Method for improving the CGI++ mobile location technique by exploiting past measurements

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Abstract—**In this paper we present a novel method for improving the mobile location estimation that the CGI++ technique produces, using a statistical approach. The method produces significant improvement without requiring considerable investment neither at the network side nor at the mobile terminal. With the utilization of a Kalman filter on the previously calculated positions by the CGI++ method, a more accurate mobile location is produced.**

I. INTRODUCTION

Location Based Services (LBS) provide personalized services to the mobile subscriber based on their current position. In this age of significant telecommunication competition, LBS open new horizons for cellular operators as well as application and content providers for the provision of innovative value added services. In order the LBS to become a success, certain technical implementations must occur basically concerning the location technology that will be used. So far, a wide variety of location techniques has been proposed, its one of them presenting certain advantages as well as drawbacks.

Improving the accuracy and applicability of location estimation for the CGI++ technique based on the existing network infrastructure would be very useful and it is the main motivation of this work. We mainly focus on GSM, GPRS networks but the idea is also applicable to 3G networks since the received signal power as well as the serving and neighboring cells for the location estimation are available.

One of the most severe issues facing cellular telephone systems is the complex propagation of radio waves in environments with obstructions, reflecting objects and interference from adjacent cells. These problems apply also to the different location techniques and especially the CGI++ since it takes into account the Received Signal strengths from Base Stations and tries to interpret these into distances, thus presenting great dependency on the propagation of the signal. By introducing our statistical approach, we try to alleviate these problems and as will be shown, the proposed approach leads to significant improvement of the accuracy originally achieved by the CGI++ method up to 65%.

This paper is organized as follows: Section 2 presents a method for extending the CGI++ technique as well as the mathematical background that was used. In Section 3 a new method is proposed based on past measurements collection and exploitation. Section 4 depicts the results of the new technique based on measurements from a commercial network. Lastly, Section 5 portrays the results and section 6 the conclusions of this paper and records the future work related with the proposed technique.

II. EXTENSION OF THE CGI++ TECHNIQUE

The CGI++ technique is based on the Cell IDs as well as the received signal strength (Rx) at the terminal side from the serving and the neighboring cells. Based on the Rx levels, an estimation of the distance between the mobile terminal and the base station is feasible by using a propagation model (e.g., Hata model [7]). This technique gives better results compared to the known CGI++ since it exploits more network related information such as the received signal strength from the neighboring cells. Below, the description of this method takes place.

The mobile device measures the power of the signals it receives from a set of neighbouring Base Stations. Based on the power level and other parameters, it selects which base station will be the primary serving station. The mobile terminal transmits these measurements back at the base stations, as a feedback for various other functions of the radio system. The mobile location server, in order to calculate the location of a specific mobile device obtains these measurements through the Operating Support System (OSS), a network element that is responsible for handling all the operation and maintenance functions of GSM and GPRS. Based on these measurements the distance of the mobile device from each base station is calculated. The distance from the BTSs is calculated by applying the Okumura – Hata model [7].

With the distances from the base stations known, the location server performs a triangulation method, in order to calculate the most probable location of the mobile terminal. The triangulation method is represented in Figure 1.
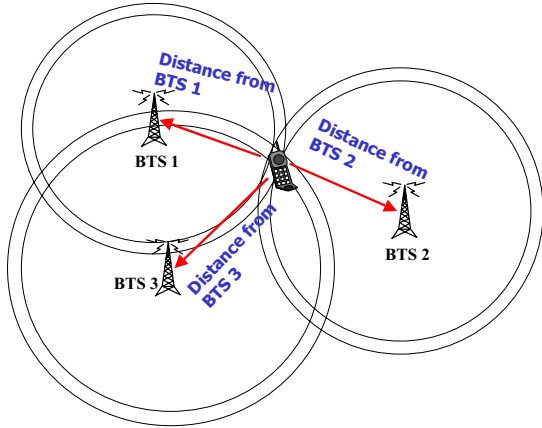
Figure 1: Triangulation method

As depicted in the above figure, the distance from each base station defines a circle around it, on which the mobile is possibly located. An error also occurs concerning the radius of the circle, which originates from the power measurement errors. If the distances from at least three base stations are known, then a single point, which corresponds to the location of the mobile terminal, can be calculated. However, due to the errors, the single point where the mobile resides cannot be always computed. What is actually calculated is an area in which the mobile is potentially located.

Suppose (x_i, y_i) are the coordinates of BTS_i. Then the equation that defines the circle for BTS_i is:

$$Dist_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}$$

where, (x, y) are the points of the circle and $Dist_i$ is the radius of the circle.

The position of the mobile station can be computed by the intersection of the three above circles. Problems arise when these three circles don't intersect. This can happen as a result of the power measurement errors. In order to overcome this issue, a Least Square Optimisation algorithm is deployed. For each point in the area of interest the differences $Dist_i$ from each BTS are computed:

$$F_i = Dist_i - \sqrt{(x - x_i)^2 + (y - y_i)^2}$$

The sum of the squares of F_i is then computed and the point where the above sum is minimized is selected as the point where the mobile terminal is located.

$$[x, y]_{opt} = \min_{(x, y)} \sum_{i=1}^{N} F_i^2$$

The concept of computing this sum is that the optimum point is the point where the difference of the distance computed by the power measurements and the distance of the current point (x, y) from the base station is minimized for all three (N generally) BTSs. By calculating the sum of the square of the differences the sign of the differences is not taken into consideration.

III. THE PROPOSED METHOD

The proposed technique can be exploited so as to improve the accuracy of the CGI++ method described in the previous section. The algorithm that follows uses sequential location measurements that derive from the CGI++ technique and then calculates the position with certain proximity. For the implementation of the proposed method the mobile terminal must have enhanced capabilities concerning storage memory. This memory will be needed in order to capture multiple measurements as described in the following procedure.

The following measurement collection software-based mechanism is employed (see also Figure 2):

The CGI++ List: The terminal stores a number of measurements N (e.g., N=20) in the so-called CGI++ List, corresponding to the N most recent measurements.

Measurement Adoption Condition: The terminal applies a condition according to which a measurement is adopted or rejected (e.g., if a measurement is corrupted or incomplete the terminal may decide not to include it in the CGI++ List, etc.).

The CGI++ Sampling Period: The sampling period T corresponds to the time period between two consequent sets of measurements.

The Time-stamp: To deal with rejected measurements the CGI++ list contains a parameter that indicates the number of periods between two consequent sets of measurements. The parameter can be a real time reference or a counter (as the difference of time will always be a multiple of the CGI++ sampling period).
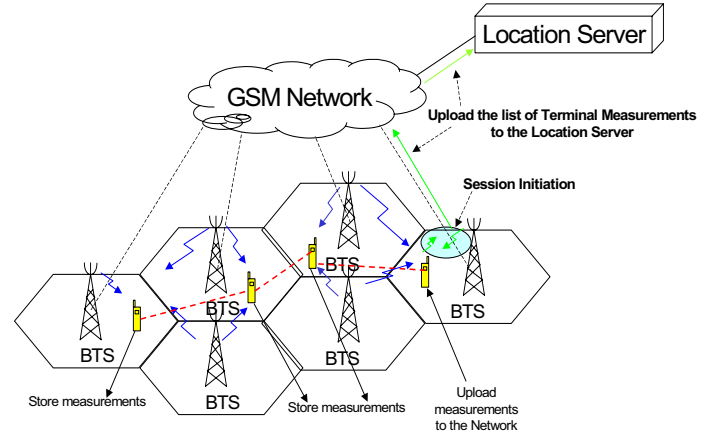

Figure 2: A representation of the concept

LBS Application Initiation: At the initiation of an LBS application (e.g., locate the nearest restaurant) the following actions take place:

- **Current Position:** The CGI++ technique is employed to estimate the terminal position.

- **Previous Positions:** The CGI++ technique is also applied for each CGI++ list entry to estimate the terminal position at previous time instances.

- **Statistical Processing:** The two previous steps have resulted a set of N+1 terminal positions corresponding to the history of the terminal motion. Based on the estimated terminal positions, standard statistical methods can be employed so as to improve the accuracy of the current terminal position estimation. The most common statistical method applied in modern navigation systems is Kalman Filtering [8, 9] a powerful method which has the following form:

$$X_k = \Phi \cdot X_{k-1} + \Gamma \cdot W_k$$
$$Y_k = M \cdot X_k + U_k \qquad (1)$$

where k represents time instance t_k and:

$$X_k = \begin{bmatrix} X_1(t_k) \\ X_2(t_k) \\ V_1(t_k) \\ V_2(t_k) \end{bmatrix}, \ Y_t = \begin{bmatrix} Y_1(t_k) \\ Y_2(t_k) \end{bmatrix}, \ \Gamma = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \Delta t & 0 \\ 0 & \Delta t \end{bmatrix},$$

$$W_t = \begin{bmatrix} W_1(t_k) \\ W_2(t_k) \end{bmatrix}, \ U_t = \begin{bmatrix} U_1(t_k) \\ U_2(t_k) \end{bmatrix} \qquad (2)$$

$$\Phi = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \ M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \qquad (3)$$

W_t is a Gaussian distributed random vector parameter with zero mean and a standard deviation of:

$$Q = \begin{bmatrix} \sigma_Q^2 & 0 \\ 0 & \sigma_Q^2 \end{bmatrix} \qquad (4)$$

with σ_Q^2 estimated either by the proposed approach of [8] or based on a more generic estimation of the mobility conditions in the area, and U_t is also a Gaussian distributed random vector parameter with a zero mean and a standard deviation of:

$$R = \begin{bmatrix} \sigma_R^2 & 0 \\ 0 & \sigma_R^2 \end{bmatrix} \qquad (5)$$

with, σ_R^2 estimated based on the set of terminal position estimations Y_t. The parameter Δt corresponds to the period T and in the generic case where some measurements may have been dropped, $\Delta t = m*T$, where m is defined according to the time-stamp of the CGI++ list.

- **Terminal Based and Network Based implementation:** The employment of the statistical processing can take place either at the terminal or at the network side. In the latter case the terminal has to transmit to the network the CGI++ list as soon as the LBS application is being initiated.

IV. APPLICATION OF THE METHOD

To study the proposed method performance we have used real GSM network measurements from Vodafone Greece commercial network. The measurements were collected from Athens area through surveys for radio coverage verification. A survey file of ~2500 samples has been used for the current paper. The measurements refer to outdoor urban/suburban environment while ~10% of them correspond to static terminal position (e.g., the survey car was stopped at a traffic light for some period of time). The results of the analysis of the measurements were quite interesting especially when studying the mobile terminal mobility conditions (not moving vs. moving terminal).

A. Not-Moving Terminal Positioning

It is well known that the Rx levels at a certain location are time varying. Thus, the employment of the method in the case of a not-moving terminal would probably improve the accuracy CGI++ provides due to the fact that multiple measurements are available, alleviating the problem of Rx level variation. However, the multi-path effect plays a dominating role in this case.

An example of measurements for a not-moving terminal is presented in

Figure 3. As it can be seen, the applying CGI++ over the multiple measurements leads to a set of estimated positions, which in the example remain distant from the actual terminal location. This is because the specific path that signals follow to reach the static terminal position remains effectively the same generating a systematic error in the estimation of the distance between the terminal and the base station and consequently in the estimation of the terminal position through CGI++. In this case our method fails to alleviate the systematic error, however it still leads to an improvement of the CGI++ accuracy since the effect of measurements with high error (e.g., suffering from fast fading) is eliminated. Based on the set of network measurements an improvement of ~25% in the average accuracy has been observed.
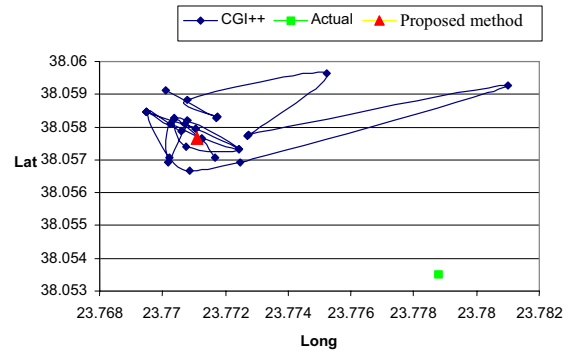

Figure 3: Example of the proposed method for a not-moving mobile terminal

B. Moving Terminal Positioning

In the case of a moving terminal, the signal level measurements are taken from different positions. Thus, the CGI++ statistical behavior, though influenced by the multi-path effect (as in the case of the not-moving terminal), is quite different. Estimating the terminal location for each individual set of measured Rx levels according to CGI++, leads to locations that will be "*surrounding*" the actual terminal location with a variable accuracy due to the variability of the multi-path effect experienced at different terminal positions. A very characteristic example is shown in Figure 4 where the measurements refer to the survey car moving at a speed of ~40km/hr in the Athens urban area avenue with buildings of various height located at the avenue sides. The proposed method in this case behaves very well and the resulting accuracy increases significantly.
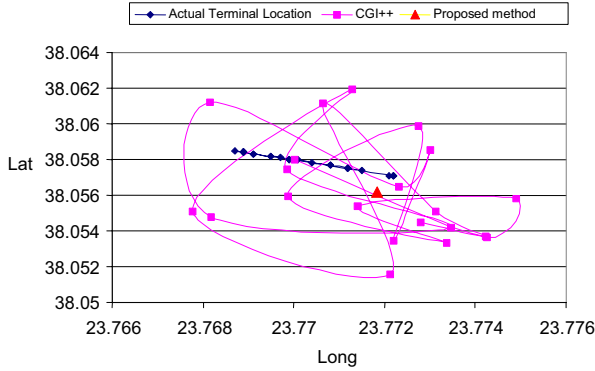

Figure 4: Example of the proposed method in the case of a moving mobile terminal

C. The Proper "List Condition" for CGI++

Taking into account the behavior of the proposed method depending on the terminal mobility status, it appears that there is a need to define an appropriate CGI++ list condition according to which the collected CGI++ measurements are stored or rejected.

While in idle mode, the terminal measures the Cell ID and Rx levels at a constant period T. Each measurement is compared with the previous one and:

- If the difference in the Rx levels of the same cells is "low" then it is assumed that the terminal is not moving and the measured sample is either ignored or it is combined with the previous sample by averaging the Rx levels.

- Else, the new sample is stored as a new entry in the CGI++ list.

This condition (see Figure 5 for the terminal operation algorithm) aims at the following enhancement:

- If the terminal is not moving, the collected measurements will improve the accuracy of the average Rx

level estimation without deleting samples from previous locations.

- The CGI++ list will contain N measurements that correspond to a certain spatial diversity (measurements of signals that followed different propagation paths) maintaining thus the accuracy the scheme achieves for moving terminals.

* Compare new Rx levels with the ones of the previous measurement.
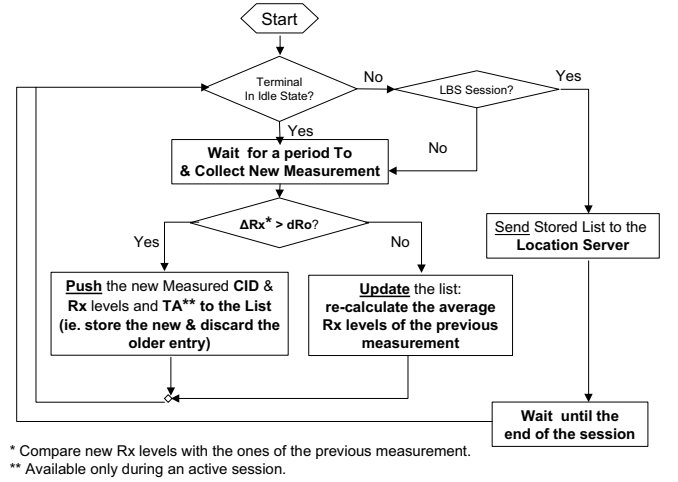** Available only during an active session.

Figure 5: The terminal algorithm for CGI++ List management

Figure 6 depicts an example of the method behavior based on the improved condition. The figure corresponds to 28 samples of measurements. Among those samples, 18 refer to terminal motion and 10 samples refer to a static terminal position. The new CGI++ list condition improved the positioning accuracy from 570m to 300m. Applying the proposed CGI++ list management in the collected network measurements, an improvement of ~8% is observed (around 10% of the collected measurements correspond to static terminal positions).
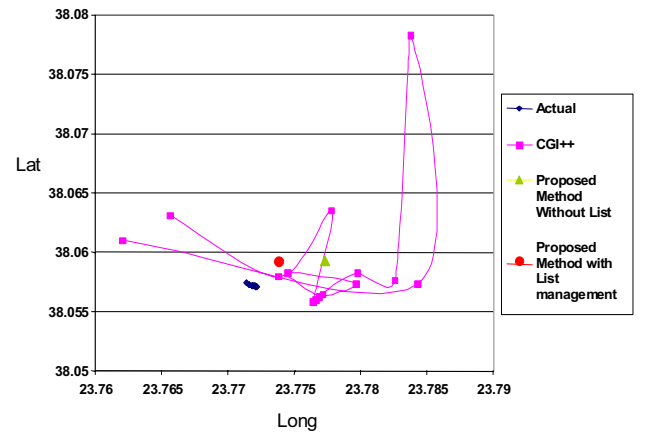

Figure 6: Example results for the proposed CGI++ List Management

It is obvious that the selection of the period T for collecting measurements is a dominating factor for its efficiency. It is clear that the period should be the minimum possible.

However, limitations like the minimum period applicable for the collection of measurements as well as the condition applied for the adoption of a measurement sample in the CGI++ list should be taken into account.

V. RESULTS-CONCLUSIONS

In this paragraph we provide the results of the proposed method in the sample of measurements collected from Athens, Greece corresponding to urban and suburban areas. The key parameters we used are as follows: CGI++ List size N=30, sampling period: T=2sec. The set of measurements, as described earlier, contains 2500 measurements.

The efficiency of the method is very promising as it leads to a gain in accuracy in the range of 65% (from 180m achieved through plain CGI++ to ~50m achieved through it). It is also important to note that the achieved accuracy is well below 100m, which is used often as an essential threshold for a set of commercial applications.

In Figure 7 we present the terminal position accuracy achieved by our method versus the number of measurements contained in the CGI++ list (N). The accuracy of the method increases with the number of samples N exploited, however, the additional gain achieved beyond a certain number of samples is marginal (e.g., N>30).
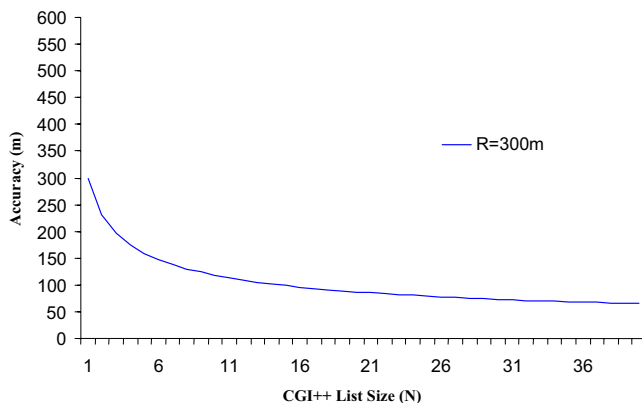

Figure 7: Positioning efficiency vs. the number of samples in the CGI++ List (N)

VI. CONCLUSIONS

The current paper has proposed an innovative method for improving the accuracy of the CGI++ location technique. The new method has been extensively analysed based on both real measurements and theoretical analysis and the following conclusions can be derived:

- The technique leads to an accuracy of better than 100m in urban/suburban environments, which is an essential result for justifying its employment.

- The deployment of the method is a rather "soft" issue, as no additional hardware is introduced. Only additional software is required at the terminal and the network side. Of course the additional processing that the method requires will probably increase the time it takes to estimate the terminal position.

Future research in this topic will include the employment of the statistical method for improving the accuracy of other location techniques. Furthermore, the analysis of indoor environments were the location techniques face major inaccuracies, as well as the exploitation of hybrid LBS methods in conjunction with the proposed List Management will be the next steps.

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