with other network information. Wireless networks automatically use this information for network operations. PM compares the set of characteristics from MS with a set of attributes which already established in network. In CDMA networks these attributes may include average pilot strength, chip offset, or pilot strength.

A cellular service area including a plurality of cells is shown in Fig. 1. One cell covered by one BS and at least one mobile switching center (MSC). The cells of service area divided in-to sub cells represented by the square formed by the grid lines. A set of detectable RF characteristics are defined for each sub cell, which are referred to as the properties of the sub cell. The MS measures the RF signals that are associated with the properties reports to the positioning determination entity (PDE). The all known set of attribute values are stored in database. The PDE statistically compares the measured values with the known attribute values of all sub cells in a predefined area. The sub cell that has the best matched set of attribute values with the measured values is the one that the MS is repeated to be in. As the MS moves, the comparison is periodically performed and the location of the MS can be determined at any given time. As a result, the problem of position can be solved by PM.

A basic concept of pCell algorithm based on network-based PM method is shown in Fig. 2. In cdma2000 1x cellular systems, MS analyzes all the received path components and classifies them into active set, candidate set, neighbor set, and remaining set according to their signal strengths [16]. Set means pseudonoise (PN) sequence offset which corresponds to one cell or one sector. One Set usually contains several path

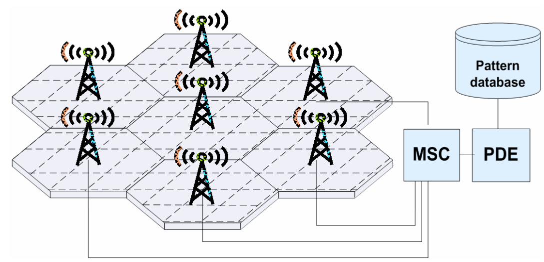

Fig. 1. Network-based Pattern Matching algorithm.

components. MS complaint to TIA/EIA/IS-801, which is called gpsOne handset, sends pilot phase measurement message (PPMM) twice during one session [8]. MS reports the path analysis results to PDE by using PPMM. For one path component of each Set, PPMM includes PN phase in 1/16 chip unit, pilot strength, system identifier (SID), network identifier (NID), PN offset and so on. The pilot channel is used by BS to provide a reference for all MS. The pilot signals from all BSs use the same PN sequence, but each BS is identified by a unique time offset. In total 512 unique offsets are provided. The PN offset is used as the BS ID to identify where the signal comes from. All these parameters are used to find MS position. The database can be constructed by using Commercial assisted-GPS (A-GPS) location results and PPMM log data. pCell algorithm can work in indoor and outdoor environment. MS position can be provided by both, GPS and BS identification information for good and poor GPS reception areas respectively.

For PM algorithm we use the probabilistic approach based on Bayes estimation [7]. Assume S is area that the MS is known to be in and $\{c_1, c_2, c_3, \ldots, c_m\}$ is a set of sub cells which is a partition of S, such that

$$S \cong \sum_{i-1}^{m} c_i. \quad (1)$$

$B = \{B_1, B_2, B_3, \ldots, B_n\}$ is the set of attributes of each sub cell (Fig. 3). In pCell case, B_1 is the PN code that identifies a particular BS, B_2 is the pilot strength and so on. PM finds the highest probability $P\left(c_i \mid B^*\right)$ by using Bayes rule that the MS is in c_i given a set of measurement $B^* = \{b_1, b_2, b_3, \ldots, b_n\}$,

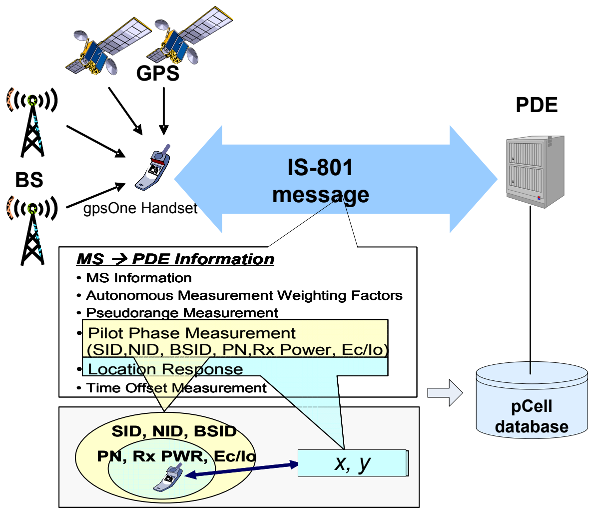

Fig. 2. Basic pCell concept.

$$P\left(c_i \mid B^*\right)=\frac{P\left(c_i\right)P\left(B^* \mid c_i\right)}{P\left(B^*\right)}. \tag{2}$$

If $P\left(c_i\right)$ can be obtained by uniform distribution. We can obtain using

$$P\left(B^*\right)=\sum_{S=1}^{m}P\left(c_s\right)P\left(B^* \mid c_s\right), \tag{3}$$

where $P\left(B^* \mid c_i\right)$ is given by

$$P\left(B^* \mid c_i\right)=\prod_{l=1}^{n}P\left(b_n \mid c_i\right). \tag{4}$$

In pCell sub cells are taken equal to 100 m × 100 m pCell has a high accuracy and stability compared with other network-based positioning method. However, it has a low accuracy in indoor environment where GPS is not satisfactory.

B. Time Difference of Arrival

TDOA techniques are based on estimating the difference in the arrival times of the signal from multiple BSs to MS. A particular value of the time difference estimate defines a hyperbola between the two BSs on which the MS may exist, assuming that the MS and the BSs are coplanar. If this procedure is done again with another BS in combination with any of the previously used BSs, another hyperbola is defined and intersection of the two hyperbolas results in the position location estimate of the MS (Fig. 4). This method is also called a hyperbolic positioning method.

Two distinct stages are involved in the hyperbolic position estimation technique. In the first stage, time delay estimation is used to find the TDOA. This TDOA estimate is used to calculate the range difference measurements between the BSs. In the second stage, an efficient algorithm is used to determine the position location estimation by solving the nonlinear hyperbolic equations resulting from the first stage.

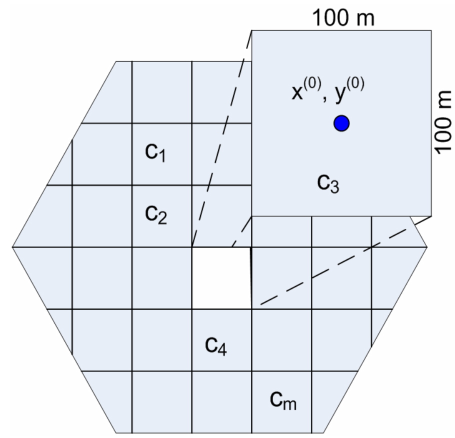

Fig. 3. Cell division into sub-cell in pCell algorithm

A general model for the two dimensional (2-D) positioning estimation of MS using M BSs is developed. Referring all TDOAs to the first BS, which is assumed to be the reference BS, let the index $i=2,\ldots,M$ unless otherwise specified, $\left(x,y\right)$ is the MS location and $\left(X_i,Y_i\right)$ be the known location of the i th BS. The range difference between BSs with respect to the reference BS, is

$$\begin{aligned} R_{i,1} &= ct_{i,1} \\ &= r_i - r_1 \\ &= \sqrt{\left(X_i-x\right)^2+\left(Y_i-y\right)^2}-\sqrt{\left(X_1-x\right)^2+\left(Y_1-y\right)^2}, \end{aligned} \tag{5}$$

where c is the speed of light, $R_{i,1}$ is the range difference distance between the reference BS and the i th BS, R_1 is the distance between the reference BS and MS, and $t_{i,1}$ is the estimated TDOA between the reference BS and the i th BS. This defines the set of nonlinear hyperbolic equations whose solution gives the 2-D coordinates of MS.

Solving the non linear (5) is not a trivial operation. We can use iteration method which can give a higher accuracy than non iteration method.

This location technique works with any handset, including legacy units and requires modification to the network only. To apply TDOA technique to the network, at least 3 synchronized BSs are needed. If a major reflector effects the signal components, the timing error may get cancelled or reduced in the time difference operation. Hence, TDOA methods may work accurately in some situations where there is NLOS signal components. Iteration methods are efficient methods in solving nonlinear equations. But their performance depends on the accuracy of initial guess position. Therefore, an initial estimation of MS position is necessary.

III. THE PROPOSED PM/TDOA POSITIONING METHOD

We find $\left(x^{(0)}, y^{(0)}\right)$ MS position from pCell PM based algorithm (Fig. 3) and apply it as the accurate initial position for iterative TDOA method.

Assume the MS is located at $\boldsymbol{x} = [x, y]^{\mathrm{T}}$ and M BSs at $\boldsymbol{x}_j$, $j \in \{1, 2, ..., M\}$ are used. The distance between the BSs and the MS is given by

$$r_j(\boldsymbol{x}) = \sqrt{(x_j - x)^2 + (y_j - y)^2}. \tag{6}$$

Thus, the range differences in term of the reference BS can be written as

$$R_{j,1}(\boldsymbol{x}) = r_j(\boldsymbol{x}) - r_1(\boldsymbol{x}) \tag{7}$$

The at most $M-1$ linear independent range differences

$$R(\boldsymbol{x}) = [R_{2,1}(\boldsymbol{x}), R_{3,1}(\boldsymbol{x}), ..., R_{M,1}(\boldsymbol{x})]^{\mathrm{T}}, \tag{8}$$

and the corresponding TDOA measurements are given by

$$R = \left[R_{2,1}, R_{3,1}, ..., R_{M_{BS},1}\right]. \tag{9}$$

Levenberg-Marquardt is the optimization-based method where cost function is first defined and we minimize it to estimate the MS position

$$\varepsilon(\boldsymbol{x}) = \left(R - R(\boldsymbol{x})\right)^{\mathrm{T}} \left(R - R(\boldsymbol{x})\right), \tag{10}$$

$$\hat{x} = \arg\min_{\boldsymbol{x}} \varepsilon(x). \tag{11}$$

Afterward, using (10), the least square method is applied in the iterated solution

$$\begin{aligned} \boldsymbol{x}^{(k+1)} &= \boldsymbol{x}^{(k)} + \left(J^{\mathrm{T}}\left(\boldsymbol{x}^{(k)}\right) J\left(\boldsymbol{x}^{(k)}\right) + \lambda^{(k)} I_2\right)^{-1} \\ &\qquad \cdot J^{\mathrm{T}}\left(\boldsymbol{x}^{(k)}\right)\left(R - R\left(\boldsymbol{x}^{(k)}\right)\right) \\ &= \boldsymbol{x}^{(k)} + \left(A^{(k)} + \lambda^{(k)} I_2\right)^{-1} g^{(k)}, \end{aligned} \tag{12}$$

where $J(\boldsymbol{x})$ is the $(M_{BS}-1)\times 2$ Jacobian matrix and it is given by (13).

Levenberg-Marquardt algorithm starts with above initial estimate $\boldsymbol{x}^{(0)} = \left[x^{(0)}, y^{(0)}\right]^{\mathrm{T}}$ and this initial position is applied to the iteration by using (12).

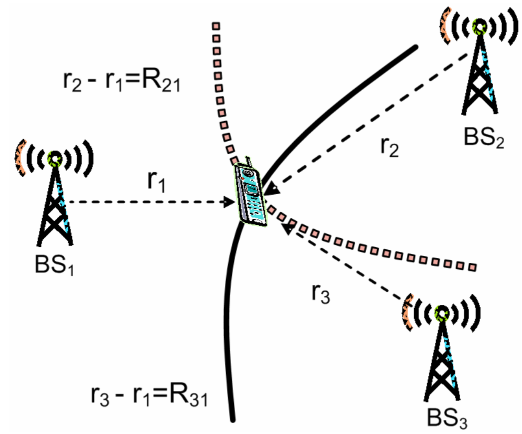

Fig. 4. Hyperbolic positioning

$$J(\boldsymbol{x}) = \begin{bmatrix} \dfrac{x - X_2}{r_2} - \dfrac{x - X_1}{r_1} & \dfrac{y - Y_2}{r_2} - \dfrac{y - Y_1}{r_1} \\ \dfrac{x - X_3}{r_3} - \dfrac{x - X_1}{r_1} & \dfrac{y - Y_3}{r_3} - \dfrac{y - Y_1}{r_1} \\ \vdots & \vdots \\ \dfrac{x - X_{M_{BS}}}{r_{M_{BS}}} - \dfrac{x - X_1}{r_1} & \dfrac{y - Y_{M_{BS}}}{r_{M_{BS}}} - \dfrac{y - Y_1}{r_1} \end{bmatrix} \tag{13}$$

IV. EXPERIMENTAL EVALUATION

Our simulation results are based on real environment data. Test configuration is shown in Fig.5. The configuration consists of MS, diagnostic monitoring module and our simulator. MS is a gpsOne supported handset. DM software shows PPMM which contains SID, NID, BSID, PN offset, pilot strength, Ec/Io, time delays in chip and real MS geographic position obtained from pCell algorithm. The iterative TDOA method is implemented by using computer simulation. For the iteration method we used SID, NID, BSID, PN offset and time delays. PN offset is used to identify the BS where the signal comes from. All BS geographic positions are known and they are used in our simulation. The MS geographic coordinates found by pCell is used as the initial position for the iteration method. The experiments are made at different indoor environment where GPS signal is a weak or not satisfactory by using the test configuration which gives the pCell results. Fig. 6 and Fig. 7 show the results of our proposed method. The simulation results are demonstrated for urban and suburban cases respectively. At the same place for each floor we made the test 100 times and accuracy was calculated for different confidence levels.

Simulation results show that the proposed method outperforms the conventional pCell algorithm and it also has better accuracy comparing to the iteration method where initial guess position is calculated as an average of summation of used BSs' positions [14].

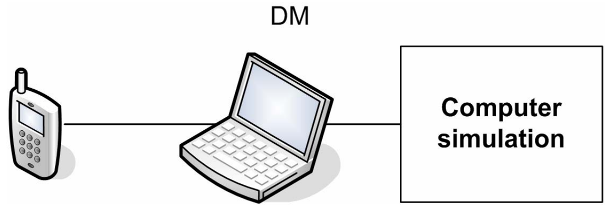

Fig. 5. Test configuration to get the results.

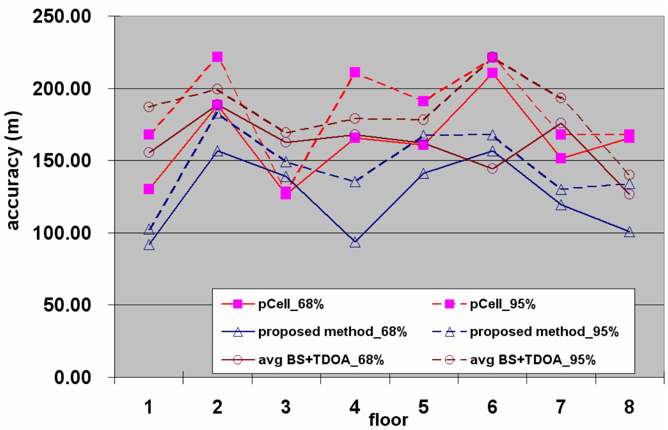

Fig. 6. Urban case (Lotte Department Store, Seoul).

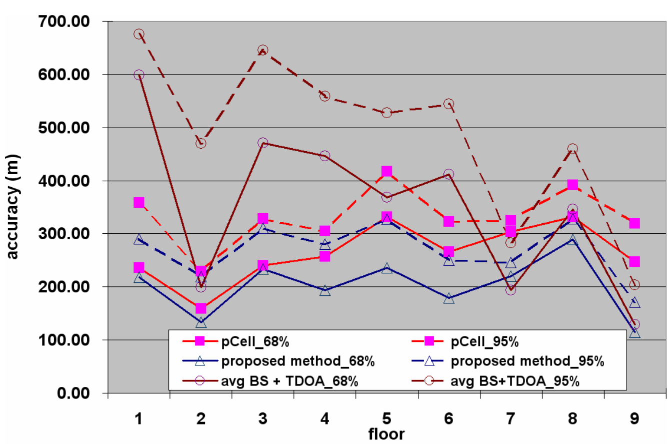

Fig. 7. Suburban case (Kyeunbuk University, Deagu).

V. CONCLUSION

This paper demonstrates the iteration method using pCell algorithm's location information. The proposed method is able to achieve better performance than conventional pCell algorithm in indoor environment. For this purpose, we combined both, iterative TDOA and pCell algorithms. The proposed algorithm highly depends on the conventional pCell algorithm's accuracy and there is no need to change the hardware of MS.

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