Increasing Position Estimation Accuracy for Internationally Roaming Mobile Subscribers

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***Abstract*—In this paper we present the methods and approaches to increase the mobile subscriber positioning accuracy while the subscriber is roaming in foreign country network. We provide a technically feasible model and a combined solution implementing different techniques. We also provide the trials made related to each technique and result in use cases that may make use of the proposed model.**

***Index Terms*—mobile position, international roaming, position accuracy, location based services**

I. INTRODUCTION

Mobile positioning has become a critical supplementary add-on for very special value added telecommunication services provided to individual subscribers, corporates, organizations or even the military. [1], [2] A mobile network operator may determine the position of their subscriber by using the existing core and radio network elements and some location based equipment such as Gateway Mobile Location Center (GMLC) and Serving Mobile Location Center (SMLC). The position accuracy depends on the positioning methods implemented in SMLC and most commonly they are limited with standards and specifications. [2], [3] Still, the accuracy value is in control of the home mobile network operator as it depends on the deployed network elements and investments.

International roaming [4] brings many difficulties on mobile communications, as the services given to the visiting subscriber depend on the visited network capabilities, technical and commercial agreements. Standard bodies had proposed many guidelines related to location services in international roaming [5], and some proposals are given for positioning services for roaming [6], but due to the complexity and the need of agreements among operators, many of the operators do not adopt this guidance. Also, mostly many services provided in home network cannot be provided in visited foreign country networks due to lack of technology or planned limitations such as barring some of the features because of commercial reasons. For example, you may not use the mobile data or internet as you did in your home network due to data roaming charges, or you may not make use of your mobile handset's capabilities due to the deficiencies of the visited network that you are being served; because your home network had decided to steer your roaming services there as they have the best commercial agreements.

Due to many reasons, visited operators do not provide position information of the roamers they serve. One of them is security; the position requester may make analysis on visited network architecture, topology and details after a period of time with many position queries done. The other one is the commercial and the technical agreements made among home and visited network. The visited network should provision all the technical permissions to let home network query the network using standard ways such as integrating to visited network GMLC with limited rights and capacity or querying the visited network Mobile Switching Centers (MSC) by direct MAP Provide Subscriber Location messages [7]. This will need many investments on visited network core and radio access network. Also, despite having an SMLC node within the network, the position accuracy provided may not be well enough due to radio network deficiencies and positioning features available within SMLC.

In this paper, effective methods for retrieving highly accurate mobile positioning information has been provided for the cases where mobile subscribers / terminals are roaming in a foreign country network operator. The aim is to design and propose a generic framework that may be adopted by many mobile network operators so that they can provide highly sensitive location based services to their subscribers even when they roaming abroad. We give details about the current situation on the mobile business. Going forward with the proposed model we give our methods theoretically and compare the test results with today's experience.

We continue with the results driven from a research on current situation and the literature. Next we give the details of the proposed solution and the methods to increase the mobile positioning accuracy in visited foreign network. Then we touch upon the trials we made and their comparison followed by use cases that may make a great difference for subscribers and operators. At the ends we sum up with conclusion.

II. LITARATURE AND CURRENT SITUATUION

In case of roaming, the easiest information that can be retrieved from the visitor network is the Cell Identity

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which is defined as the cell that serves the visitor roaming subscribers. Two dimensional coordinates corresponding to the Cell Identity is assumed to be globally known, as it is possible to find them in open databases. So that, the information provided to the home network is the coordinates of the serving cell. In fact, this also needs a query with a standard MAP Provide Subscriber Information (PSI) message. But we do not have any idea on the position of the subscriber. She may be anywhere covered by the serving cell, so that it may be in a couple of meters or many kilometers away. So that we must assume that the position accuracy of the subscriber may range up to the theoretical limit that the radio standard permits. If the cell is a macro cell, then it may go up to 35 kilometers, and we should accept that the subscriber is within a circle of radius 35 kilometers [8]. The basic shape is given in Fig. 1.

Figure 1. Common position accuracy for roaming subscribers.

Theoretically the visited network may provide the same capabilities for their visitor roamers if they have commercial and technical agreements with the home operator, and the position accuracy provided may even go down to meters, but this requires huge core and radio access network investments and many of the current mobile network operators do not afford these.

Currently there are more than 700 commercial mobile network operators throughout the world. After the trials and discussions we have made with the other operators, less than %1 of them provides the position information of the visitor roamer to the home network operator. The most accurate result observed is shape of a disc where the thickness of the disc is about 550 meters. Actually the result can be driven by using the parameter Timing Advance (TA) [7], defined as the length of time a signal takes to reach the base station from a mobile. Base stations have the TA value for each served subscriber and it can be reported to the SMLC nodes if the core and radio access network supports the feature and if the visited network has a SMLC. Fig. 2 shows the shape of the position where the visitor network has SMLC deployed and permits the home network make positioning queries. The value of TA is generally 550 meters for GSM technology and may differ based on the deployed access technology.

Figure 2. Shape for timing advance.

The general tendency of visited network operators on positioning queries is given below:

- *Providing Cell Identity for PSI queries to MSC nodes:* This may rnage up to 35 kilometers and can not be used for location based services that need high precision.
- *Blocking positioning requests from foreign networks:* This a common method as many network operator does not have positioning agreements.
- *Providing fake responses to positioning requests*: In order to prevent retries from the querying network, visitor network return fake position values.

Currently, there is no home mobile network operator that provides a position accuracy better than the visitor network provided for the roaming visitor subscribers. The reason is that their positioning architecture is visitor network dependent and if the visitor network does not provide any position information, then there is nothing done by the home operator to make it possible.

However, it is possible to provide position information and if available incrase the accuracy even for international roaming. These are given in following sections.

III. Proposed Model

We propose a roaming positioning framework model that should be adopted by all the mobile network operators that desire estimating the possibly best position accuracy regardless of the positioning capabilities of visited/roamed network.

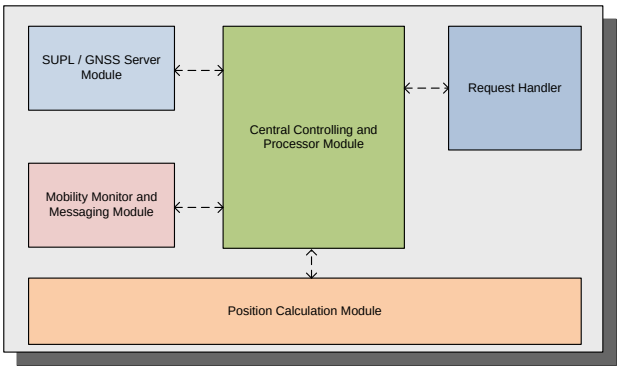

Figure 3. Proposed model.

The framework monitors all the international mobility signaling for the roaming subscribers so that it can understand the currently attached foreign network. The preferred mobile operator list is also stored for each possible country, so that the framework may try to steer the subscriber to any desired visited network over the air Framework is capable of sending standard mobile terminating binary SMSs and analyzing the content of standard mobile originating SMSs. Also there is an internal module to encode preferred mobile network lists or any kind of SIM commands [9] to mobile terminated SMSs. There is a remote connection to one or more well maintained Global Navigation Satellite System (GNSS) provider so that the satellite navigation data can be received for foreign countries. These kinds of GNSS

providers (e.g. EGNOS) deploy antennas over several countries so that it is possible to get observation value in real-time for the desired country. The framework should have a so called central unit to process all the data flowing through the interfaces, to store the entire subscriber and terminal related data in an internal database, to determine the commands to send to subscriber's terminal and the content of the signaling messages monitored. The final part of the framework is the position estimation module where the position calculation algorithms are performed. Fig. 3 gives the lay out of the proposed framework.

A. Request Handler

This component receives the positioning requests from operators location based services. It passes the request towards the central unit and waits for the response. Upon the reception of response, provide the calculated positioning data for the related location based roaming service.

B. Mobility Signaling Monitoring and Messaging Module

This component monitors the mobility signaling (Location Update Procedure) for the roaming subscribers. Module monitors the standard circuit switched mobility and packaged switched (mobile data) mobility requests. So that system can understand from which country and operator the roaming subscriber is trying to have the services. Additionally, module can send mobile terminated SMSs towards the serving mobile switch. The other feature of the module is to analyze the mobile originated SMSs coming from foreign networks.

C. SUPL and GNSS Server Module

Secure User Plane Location (SUPL) [10] protocol is an IP based protocol for transmission of satellite data for the terminals. This module covers the SUPL serving function so that any kind of SUPL messaging can be done.

GNSS Server functionality is a type of IP based connection to a remote Satellite Based Augmentation Systems (SBAS) to get the satellite navigation information observed from the visited country. There are many SBAS systems worldwide; EGNOS for Europe and Northern Africa, WAAS for USA, MSAS for Japan, GAGAN for India etc.

D. Central Controlling and Processing Unit

This is the central unit of the framework. It processes the whole data and events received from other modules and correlate them using the internal state machines. Module stores the subscriber and terminal details, preferred network operators lists per country, terminal attributes in its internal database. Module provides all the retrieved position related data to the position calculation module and passes the result to the relevant requester.

E. Positioning Calculation Module

Module is response to make the best estimate depending on the received parameters from central unit. Module decides to perform the best algorithm to find the most accurate positioning information. It performs all the estimation methods given in standard bodies [2], [3], as well as the non-standard, locally produced methods.

IV. Methods to Increase the Roaming Position Accuracy

With the proposed model, it is possible to generate many methods that will increase the number of options. We prefer to give methods that are not being used for roaming cases and do not depend on the visitor network capabilities:

- Getting TA value from SIM
- Assisted GPS with SUPL
- Getting TA from more than one foreign operator.

F. Getting TA Value from SIM

With this method, system monitors the mobility management signaling. After attaching the subscriber to the visitor network, a Mobile Terminated SMS (MT-SMS) containing encrypted commands to request the Cell Identity and the TA value in a self-triggered Mobile Originated SMS (MO-SMS) from the SIM. These commands are given in [9]. SIM reads these commands and triggers a MO-SMS that contain the Cell Identity and the TA value. Fig. 4 gives the basic flow for the method. The result will be a shape similar to that given in Fig.2; a disc where the inner and outer radiuses are fixed; the thickness of the disc is approximately 550 meters where the center of the disc is the base station. As seen, there is no visited network dependency. The visited network cannot block binary MT-SMSs, as it is already forbidden by the regulation body GSMA in [11], as binary SMSs may contain digital signatures, or home network specific services.

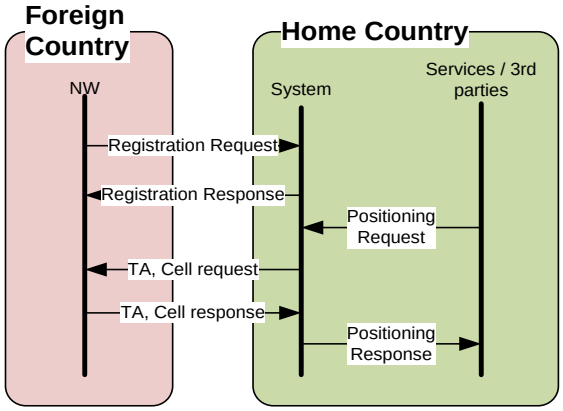

Figure 4. Getting TA via SIM.

G. Assisted GPS with SUPL

With this method we are trying to force the terminal of the roaming subscriber to use the provided satellite navigation data observed above the current foreign country / city. This method assists the mobile handset with the satellite related information (almanac, ephemeris, ionospheric model etc.) so that the Time-To-First-Fix value is minimized compared to the case where handset tries to find the satellites.

Fig. 5 shows the corresponding flow for the method. System continuously monitors the satellite navigation

data provided by the GNSS data provider. Additionally, system understands that subscriber is having a mobile data connection in the visited foreign network. We need to say that, this method will not work if the subscriber turns off mobile internet usage due to data roaming charging concerns. A SUPL message is sent to the subscriber using the data connection made in the visitor network. This message contains the satellite assistance data for the roaming subscriber's handset. The handset does not look around to find the available satellites as they are already given in the request. The satellite assistance data includes the satellites that are observed by the GNSS provider's nearest antenna to the subscriber. The position calculation made by the handset is then received in a SUPL response message and then re-processed to be relayed to querying location based roaming service.

As the method depends on GPS capabilities, the resulting positioning accuracy is extremely good; in many occasions less than 30 meters. The shape will generally be a circle centered on the position of handset with some uncertainty radius value (<= 30 meters). The drawback is that, this method needs a handset with SUPL support and GPS chipset. Many modern smartphones already have these features but system checks the device capabilities from its internal database to decide applying this method.

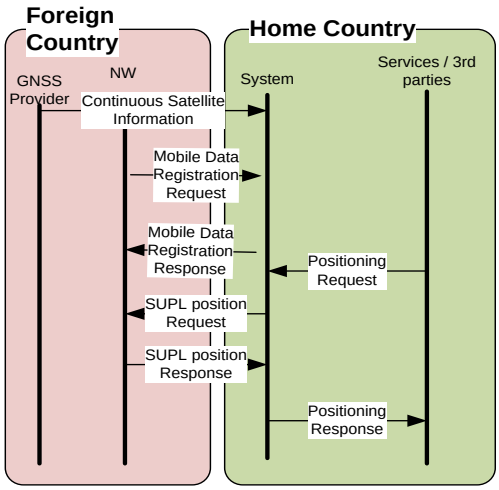

Figure 5. Assisted GPS with SUPL.

H. Getting TA from More than One Visited Foreign Operator

This method is similar to the first method but relies on TA values from more than one operator. The TA and Cell Identity information is retrieved as we did in first method but then system sends another MT-SMS containing an updated preferred network list to the SIM. The most preferred operator will be a network different than the current one.

The SIM reads the command and triggers the handset to jump to other foreign operator. Then the handset begins the location update procedure from other foreign operator. After the completion of the registration to the other foreign network, the same TA and Cell Identity retrieval process is performed. The flow for two foreign operators is given in Fig. 6.

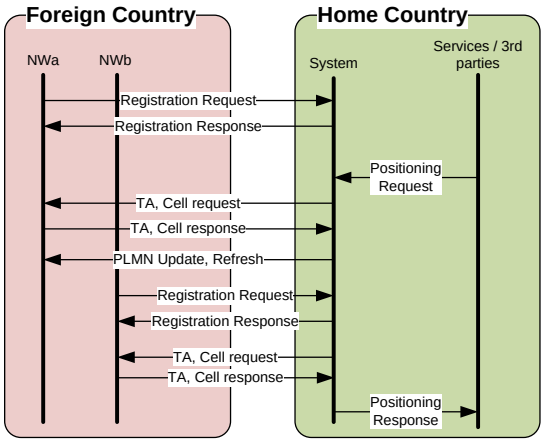

Figure 6. Multiple TAs from different operators.

The resulting position will be the intersections of discs obtained from each separate operator. Even two operators will make the position accuracy much better as the resulting position will be the area obtained by intersecting the circles. By increasing the number of networks, it is possible to make a more accurate estimation but the estimation algorithm will be more complex.

TABLE I. COMPARISON OF EXISTING AND PROPOSED METHODS

Positioning Method	Accuracy (meters)	Details
Cell Identity	From 200 to 35.000, circular	Only Cell Identity is known. Cell size differs based on the location type. Maybe micro or macro
Visited Network SMLC support	550, circular	Requires special agreements, provisioning and SMLC investments on visited network
TA with SIM commands	550, circular	Cannot be blocked by the visited network. No requirement on visited network.
A-GPS with SUPL	From 30 to 50, circular	Mobile internet connection required in visited network. Handset should support A-GPS and SUPL. A GNSS provider integration is required.
Multiple TA from multiple operators	From 40 to 550, circular	Cannot be blocked by the visited network. No requirement on visited network. Complex mathematical algorithms required when number of visited networks increases.

V. TRIALS AND COMPARISONS

We have performed several trials to test the results for each method. For TA based method, only 2G (GSM or GERAN) connection is tried. For other access types such as 3G or 4G the TA value differs depending on the used frequency and modulation types. Table I gives the summary of the results.

First two methods are the ones that most commonly observed in nowadays roaming cases. The Cell Identity is the most general one as the accuracy depends on the deployed cell type. Accuracy increases for the cells

located in city centers and decreases for rural areas where a macro cell is used.

If the visited network has a SMLC, and positioning requests from home network is allowed (corresponds to %1 of the whole network range), the accuracy will be higher, and generally result in a disc shape centered on base station and the disc thickness is about 550 meters.

When TA is retrieved by sending commands to SIM, the result will be a disc with 550 meters of thickness centered at base station.

For Assisted GPS trial, The EDAS of EGNOS [12] has been chosen as the GNSS provider. Mobile internet is activated for the subscriber. 6 to 8 satellite information has been assisted to the handset and the result is gathered within 4 seconds. The result is a circle centered on handset with varying uncertainty values. An accuracy of 30 meters has been achieved.

With multiple TA from multiple visited networks, the accuracy differs based on the intersection of radiation patterns of each cell. We have tried to different foreign operators. In some cases, a regular intersection area is obtained and an accuracy value of 40 meters is obtained. For some cases, different operators use the same antenna tower, so that the centers are common, in this case if the TA value is the same then the resulting accuracy will be 550 meters with circular shape.

VI. Uses Cases

With higher positioning accuracy it is possible to provide services with great value. Some of them are:

A. Emergency Services

E.911 like services can be provided for the subscribers roaming abroad. In an emergency situation, the position of the subscriber can be estimated with a high accuracy and can be provided to any organization located within visited country in real time. This will be a top class service that will increase the customer satisfaction. Also operators are responsible to help their subscribers every time and everywhere, but none of the mobile operators are doing this very well.

B. Position Based Marketing

Operators can provide position based marketing notifications about the place that the roaming subscriber exists. Think about a case that you are far away from your home network, and you receive an SMS from your operator about the shopping center you are in.

C. Legal Tracking

Operators can provide an interface to the government for legal tracking requirements. In any case, the position can be provided with a high accuracy even when the tracked subscriber is abroad.

D. Commercial Tracking

Operators can provide tracking services for third party organizations as well. Think about the case that you have a fleet of vehicles and you track them street by street even when they are abroad.

E. Position based Charging

The home operator can provide position based discounts to their roaming subscribers. The operator may define position based tariffs, and Home Zone like services that will make calls or data usages from a specific location cheaper.

VII. Conclusions

We have proposed a solution model and set of methods to get highly accurate position information in visited networks for roaming cases. With current roaming topologies and behaviors of visited networks, the accuracy of positioning information is very low. In many cases, it is not possible to get such information. To overcome the technical limitations and the complexity of the guidelines provided by GSMA, a couple of methods have been raised. We have tested proposed methods and compared with the current situation that all the other mobile network operators face either. It has been proven that with minimum technical investments and smart methods, it is possible to get highly accurate positioning data when the positioned subscriber is roaming in the visited foreign country network. The methods do not depend on any kind of visited network capability so that the home network will have the whole control on the process. We have provided a couple of uses cases that will fit the proposed model.

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