Abstract - This paper proposes a mobile location estimation and tracking technique for wireless communication systems. The location estimation is based on the differences of downlink signal attenuations, which are used to determine circles composed by possible mobile locations. Then the actual location is given by the intersection of the circles. The great advantages of this method are the non-necessity of a known and accurate path loss modelling and the reduction of shadowing effect. Furthermore, a mobile tracking technique via piecewise linear optimization using a simple genetic algorithm is applied to improve the locations estimation. As the results are shown, the estimation errors are much smaller than the errors from cell-ID method in a real GSM system.

Keywords – Mobile location, tracking, genetic algorithm.

I. INTRODUCTION

Mobile location estimation brought up many attentions in these few years. It has great potential in areas such as rescuing, navigation, tourism, and entertainment. For example, people may want to know where the nearest shop is or parents would like to know where their children are.

Over the past decades, a considerable number of studies have been made on mobile location estimation. Those estimations would be divided into four categories. The fist one is Global Positioning System (GPS) [1], which is based on signals transmitted from satellites. GPS is accurate but requires non-standard features either in the mobile terminal or the network, which needs additional cost. Besides, GPS fails when satellites’ signals are blocked, such as in a setting when the mobile in close to a large building or used indoor. The second one applies channel propagation model to estimate the distance between the base station (BS) and the mobile to locate the device [2][3]. This approach works without additional costs, but its accuracy is often inadequate due to the complex propagation mechanisms including reflection, diffraction, scattering, etc. The third one estimates the distance between the BS and the mobile trough the propagation delay time [4][5][6]. This method works in third generation (3G) mobile communication systems, but, in GSM systems, only one time advance is available and its resolution is too rough to locate a mobile. The last category recognizes the channel status [7], such as path loss, angles of arrival and power delay profile, for location estimation [8][9]. The accuracy of this method strongly depends on variation of channel status and the size of database. However, the constructing and maintaining of the large database is a time-consuming work.

This paper proposes a mobile location estimation and tracking technique for GSM systems. The proposed location estimation is based on the differences of signal attenuations, and its advantages include the non-necessity of a known and accurate path loss modelling and the reduction of shadowing effect. Also, the correlations of sequential locations of the moving mobiles are used to improve the estimations. Several approaches, such as Kalman filtering [10] and Markov model [11], for mobile tracking have been proposed in literature. However, these methods are very complicated and need time-consuming works. This paper proposes a tracking technique based on piecewise linear optimization using a simple genetic algorithm (GA). A short distance route could be approximated as a straight line, then, the variation of location estimation could be reduced. The proposed location estimation and tracking techniques were applied to a practical GSM system. The proposed method performs greater than cell-ID method. Besides, the complexity of the proposed scheme is low and no additional costs needed.

The rest of this paper is organized as follows. The proposed location estimation and tracking technique are presented in Section II and III, respectively. Section IV discusses the location errors in a real system, and Section VI gives several concluding remarks.

II. MOBILE LOCATION ESTIMATION

The proposed location estimation uses the differences of signal attenuations to determine the circles, composed by possible mobile locations. Afterward the actual location of the mobile is obtained according to the intersections of these circles.

A. Determining the ratio of distances

In a real propagation environment, the attenuation of signal power is contributed from two terms, namely path loss and shadowing. Path loss basically increases with distance from transmitter to receiver, and many models have been proposed. For example, Hata model, Lee model and Walfisch-Ikegami model are commonly used in wireless communication systems [12]. In terms of shadowing, it can be modeled as a log-normal distributed radon process, i.e., the signal attenuation due to shadowing effect is a zero-
mean stationary real valued Gaussian random process when expressed in decibels. Accordingly, a generalized form of signal attenuation could be modelled as path loss plus shadowing component and expressed as

\[ A = k_1 + k_2 \log f - k_3 \log h_b - k_4 \log h_m + 10n \log d + X \]  (1)

where \( A \) is the signal attenuation in decibels, \( k_1, k_2, k_3 \) and \( k_4 \) are constants in the same clutter type of environment, \( f \) is the carrier frequency, \( h_b \) and \( h_m \) are BS height and mobile height respectively, \( d \) is distance between transmitter and receiver, \( n \) is path loss exponent, and \( X \) is a zero-mean Gaussian random process with variance \( \sigma^2 \).

Figure 1 illustrates a situation that one mobile connects with two BSs, \( BS_1 \) and \( BS_2 \), simultaneously. Assume the heights of the two BSs are the same, the difference of signal attenuations between these two links are given by

\[ A_1 - A_2 = 10n \log \frac{d_1}{d_2} + (X_1 - X_2) \]  (2)

where \( A_1 \) and \( A_2 \) are the signal attenuations of these two links, \( d_1 \) and \( d_2 \) are the distance from mobile to \( BS_1 \) and \( BS_2 \) respectively, \( X_1 \) and \( X_2 \) represent the shadowing of these two links. Define \( X' = X_1 - X_2 \), \( X' \) is also a zero-mean Gaussian random process. In a real environment, \( X_1 \) and \( X_2 \) are not independent of each other, and the correlation is "site-to-site correlation" [12], which mainly depends on 1) the angle, \( \phi \), between the two paths along the mobile to the BSs shown as Fig. 1 and 2) the relative values of the two path lengths. Assume \( X_1 \) and \( X_2 \) have the same variance \( \sigma^2 \), then the variance of \( X' \) equals \( 2\sigma^2[1-\rho] \), where \( \rho \) is the correlation coefficient between \( X_1 \) and \( X_2 \). From equation (2), the ratio, \( k \), of \( d_1 \) to \( d_2 \) can be obtained,

\[ k = \frac{d_1}{d_2} = 10 \frac{k_1-k_2}{10n} X' \]  (3)

where the uncertain term, \( X' = X'/(10n) \), is also a zero-mean Gaussian random process with variance \( 2\sigma^2[1-\rho]/(10n)^2 \).

The standard deviation of shadowing is greatest in suburban areas and smallest in open areas, and it tends to increase with frequency and path length. In [13], the standard deviation was found in the range 4.2-7.7dB in suburban/residential environment and in the range 2.2-8.3dB in urban environment for microcells operating at 900MHz frequency band. In [12], \( \rho \) ranges from 0.3 to 0.8 when \( d_1=1km \) and \( d_2=2km \). Thus it could be conclude that the variation of \( X' \) would be small with highly site-to-site correlation. Moreover, the \( k \) value is related only with the difference of signal attenuations and path loss exponent. In other words, even if the exact path loss model is unknown the value of \( k \) could be extracted with high preciseness.

B. Determining circles and mobile location

The \( k \) value, ratio of \( d_1 \) to \( d_2 \), is now used to determine the possible mobile locations. In a 2-dimentional space, those points subject to \( d_1 : d_2 = k \) are the possible locations of the mobile. The locus of those points is a circle and given by

\[ \left( x - \frac{k' x_1 - x_2}{k'-1} \right)^2 + \left( y - \frac{k' y_1 - y_2}{k'-1} \right)^2 = \left( \frac{1}{k'-1} x_1 - \frac{1}{k'-1} x_2 \right)^2 \]  (4)

where \( (x_1,y_1) \) is the coordinate of \( BS_1 \), \( (x_2,y_2) \) is the coordinate of \( BS_2 \), and \( D \) is the distance between \( BS_1 \) and \( BS_2 \). Arbitrarily two BSs yield one circle, hence there would be many circles if more than 2 BSs are available, and the intersections of the circles could be used to estimate the mobile location.

Because seven BSs (one serving cell plus six neighbouring cells) at most are available in a GSM system, the circles in total are 21 ( = \( C_7^2 \) ). Arbitrarily two circles would construct two intersections, where one of them is relative far from the actual mobile location. Consequently, there would be 420 ( = \( C_7^2 \cdot 2 \) ) intersections constructed and a half of them should be eliminated. To extract the actual mobile location, the center of gravity, \( (x_{0},y_{0}) \), of these points are calculate at first, then, half the points farther from \( (x_{0},y_{0}) \) are eliminated. Finally, the center of gravity of the rest points is calculated again and assigned as the estimated location.

III. MOBILE TRACKING

If a mobile moving within a short distance, the route could be approximated to a straight line. Although arbitrary location technique could be used to estimate the mobile locations, these estimated locations are always not exactly the mobile position, i.e. the x-y components of the position coordinates are both noisy. Therefore, it is not proper to derive the fitted straight line using linear regression. This paper proposes a tracking technique based on piecewise linear optimization using a simple GA to reduce the variation of location estimation.

(GA), developed by Holland [14], is a nature-inspired algorithmic technique basing on the principles of natural
evolution and widely used to solve optimisation problems. The individuals with better gene, which leads to be fitter for the environment, will survive in evolution process, but otherwise eliminated. After the elimination by the natural environment, the survivals mates with each other and bear their offspring. The offspring inherit their parents’ genes, which are the same as their parents or even better. The best gene could be obtained by iterating the evolution process [15].

With GA, the searching of the fitted lines for mobile’s moving routes is easy. The straight line, , is given by

\[ L: y = (\tan \theta) \cdot x + c \cdot \sin \phi \]  

where \( \tan \theta \) is the slope, \( c \cdot \sin \phi \) is the intercept, and \( \theta \) and \( \phi \) are both in the range \(-\infty \rightarrow \infty\). The converting of the slope and intercept into functions of \( \theta \) and \( \phi \) would facilitate the searching of optimum solution. Before explaining the algorithm, the definition of the notations used are given as follows:

1) \( N \) is the number of locations used for searching of the fitted route,
2) \( p_{i}^{(e)} \) is the \( i \)-th estimated location using method proposed in section II,
3) \( L_{i}^{(f)} \) is the fitted line obtained at \( j \)-th searching, \( L_{i}^{(f)} \in L \),
4) \( p_{i}^{(p)} \) is the projected position of \( p_{i}^{(e)} \) onto \( L_{i}^{(f)} \), \( i = 1,2,\cdots,N \),
5) \( p_{j}^{(r)} \) is the \( j \)-th reported location which is obtained after tracking,
6) \( d_{ij}^{(e)} \) is the distance between \( p_{i}^{(e)} \) and \( L_{j}^{(f)} \), \( i = j - (N - 1), j - (N - 2),\cdots,j - 1 \) and \( i < j \), and
7) \( d_{ij}^{(r)} \) is the distance between \( p_{i}^{(r)} \) and \( L_{j}^{(f)} \), \( i > j \).

The cost function for the GS is defined as

\[ \text{cost}_{j} = w_{e} \cdot d_{ij}^{(e)} + \sum_{i=1}^{N} (w_{i} \cdot d_{ij}^{(r)}) \]  

where \( w_{i} \) is the weightings. With proper setting of \( N \) and \( w_{i} \), the tracking performance would be greater.

Figure 2 is a tracking example with 5 estimated locations \((N=5)\). Assume a mobile moving along a route (“actual route” in Fig 2.), and a location estimation is used to obtain the discrete mobile locations, \( p_{i}^{(e)} \). For the 1\textsuperscript{st} reported location, \( N \) estimated locations \( (p_{1}^{(e)}, p_{2}^{(e)},\cdots,p_{N}^{(e)}) \) must be buffered before tracking calculation. These \( N \) estimated locations are used for the searching of the first fitted line, \( L_{1}^{(f)} \). Then, \( p_{1}^{(r)} \) is taken as the reported location, \( p_{1}^{(r)} \), which is the projection of \( p_{1}^{(e)} \) onto \( L_{1}^{(f)} \). For the 2\textsuperscript{nd} reported location, \( p_{2}^{(e)}, p_{3}^{(e)}, p_{4}^{(e)}, p_{5}^{(e)} \) and \( p_{6}^{(e)} \) are used for the searching of the second fitted line, \( L_{2}^{(f)} \). The projected location of \( p_{6}^{(e)} \) onto \( L_{2}^{(f)} \) is taken as the second reported location \( p_{2}^{(r)} \). For the 3\textsuperscript{rd} reported location, \( p_{1}^{(e)}, p_{2}^{(e)}, p_{3}^{(e)}, p_{4}^{(e)} \) and \( p_{5}^{(e)} \) are used for the searching of the third fitted line, \( L_{3}^{(f)} \). The projected location of \( p_{5}^{(e)} \) onto \( L_{3}^{(f)} \) is taken as the third reported location \( p_{3}^{(r)} \).

![Fig. 2. The illustration of tracking technique a)the derivation of 1\textsuperscript{st} reported location b)the derivation of 2\textsuperscript{nd} reported location c)the derivation of 3\textsuperscript{rd} reported location](image)

### IV. ACCURACY VERIFICATION

The proposed location estimation and tracking technique were applied to a practical GSM system (1800MHz) in urban Taipei city. Calls were performed from a car, driving along routes shown in Fig. 3, which is an area of 2.1km by 1.7km square digitized building map with triangles denoting sectors. The averaged cell radius of the microcells is about 330m. The verification includes 3 routes: point A to B is route 1, point C to D is route 2, and point E to F is route 3. The measurements were conducted through “TEMS Investigation GSM”, which recorded the GPS coordinates of mobiles and its receiving power level of serving cell and neighbouring cells. Subsequently, the proposed location estimation and tracking technique were used to estimate the mobile locations.

In the analysis, the weightings, \( w_{i} \), in equation (6) were set as \( 1/N \). Uniform crossover and 10\% mutation rate were used in the GA. Considering about the computation complexity, only 100 individuals per generation were calculated and computation terminated after 30 generations. The proposed
method was compared with the cell-ID location method, and Table 1 shows the statistics for location errors. Using cell-ID method the 67 percent of the location errors are less than 215.7 meters, 221.5 meters and 231.4 meters for route 1, route 2 and route 3, respectively. While using the proposed location estimation, the corresponding values are 143.1 meters, 163.5 meters and 172.0 meters, respectively. The corresponding values after tracking are 132.8 meters, 154.6 meters and 164.3 meters, respectively. The accuracy of the proposed location estimation is greatly improved when compared with the cell-ID method. Figure 4 shows the accumulative distribution function (CDF) of the location errors along route 1. Again, the location accuracy is improved by our proposed method, and the worse location cases are corrected after tracking, i.e. the proposed tracking technique smoothes and corrects the location errors. This is clearly revealed in Figure 5 and 6, where Fig. 5 is the estimated locations without tracking along route 1 while Fig. 6 is the estimated locations after tracking. The estimated route in Fig. 6 is much close to the GPS route then that in Fig. 5. Furthermore, with the help of digital map, system monitor could almost confirm which route the mobile user locates.

### Table 1

<table>
<thead>
<tr>
<th></th>
<th>Route 1 (1235 pts)</th>
<th>Route 2 (1951 pts)</th>
<th>Route 3 (1991 pts)</th>
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<tr>
<td><strong>Cell-ID Method</strong></td>
<td></td>
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<tr>
<td>mean</td>
<td>179.9</td>
<td>193.5</td>
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<td>std</td>
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<td>166.6</td>
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<td>98%</td>
<td>434.7</td>
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<tr>
<td>maximum</td>
<td>469.6</td>
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<td>855.2</td>
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<tr>
<td><strong>Proposed Method without Tracking</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>mean</td>
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<td>150.6</td>
<td>151.0</td>
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<tr>
<td>std</td>
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<td>median</td>
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<td>123.7</td>
<td>127.1</td>
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<td>67%</td>
<td>143.1</td>
<td>163.5</td>
<td>172.0</td>
</tr>
<tr>
<td>98%</td>
<td>367.3</td>
<td>402.7</td>
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<tr>
<td>maximum</td>
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<tr>
<td><strong>Proposed Method with Tracking</strong></td>
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<tr>
<td>mean</td>
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<td>144.0</td>
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<tr>
<td>std</td>
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<tr>
<td>median</td>
<td>102.9</td>
<td>119.7</td>
<td>124.5</td>
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<tr>
<td>67%</td>
<td>132.8</td>
<td>154.6</td>
<td>164.3</td>
</tr>
<tr>
<td>98%</td>
<td>341.9</td>
<td>338.8</td>
<td>348.4</td>
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<tr>
<td>maximum</td>
<td>467.5</td>
<td>490.2</td>
<td>419.3</td>
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</table>

Rows 67 percent and 95 percent denote the 67th and 95th percentile, respectively.

![Fig. 3. The measurement environment](image)

![Fig. 4. CDF of location errors along route 1](image)

![Fig. 5. Estimated locations without tracking along route 1](image)
V. CONCLUSIONS

This paper has proposed a mobile location estimation and tracking technique for GSM systems. The estimation is based on the differences of signal attenuations, and its advantages include the non-necessity of a perfect path loss modelling and the reduction of shadowing. The proposed scheme was applied to a practical GSM system. Although it would perform better in rural environment than in urban city due to shadowing, encouraging location accuracy is obtained in urban city. The 67 percent of the location errors are less than 143.1 meters, 163.5 meters and 172.0 meters for route1, route2 and route 3, respectively, which are less than that from cell-ID method. Furthermore, the proposed tracking technique, piecewise linear optimization using GA, smoothes and corrects the location errors. The corresponding values after tracking are reduced to 132.8 meters, 154.6 meters and 164.3 meters, respectively. With the help of digital map, system monitor can almost confirm which route the mobile user locates.

Fig. 6. Estimated locations with tracking along route 1

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