2G Ultra Low Cost Mobile Phone Positioning without GPS

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***Abstract*—This paper describes the possible location methods available in Global System for Mobile Communications (GSM) when the Ultra Low Cost (ULC) mobile phone is not equipped with a Global Positioning System (GPS) system. The proposed simplified location procedure is to be used especially in the case of emergency calls, but also in the scope of other applications.**

Keywords-positioning, emergency, low cost, GSM, EOTD

I. INTRODUCTION

In the last years, the wireless communication systems had a continuous evolution driven by the user increased requirements and expectations: more data throughput everywhere and anytime, mobility support at higher and higher speed, enhanced applications providing a huge amount of all types of information. And of course, the paid price was an increase complexity of the equipments, both on network and on user sides. So, it comes naturally to request many things from an expensive User Equipment (UE) belonging Universal Mobile Telecommunications System (UMTS) with High Speed Packet Access (HSPA+) or Long Term Evolution Advanced (LTE-A) communication systems. And one of most important aspect refers to positioning capability. Having a GPS system included in the UE allows fast positioning when the link is available and even in deep indoor situations, when the link is not available, the Assisted GPS (A-GPS) feature provides good results. So, all the commercial applications based on UE positioning work fine in almost all the cases. But one more important aspect is that the positioning may be obtained precisely and very fast during emergency calls (911 for US or 112 for Europe), and this can save human lives.

If the above mentioned characteristics correspond to latest wireless communications systems, the main question is what is happening in the case of initial GSM system? Can a 2G only ULC mobile phone, without General Packet Radio Service (GPRS) or Enhanced Data Rates for GSM Evolution (EDGE) capabilities and without a GPS system, benefit from the same positioning features as an expensive UE? To launch such a question today is not something out of interest. Although not too many 2G only mobile phones are designed anymore, there are still a lot of 2G chipsets used in Machine to Machine (M2M) applications (for example emergency systems installed on cars which activate in case of crush). Based on this remark, the goal of this paper is to list the potential positioning methods available in a 2G network and to select one of them and to present a simplified version and the obtained results when a 2G network topology is simulated.

This paper is organized as following: Section II describes the most important positioning methods available for a GSM network, Section III presents the Enhanced Observed Time Difference (EOTD) method in details and the proposed update, Section IV provides the obtained results when two cases were simulated and Section V includes the conclusions of the study.

II. POSSIBLE LOCATION METHODS USED IN GSM

The most important and also the well known location methods in GSM can be organized in two categories, based on the principles they are applying [1][2][3] and based on the place inside the network architecture where they are being executed [4].

A. Possible location methods in GSM

- Cell-ID and Timing Advance (TA) is the simplest, but also the less accurate positioning method. Cell-ID is a procedure based on knowing which cell sector the Mobile Subscriber (MS) belongs to. The sector is known only during connected state (voice or data call) and with this method no air interface resource is required to obtain cell sector information (if the user is active). Since the location is not accurate at all (a complete sector is the place where the MS may be), additional information can be added to increase the performances. Timing Advance represents the round trip delay between the MS and the serving GSM Base Transceiver Station (BTS) and it is the time MS advances its transmission with. Using Cell-ID and TA, the MS position is narrowed down to a band within a sector.
  Another approach to improve accuracy is based on an additional radio link quality indicator. The RxLEV is a GSM parameter used to describe the received signal strength. With suitable propagation models, the distance between MS and BTS can be estimated. Figure 1 depicts the stages of this Cell-ID based method.
- Time of Arrival (TOA) determines the mobile phone position based on the intersection of the distance circles. The distance is related to the propagation delay, so knowing the time on the radio link provides the distance between BTS and MS, i.e., there is a circle around BTS where the MS can be placed. 3 measurements are required, so 3 circles to be intersected (same principle applies also in GPS, but in that case circle becomes sphere), as depicted in Figure 2.

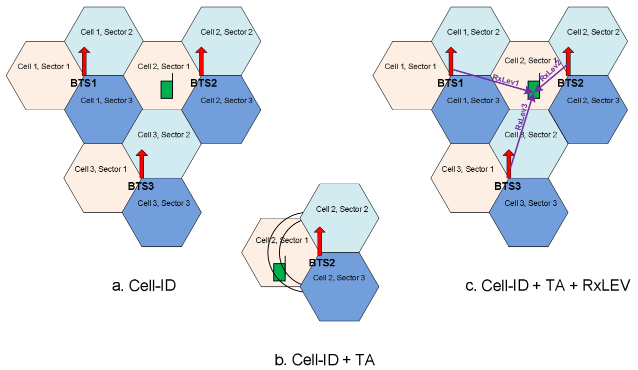

Figure 1. Cell-ID based method

- A-GPS is a method that is used when the mobile phone is equipped with a GPS system. Usually the positioning is made in this case with the information obtained from the GPS satellites. But when the Line of Sight (LOS) to the satellites does not exist, like in deep indoor situations, or when the procedure to get a fix on mobile phone position is too long, the needed information may be received via the wireless communication system. This method is not of interest for this paper since a 2G ULC mobile phone is considered, without having a GPS system available.
- EOTD is based on Time Difference of Arrival (TDOA), so a time difference measurement is required instead an absolute one. It is called the hyperbolic system because the time difference is converted to a constant distance difference to 2 BTSs to define a hyperbolic curve. The intersection of 2 such hyperbolas indicates the MS position, as described in Figure 3. The details of EOTD will be provided in Section III.

B. *Types of positioning methods*

- MS – based with/ without Network – assisted: for this type of methods the position is computed at MS end based on measurements performed on MS side and with/ without inputs received from network side
- Network – based with/ without MS – assisted: for this type of methods the position is computed at network end based on measurements performed on network side and with/ without inputs received from MS side

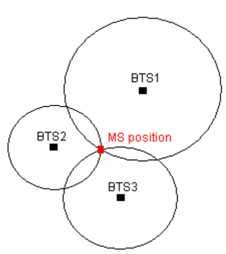

Figure 2. TOA principle

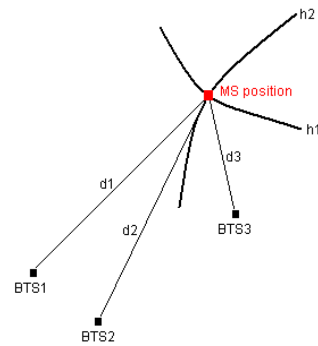

Figure 3. TDOA principle

III. ENHANCED OBSERVED TIME DIFFERENCE

A. *EOTD parameters*

There are 3 timing values required for this feature. The first one is the *Observed Time Difference* (*OTD)* and it represents the time interval observed by a MS between the bursts coming from 2 different BTSs.

The second parameter is *Real Time Difference* (*RTD)* and it represents the relative synchronization interval in the network between 2 BTSs. This time interval has to be measured by a Location Measurement Unit (LMU) on network side as the time difference between the moment when BTS_1 is sending a burst and the moment when BTS_2 is sending a burst.

The third parameter is the *Geometric Time Difference* (*GTD)* and it is the time interval measured at MS between bursts from 2 BTSs due to geometry. In other words:

$$GTD = (d_2 - d_1) / c = PD_2 - PD_1 \qquad (1)$$

where d_1 and d_2 are the distances between BTS_1 and BTS_2 and the MS and c represents the speed of light. In this context PD_1 and PD_2 are the propagation delays between BTS_1 and BTS_2 and the MS.

The following relation applies:

$$GTD = OTD - RTD \qquad (2)$$

In order to better understand the above explanations and the meaning of each of the 3 timing parameters, the following 2 examples are given in Figure 4. The first one considers the case when the timing relations between the 2 bursts from BTS_1 and BTS_2 is changed until MS reception due to propagation delays, while the second one keeps the same timing relation between the 2 bursts on MS reception as it was on BTSs transmission.

In Figure 4, one can observe how the timing relation between the two considered bursts was measured on LMU side and how, after the propagation delay effect was introduced by the radio channel, the bursts timing difference was observed on MS side.

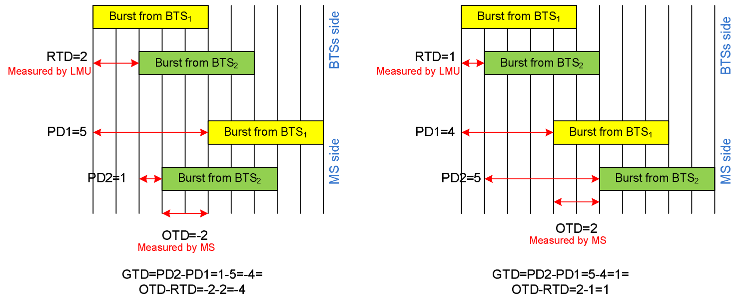

Figure 4. EOTD examples

B. How EOTD works?

In order to understand how EOTD really works, the 3GPP specifications [5] related to this feature will be also presented.

The first step of the EOTD procedure is when MS receives from network the *RTD*s values between neighbour cells and serving cell. 3GPP TS 44035, Section 4.1.1 describes the Broadcast Assistance Data received by MS from network, as presented in Table 1, with details in Section 4.1.1.12 where the Channel RTD Value IE is presented, as in Table 2.

TABLE I. EOTD ASSISTANCE DATA BROADCAST MESSAGE CONTENT

Information element	**Type/ Reference**	**Presence** (Mandatory, Conditional)
Message Structure Definition	Message Structure Definition 4.1.1.1	M
Reference Time	Reference Time 4.1.1.2	M
Ciphering Serial Number	Ciphering Serial Number 4.1.1.3	C
Time Slot Scheme	Time Slot Scheme 4.1.1.4	M
Neighbour Bitmap Definition	Neighbour Bitmap Definition 4.1.1.5	C
Sectored Channels Definition	Sectored Channels Definition 4.1.1.6	C
Sectored Channels BTS ID Definition	Sectored Channel's BTS ID Definition 4.1.1.7	C
Sectored BTS Sync/Async Definition	Sectored BTS Sync/Async Definition 4.1.1.8	C
51 Multiframe Offset Values	51 Multiframe Offset Values 4.1.1.9	M
BCC Definition	BCC Definition 4.1.1.10	M
RTD Drift Factor Values	RTD Drift Factor Values 4.1.1.11	C
Channel RTD Values	Channel RTD Values 4.1.1.12	C
Serving Cell Location	Serving Cell Location 4.1.1.13	M
Relative Neighbour Location Values	Relative Neighbour Location Values 4.1.1.14	M

TABLE II. CHANNEL RTD VALUE IE

(MSB)Varying Length (12-18 bits)(LSB)
Neighbour RTD (Last) **(MSB)**
Neighbour RTD (Last-1)
…
Neighbour RTD (2)
Neighbour RTD (1) **(LSB)**

At the second step the MS measures the *OTD* between the same neighbour cells and the serving cell from which it already received *RTD*s.

At the third step the MS computes for each neighbour cell a *GTD* related to the serving cell.

At the last step, the intersection of the obtained hyperbolas will provide the MS position (see Figure 3).

C. The math behind the TDOA principle

This section will explain in detail what computation is needed to apply the above described principle if additional BTS-MS distance information is available (extracted from TA information). The complexity of computational effort in this case is lower than the classical way of solving the problem [6]. The scope of this section is just to give an example of how this positioning problem can be solved on MS side.

Considering the notation from Figure 5, the distances between each BTS and the MS can be computed as

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2},\ i = 1,2,3 \tag{3}$$

Subtracting the square of (3) for i=1 from the two corresponding to i=2,3 it results

$$\begin{aligned} d_j^2 - d_1^2 &= (x_j - x)^2 - (x_1 - x)^2 + \\ &+ (y_j - y)^2 - (y_1 - y)^2,\ j = 2,3 \end{aligned} \tag{4}$$

If the bellow notations are used

$$\begin{aligned} &x_{j,1} = x_j - x_1 \text{ and } y_{j,1} = y_j - y_1 \quad ,j = 2,3 \\ &p_{j,1} = \frac{(x_j^2 + y_j^2) - (x_1^2 + y_1^2) + d_1^2 - d_j^2}{2} \quad ,j = 2,3 \end{aligned} \tag{5}$$

the relations in (4) can be re-written as

$$x_{j,1}x + y_{j,1}y = p_{j,1} \quad ,j = 2,3 \tag{6}$$

and the corresponding solution is

$$x = \frac{y_{2,1}p_{3,1} - y_{3,1}p_{2,1}}{x_{3,1}y_{2,1} - x_{2,1}y_{3,1}} \quad y = \frac{x_{3,1}p_{2,1} - x_{2,1}p_{3,1}}{x_{3,1}y_{2,1} - x_{2,1}y_{3,1}} \tag{7}$$

IV. SIMULATION RESULTS

For simulation purposes, a 2D space between –*N*:*N* units on x axis and –*N*:*N* units on y axis was considered. *N* parameter and the value of one unit depend on the cell radius. In the below simulations *N* was considered 10 for better results analysis. In real life, the value of *N* should be aligned with the resolution provided by the network parameters (*RTD*s) and with the one of the MS measured parameters (*OTD*s). In other words, if the resolution for algorithm inputs is for example 3 meters, *N* will be chosen in such a way so that, dividing the considered distance in *N* units to obtain squares of at least 3 meters. The simulations below will show that the correct square is found. This means that the MS will be placed correctly inside a square, but the exact position in that square will remain unknown, this being the localization resolution.

In Figures 5 to 8, the BTSs are depicted with higher amplitude and with red color, while the MS is represented with lower amplitude and with green color. In both cases, Figure 5 and 7 described the considered scenario and on Figures 6 and 8 are the obtained results after applying the previously described procedure.

The first scenario corresponding to Figure 5 considered BTS_1(-1,-1), BTS_2(2,2), BTS_3(3,4) and placed the MS(7,8).

The second scenario corresponding to Figure 7 considered BTS_1(-6,8), BTS_2(-4,-7), BTS_3(8,8) and placed the MS(2,3).

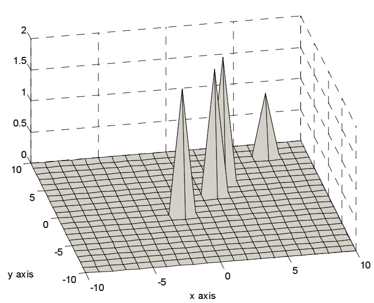

Figure 5. Simulation 1 scenario

V. CONCLUSIONS

This paper summarized the main positioning methods used in a GSM wireless communication system when no GPS module is available on MS side. It described in details the EOTD method and it provided a very simple procedure of location with low computation effort based on TA usage over the classical EOTD. Two simulated cases were presented, showing the performances of the proposed procedure. The main goal of this paper was to provide a simple positioning method suitable for 2G ULC mobile phones to be used especially in case of emergency calls, so that a tragedy effect to be limited.

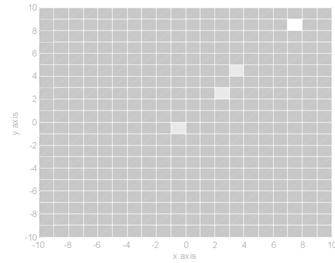

Figure 6. Simulation 1 obtained results

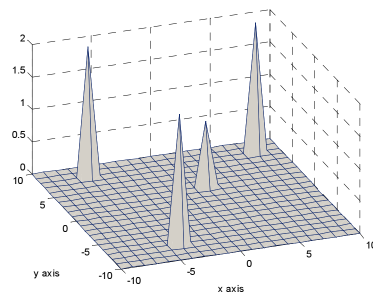

Figure 7. Simulation 2 scenario

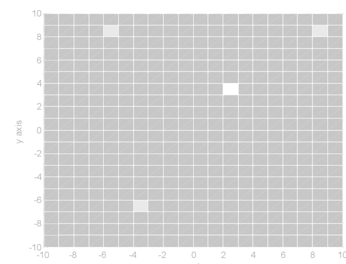

Figure 8. Simulation 2 obtained results

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REFERENCES

[1] A. Melikov, “Cellular Networks – Positioning, Performance Analysis, Reliability”, In Tech, 2011.
[2] A. Schmidt-Dannert, “Positioning Technologies and Mechanisms for mobile Devices”, SNET2, Seminar Master Module, TU Berlin, 2010.
[3] “Overview of 2G LCS Techniques and Standards”, 3GPP TSG SA2 LCS Workshop, London, January 2001.
[4] N. Deblauwe, “GSM-based Positioning: Techniques and Applications”, ASP/VUBPRESS Brussels, 2008.
[5] 3GPP specifications, http://www.3gpp.org/specifications/specification-numbering, last accessed on November 2014.
[6] B. T. Fang, “Simple Solutions for Hyperbolic and Related Position Fixes”, IEEE Transactions on Aerospace and Electronic Systems, vol. 26, no 5, September 1990, pp. 748–753.