A new Technique using Signal Correlation of One Node B to Estimate Mobile Location

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Summary

In Universal Intelligent Positioning System (UIPS) project, Location Determining Techniques were developed to estimate mobile user's location (position) in 2G, 3G and beyond networks. Timing techniques were developed to improve accuracy of estimating mobile user's location when measurements (such as time differences of arrival) are available from 2 and more than 2 Node B (base station). In this extension of study, a technique called Signal Correlation Method (SCM), based on Artificial Neural Network is introduced when measurements are only available from one serving Node B. Received signals collected during drive test (survey) are stored in UIPS servers. Mobile user's current receive signal is compared to the stored signals to estimate user's location. Technique to match stored received signals from many base stations' (cells) to current user's received signals is referred to as fingerprinting technique. However, SCM technique only uses one Node B's signal measurement for location estimation and produces simulation results that meet FCC E-911 location accuracy requirements for network based positioning.

Key words:

Location Determining Techniques, Positioning in UMTS, Location Based Services, Neural Network

1. Introduction

The accuracy to estimate user's location is dependant on the location techniques and measurement parameters obtained in different environment of the cellular network. For example, time difference measurements from at least 3 base stations (trilateration of time difference) are required in order for downlink Observed Time Difference of Arrival (OTDOA) [1] method to work. Hyperbolic equations of time difference would then be solved for estimating the User Equipment's (UE) location.

The collection of the Location Determining Techniques (LDT) forms part of UIPS LDT module. Figure 1 shows UIPS and its modules. UIPS will decide when to use each technique based on the accuracy level to be provided to Location Base Services (LBS) requester, the environment conditions (Line of Sight or unknown conditions of multipath delay), type of measurements available (time

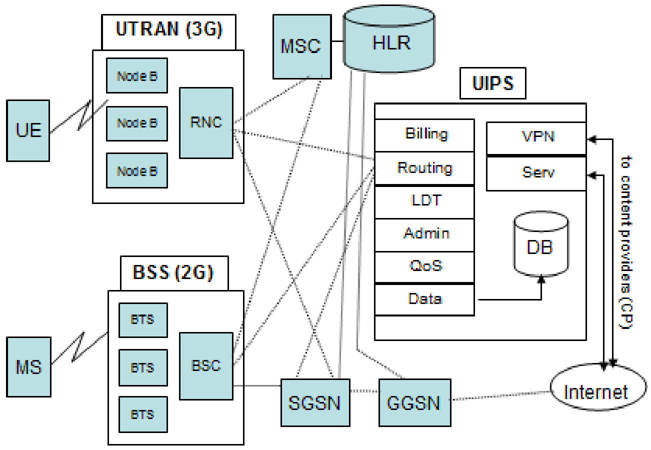

Fig. 1 UIPS in Telecommunication Provider's network

difference of arrival, angle of arrival, received signal strengths, etc.), and the constraint factors. Constraint factors could be caused by many reasons due to the nature of the cellular network (radio propagation, power control, configurations of network measurement reporting). In 3G, hearability problem exists when UE is too close to the serving Node B. When UE is unable to hear to 3 unique Node B, OTDOA trilateration method will fail. For time trilateration (triangulation) method, at least 3 Node B's time measurements are required to be observed by UE in order for location servers (centers) in Telecommunication Provider's (Telco) network to further solve the mathematical equations (to estimate location). Even techniques when measurements are only available from 2 Node B have been implemented into UIPS LDT module. In this study, we will propose a technique using SCM and when measurement (information) of received signal is only obtained from 1 Node B.

Although studies of fingerprinting techniques such as Database Correlation Method (DCM) [2] shows that obtaining signals from many Node Bs' samples produces better user estimation than by obtaining signals from a few Node Bs, but our reasons to develop a new LDT for UIPS are as following:

a.) a technique to be utilized when timing

Manuscript received April 5, 2008
Manuscript revised April 20, 2008

measurements are unavailable from 2 or more Node Bs.

b.) a technique to be used when LBS requests are huge and suitable for continuous query from Navigation Based Services. Too many request of Network Measurement Reports (NMR) for signal levels from user's neighboring cells for purpose of location services, could congest Telco's voice signaling networks. Installing the phone with client to interrogate over the air parameters such as received signal level from the serving cell of Node B (without the need of UTRAN/network to participate in acquiring measurement parameters), is useful during Navigation Based Services. The grabbed measurements will then be sent to UIPS Serv module (location and navigation service module) for estimating user's location.

c.) a technique suitable for urban, suburbs and rural (in rural only one omni directional serving cell is available and Node Bs are very distant from each other), while meeting FCC E-911 location accuracy requirement for network based positioning.

LDT based on one single cell's information is called Cell ID. It is readily available in Telco's network and stored as Home Location Registry (HLR) or Visitor Location Registry. But by estimating user's location with only knowing the current cell where the user is in, does not meet FCC E-911 accuracy requirements (at least 67% should be within 100 m of accuracy and 95% of estimated location should be within 300 m of accuracy) [3] because cell estimation is dependant on Node B's cell size (around 200 m in buildings and up to 15 km in rural areas) [1]. Therefore other parameters based on radio propagation like received signal strength (from signal losses vs. distance such as Okumura-Hata propagation model) [4] could be used along with the knowledge of the serving cell (Node B) to estimate how far the user is from the base station. The only problem is, without accurate angle of arrival information, distance alone could not pinpoint UE's direction from the base station. In cities where Node B's cells are divided into 3 sectors, only a rough guess of user's direction could be estimated based on the serving cell's direction. Each cell is divided into 60 to 120 degrees of beam width to cover UEs within its' coverage area.

The new technique will use Cell ID's information and received signal level of the serving cell. Even though SCM technique does not have the luxury as fingerprinting technique to estimate location from several Node B's or several sectored cells' signals, but by using Artificial Neural Network with training sequence, user's location could be estimated from only one Node B's cell.

2. Signal Correlation Method (SCM)

In general, artificial Neural Networks (NN) are used [5] to train, learn and predict pattern recognition. We will use NN to create Signal Correlation Method (SCM) based on 1 cell's of Node B's Receive Signal Strength Indicator (RSSI). In [6], Neural Network was constructed with back propagation Multi Layered Preceptron (MLP) and compared with Generalized Regression Neural Network (GRNN) when signal strengths are received from 2 or 3 GSM Base Stations (BTS). However, we will build our NN model using Matlab 7 software tool with 2 layer of GRNN network for function approximation. The first layer contains the Radial Base neurons (input weight calculated with Euclidean distance) and the second layer consists of Purelin Neurons as in reference [7].

The elements of input, P_i required from real drivetest data collection are represented by:

1. x coordinate in meters
2. y coordinate in meters
3. UMTS RSSI level in dBm
4. Cell ID number (decimal) or Primary Scrambling Code of the serving cell

Figure 2 illustrates the data collection process. The drivetest equipment used for data collection consists of:

- Laptop installed with commercial drivetest software
- GPS (Global positioning system) antenna which is mounted to the rooftop of Telco's vehicle. The GPS's USB connector is connected to the laptop so real reading of the coordinates could be obtained for each sample.
- 3G phone (UE) connected to the laptop. This phone is set to active voice call mode so the drivetest tool could collect active serving cell's signal strength and Cell ID.

Three repetitions are required of the same route (point A to point B) in a given day. For the first route (trial), average vehicular speed of 60 km/h is maintained to collect all the samples along the route. One sample (i^{th} sample of P_i) represents a collected signal measurement within a time interval. For example, every 0.5 seconds one sample of signal strength from serving cell is collected.

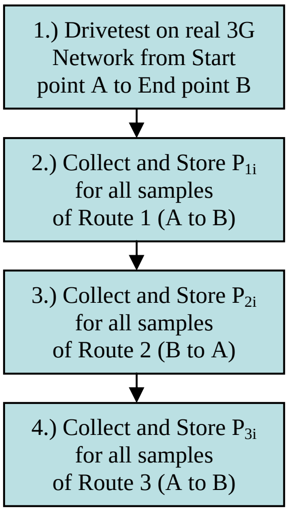

Fig. 2 Data Collection Process

The second route is basically the same route but returning from the opposite direction of point B to A with average speed of 60 km/h. The third route is again route A to B but with reduce speed and stopping over to collect stationary serving cell. The three different routes are important in order to get connected to as many unique Node Bs along the route, resulting from the different direction of handovers. During stationary where handover is less, it is desirable to collect the dominant serving cells along the route.

Once the input samples for all the 3 routes are collected, the process for developing and training the algorithm follows as in Figure 3. The strategy is to use only highly diverse data or unique data for storage. Too much unnecessary data could slower the NN process. Our goal is also to optimize the UIPS's processing performance. The first step is to take only 12% of route 1's data (samples) which is unique from one another. Then route 2's data is simulated using GRNN network with the above 12% data to estimate route 2 mobile location. The worst performance data of the i^{th} samples are then injected to the 12% route 1's original data. The purpose to do this is due to SCM algorithm needs to learn-another (which means to say one is learning from another's weakness in order not to repeat the same mistake). Learn-another (LEAN) process will optimize the acquisition of more diversified samples. Once route 2's worst data (using LEAN) is combined with route 1's 12% data, simulation process for route 3 begins. Again the highest distance (highest error difference between estimated to real locations) are taken as LEAN for route 1 and route 2 samples earlier. This final process will consists of around 20% to 23% of route 1's sample size.

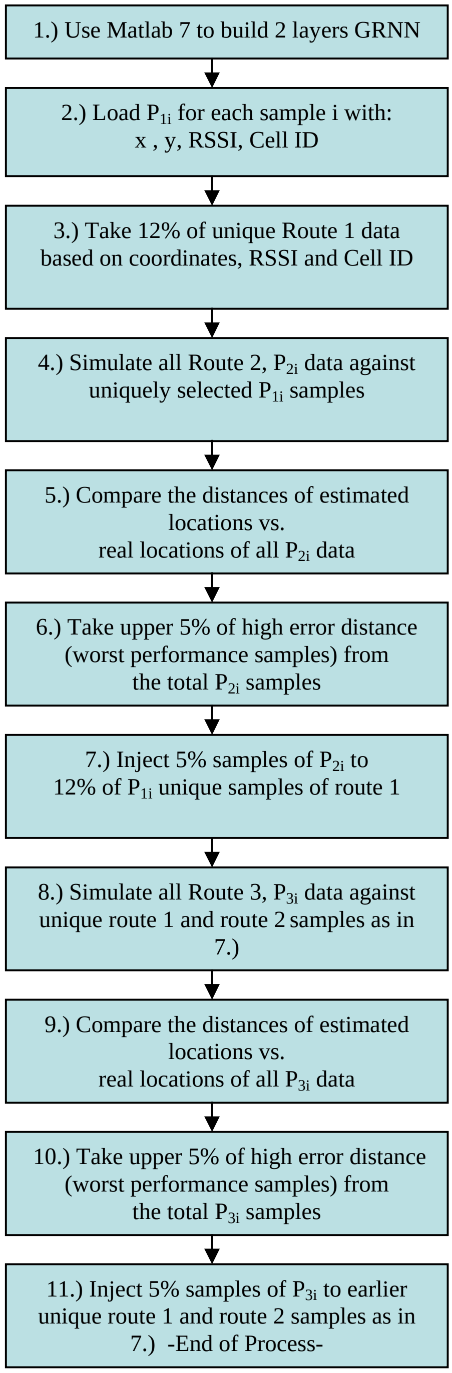

Fig. 3 SCM algorithm with optimized learned-another (LEAN) data ready for actual usage

SCM is now ready to be used for the actual real live situation around the vicinity of point A to point B.

The elements of simulated input (actual input), S_i are represented as:

1. RSSI level (received signal level in dBm from serving cell)
2. Cell ID of serving cell

The elements of simulated output, T_i are represented as:

1. x coordinate in meters
2. y coordinate in meters

The coordinates could also be reconverted to longitude or latitude in degree decimal units.

3. Simulation Environment

In the previous section, the data collection process along the 3 routes (trial) was described. In general, the routes are referred to as 3 routes but it is actually the same route area but just the order of collecting the drivetest data at different times, different directions (A to B or B to A) and different orientation (faster or slower speed). The percentage of Node B placements (distances) with respect to UE in route 1 (trial 1 from A to B) is as shown in Figure 4. Node B placements with respect to UE in route 2 (trial 2) is shown in Figure 5. Node B placements with respect to UE in route 3 (trial 3) is shown in Figure 6.

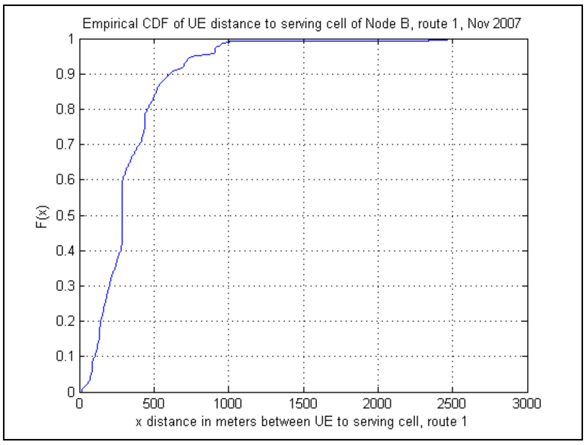

Fig. 4 Cumulative Distribution Function (CDF) of UE distance to serving Node B (route 1)

The data obtained during drive test of urban route in November 2007 was used as basis for the actual simulation environment. The Simulation parameters are listed in Table 1.

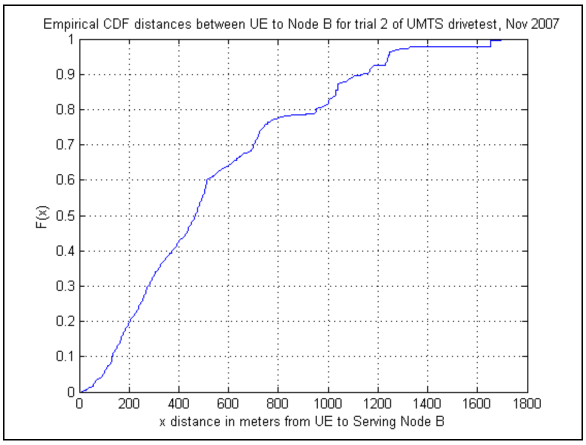

Fig. 5 CDF of UE distance to serving Node B (route 2)

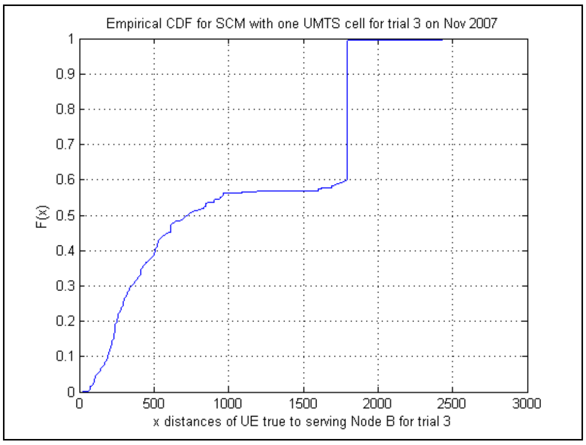

Fig. 6 CDF of UE distance to serving Node B (route 3 or trial 3 of SCM data collection process)

Every 0.5 seconds, received signal level from the serving cell, is measured by the UE (client in the UE) and sent to UIPS Serv (Services Module of UIPS server). UIPS will utilize SCM technique to find the best signal correlation in order to estimate the user's location. If LBS is requested (such as find the nearest restaurants), with the estimated location, UIPS will contact 3rd party Content Provider via its secure VPN Module (as in Figure 1) to provide information to the requested user (information of the nearest restaurants). The Data Module will be used to store the optimize samples of trials for all the drive test routes that has been conducted. For example route A to B (with 3 trials) is categorized as 1 set of SCM with LEAN data. UIPS will also store all the Telco's updated planning data such as coordinates of Node B, Cell ID, Primary Scrambling Codes, Antenna Height, etc.

Table 1: Simulation Parameters in UMTS Network

No	Descriptions	Parameters
1	Node Bs distance to UE during drivetest for Trial 1	67% Node Bs are 360 m 95% of Node Bs are at 767 m
2	Node Bs distance to UE during drivetest for Trial 2	67% Node Bs are 653 m 95% of Node Bs are at 1242 m
3	Node Bs distance to UE during drivetest for Trial 3	67% Node Bs are 1796 m 95% of Node Bs are at 1796 m
4	Total query of location during trip	2121 samples (0.5 seconds interval between each sample
5	Total Measurements	2121 measurement samples (0.5 seconds each received signal is collected and sent to UIPS via Serv module for processing
6	Distance of trip	9.77km (from start to end). Point A to B (same route as route 1)
7	Type of location search	Vehicular Navigation/Tracking
8	Average vehicular speed	50km/h (with light traffic jam)
9	Terrain Environment	Good Line of Sight (LOS), urban Okumura-Hata propagation with average Node B Height of 35m
10	Total navigation time	17.675 minutes (start to end journey)
11	Technique	SCM with LEAN (3 trial route stored signals between point A to point B)

For the simulation model above, 3 trial data (as described in the previous section) was used to construct the stored received signal for SCM LEAN (optimized learn-another diversified samples). Then real data set of 2121 samples from route A to B will be used as part of the actual simulation to test and verify the accuracy of the SCM technique.

4. Results and Discussion

The results for simulation based on actual drivetest from route A to B is illustrated as Cumulative Distribution Function Plot (CDF) in Figure 7. The final result shows that 67% of the estimated location is at 85 meters of accuracy, 95% estimated location error is at 291.5 meters of accuracy, and maximum error is at 721 meters as shown in the Figure. The 67% and 95% definitely meets FCC requirements for location accuracy. The mean estimated location error is at 31.92 meters.

In [6], using MLP method for GSM (no data was available to compare for UMTS) with 2 base station real signal strength's data, the mean estimated location error is 44.4 m, and using GRNN method, the mean estimated location error is 43.6 meters. Table 2 compares SCM and DCM [2] techniques simulated on urban route with CDF results for 67% and 95% error distance (meters).

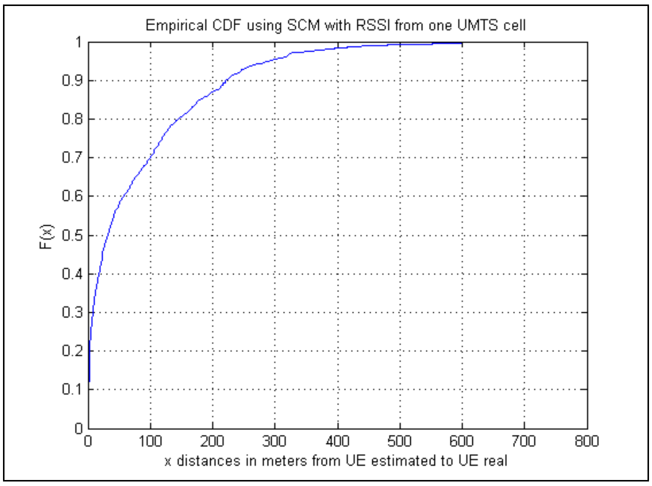

Fig. 7 CDF of SCM technique based on real data

Table 2: Comparing with Other Fingerprinting Performances in Urban UMTS

Techniques	67% (m)	95% (m)
SCM (1 hearable cell)	85	291.5
DCM (average 2.2 hearable cells in Finland) [2]	106	379

Figure 8 shows that when learned-another process (LEAN) is not used on any one of the trial route (i.e. route 3), the errors are very large. During the data collection process of route 3, total samples of 2540 were collected from point A to point B within 21.2 seconds of total trip time (the route with slower velocity and stationary movements). For example at 1000th sample when the vehicle was stationary (the vehicle was stationary for some time in between the same route of A to B), estimated location error is 2096 m. When learned-another (LEAN) was applied to the same sample point as in Figure 9 (1000th sample of the same drivetest route), estimated location accuracy improved significantly to 3.37×10^{-5} meters. This is because during stationary, the Node B that was selected was not in the stored list of received signals and when SCM have learnt from this Node B's behavior, the bad values (high distance errors between UE estimated and UE real) become part of the diversified samples in order to further improve the estimation accuracy. In Figure 9, most of the stationary samples points and worst points have been corrected by SCM with LEAN. The maximum error for this route was corrected and reduced to 719 m (maximum error now occurs at sample 2533).

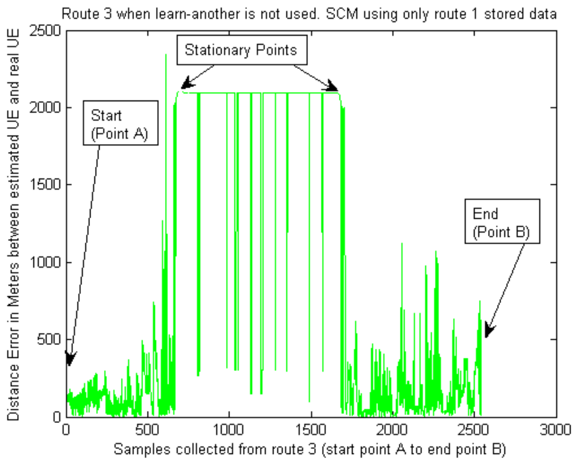

Fig. 8 SCM Simulation Performance on Route 3 when learned-another (LEAN) not used

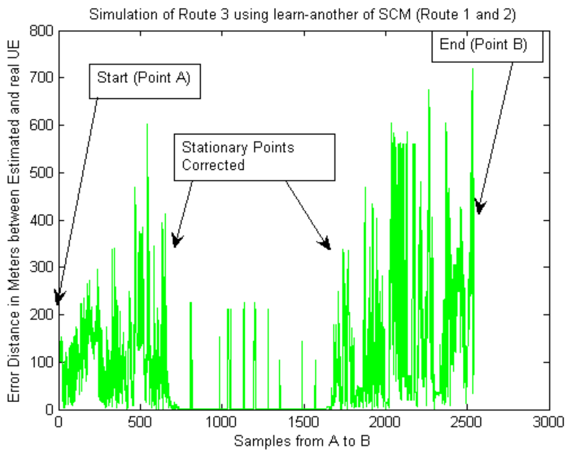

Fig. 9 SCM Simulation Performance on Route 3 when learned-another (LEAN) from route 1 and route 2 are used

Even though 95% of the Node B's (cell) distance to UE along route 3 is at 1796 m (as in Table 1, 95% of Node Bs distance of route 3 is the highest among all routes), but SCM with LEAN (after completing optimized learned-another data storing process) was able to reduce the 95% location estimation accuracy to 291.5 m during the actual simulation. Figure 10 illustrates the estimated UE movement versus the real UE movement on actual simulation route A to B.

In terms of processing time, the entire training process of running SCM as in Figure 3(GRNN with 3 routes' of LEAN) takes 9.33 seconds. The actual testing/simulation of finding one location estimate took 37 milliseconds and the total time for finding 2121 estimate of locations (CDF performance as in Figure 7) took 0.78 seconds.

FCC E-911 requires that Network based positioning techniques to be within 100 meters of accuracy for 67% of the location estimation and 300 meters of accuracy for 95% of the location estimation. So SCM (as in Table 2) does meet this requirement.

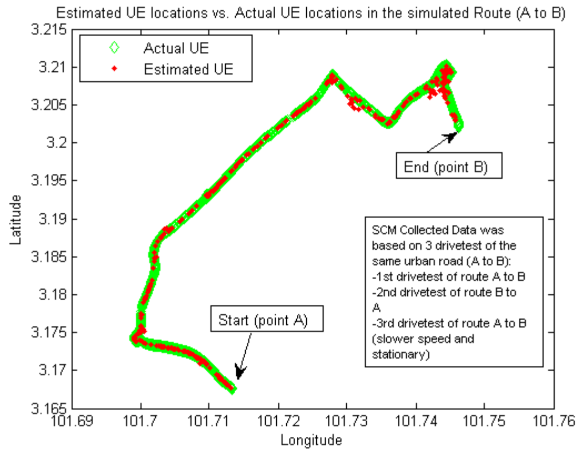

Fig. 10 SCM estimated UE locations on simulated route (A to B)

5. Conclusion

SCM technique proved to be accurate even though using just one cell's signal level. This is due to using a new process to train data samples. This new process is called LEAN (learned-another). In addition to acquiring diverse samples, it will also acquire the information of samples that caused the highest degradation so that in future, the same degradation does not get repeated.

Other fingerprinting techniques require more base stations to improve location estimation accuracy such as Database Correlation Method (DCM) (which requires more Node Bs). Even then, the performance of SCM is more accurate in urban areas where LBS would mostly be used. In LBS services, UIPS would request UE (phone assisted) to obtain signal measurement, which will be returned back to UIPS for further calculations (using SCM technique). In rural areas, where only the serving cell is dominant (hearable) or during emergency search of location, UIPS would request UTRAN to interrogate UE and then SCM will be used to estimate location.

For future work, Round Trip Time's information from the serving cell to UE would be utilized with this LDT (SCM technique) as hybrid technique.

Acknowledgment

This work was supported in part by the Ministry of Science, Technology and Innovation, Malaysia under Grant 01-01-02-SF0344.

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