Mobile Location Estimation for Emergency Calls using Data Correlation Method

Renato Patrus Mundim Pena
Agência Nacional de Telecomunicações
ANATEL
R. Maranhão, 166 – 30150-330
Belo Horizonte - MG – Brazil
renatop@anatel.gov.br
renato.pena@prof.una.br

Camila Figueiredo Vasconcelos Vidal
Centro Universitário UNA
Av. Raja Gabaglia, 3950 - 30350-540
Belo Horizonte - MG - Brazil
camila.vidal@prof.una.br

Gustavo Henrique Rocha Lopes
Agência Nacional de Telecomunicações
ANATEL
R. Maranhão, 166 – 30150-330
Belo Horizonte - MG – Brazil
gustavolopes@anatel.gov.br

***Abstract*—In this work, we review the methods for location of legacy GSM handsets (MS) based on the network parameters in four groups: Cell Identity (CID), received signal strength methods, time methods and all the methods together using data fusion. Then, we present several computational algorithms that improve the accuracy, with focus on the Data Correlation Method (DCM) or fingerprinting. Considering the study case of Brazil, who intends to design its Mobile Location Estimation System in Emergency Calls, it is analyzed the precision of each method in urban and suburban area in order to subsidize the decision about the specification of the system that will be deployed. The BTS number of each Brazilian Mobile Operator is presented to show how the analysis, in the same System, of all the parameters of all neighbors BTS, independent of which operator, is imperative for Brazilian case.**

***Index terms:* Data Correlation Method, Emergency Calls, GSM Tecnology; Mobile location estimation**

I. Introduction

The mobile location system have been deployed and refined in several countries in order to do different applications, such as location emergency calls, billing based on position, people and vehicles tracking, WEB information based on position, entertainment and improvement of handover paging and cellular network [1]. It hasn't been found in literature any questions against for its importance and its applicability at mobile location for emergency calls.

However, the developed system must respect the user's privacy concerns about their location, according to the Law of each country and the need of user's request for each application. Applications software for location anonymity and privacy awareness that protects user's privacy, who doesn't want to be located, has been created in order to preserve location privacy [2], [3], [4].

The Federal Communications Commission (FCC) has regulated the system to locate calls for 911 emergency number which dialed from mobile station. The first stage started in 1996 and the MS location method was related to the identification of the serving base transmission station. The second stage began in 2001 with the mobile location accuracy of the Table I [5], [6]:

TABLE I
Mobile Location Accuracy

METHODS	IN 67% OF THE CALLS	IN 95% OF THE CALLS
Network-based	100 meters	300 meters
Handset-based	50 meters	150 meters

The European Union (EU) has specified the localization process for calls to the European emergency number 112. It was determined that the location would be mandatory and it was expected at least fifty meters accuracy for urban areas and the precision would be worse as they stand off from urban centers [7]. The European Telecommunications Standards Institute (ETSI) is responsible for publishing the technical specifications of GSM and 3G cellular systems. All the operation's process of the cellular network and the messages exchange between different network devices are standardized, with technical specifications devoted to the positioning issues and the mobile station's location for second generation GSM [8] and third generation 3G networks [9], [10].

In Brazil, the National Telecommunication Agency (Anatel) regulated the Short Message Service (SMS) system to the public emergency calls (numbers 190, 191, 192, 193 and 199) in 2011 [11], [12]. It has been ruled that telecommunication companies should send the text messages made by the public emergency users, respecting technological limitations, and after the request of those responsible for public emergency services. The regulation fixes that the user's carrier must send all emergency calls even if it's necessary network sharing with others mobile network operators involved in the call when the user is in roaming. A suggestion of specification (latency and accuracy) of this system will be seen in the Section V.

II. Mobile Station Location Determination Techniques

The methods for mobile stations locating can be classified into the following characteristics [1]:

- MS involvement or participation;
- Minimum number of sectors or cells to provide the location;
- Necessity of additional elements for the Radio Access Network (RAN);

- Requirement of Line-of-sight (LOS) or non-line-of-sight (NLOS) of the radiant system to the MS;

The network based techniques have the advantage of being implemented for all MS models and the application of these methods are essential in a localization system for emergency calls.

The handset (or MS) based techniques include the MS involvement in location estimate either through a measure of the received power signal or by measurement of its coordinates through its GPS. The GPS measurement requires line-of-sight to the global positioning satellites (GPS) and the GPS application in mobile station must be turned on.

The mobile station based techniques have the advantage of improving the accuracy measurement, but it depends on the MS technology. It is not possible to make use of it in ordinary GSM mobile (MS legacies). Considering that the number of MS legacies is reducing, the MS based techniques must be applied in mobile location estimation systems for emergency calls to improve accuracy location.

Due to the need of the location estimation system for emergency calls be applied to the MS legacies, these systems consist in solutions by network based techniques. Studies and computational techniques, mentioned in Section IV, have been developed to improve the MS location accuracy, especially in areas with only one serving base transmission station or in an indoor environment. Other requirements of a location system for emergency calls are minimal amount of sectors to localization equals one; reduced time to fix positioning; using pre-existing signaling and dispensing the installation of RAN elements [1].

III. NETWORK BASED TECHNIQUES

In this section, we review the location techniques of GSM handset legacies based on the network parameters in four groups: Cell Identity (CID), Received Signal Strength methods (RSS), time methods and combination of location techniques.

The network based techniques use as information the parameters from air interface of base transmission station (BTS) in GSM cell systems. The following main parameters can be measured or obtained through RAN access to estimate the MS location [13]:

- CID (Cell Identity) – It is the cell or sector identity of the base transmission station. Each BTS's sector has its CID determined by the carrier and, in Brazil, it is registered its coordinates in Anatel (National Telecommunication Agency) [14];
- Propagation time of a symbol or message from the base transmission station to the mobile station and its return;
- Received Signal Strength (RSS) or Received Signal Level (RXLEV);
- Received Signal Quality (RXQUAL).
- Time Advance (TA).
- Angle of Arrival (AOA) or Direction of Arrival (DOA) [15], [16]. This technique requires a set of RAN [11], [32] directive antennas and therefore will not be studied in this work.

A. *Cell ID based positioning technique*

In the cell identity locating technique (CID-PLAN), the MS position is assumed to be equal to the best transmitting antenna server [1], [13]. Although the CID-PLAN technique has low complexity and high availability, it displays an accuracy dependent of the area of interest density [1].

As shown in Figure 1, if the MS signal is received by more than on cell, the calculating instrument of the plane geometrical figures of the centroid can be applied to improve accuracy location, since the coordinates of each base station is known and the mobile station may be closer to the server base transmission station. This technique is called AVG-CID [13].

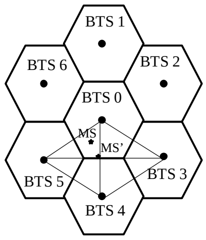

Figure 1. – Simple Centroid Figure

These techniques can be used as reference point and the beginning for all location systems. Its accuracy is proportional to the number of neighboring BTS from the MS, so the triangulation can be performed.

In Brazil, the Regulation provides that the carriers must forward the user's emergency calls, even requiring network sharing with other operator involved in the call, what happens when the user is in roaming [12]. This can allow the integration of the location estimation system for emergency calls by the base transmission stations of all mobile operators, increasing the location accuracy by triangulation process.

There are four national mobile phone operators in Brazil with market share of with 18.85% (Oi), 25% (Claro), 26.92% (TIM) and 28.91% (Vivo) [17]. Considering the network technology in Brazil, 74.19% of the mobile stations are GSM and 20.55% are W-CDMA (3G) [18]. The LTE Technology will be available until June, 2013, in six major cities of Brazil.

With regard to the base transmission station's distribution by mobile phone operators, the four major companies have a distribution of BTSs in all the Brazilian country, as shown in Table II [14], [19]. In Table III, it is presented the number of mobile phone operators in each city of Brazil [14].There are 8 mobile phone operators in Brazil, 4 of them with national service area.

TABLE II
NUMBER OF BASE TRANSMISSION STATIONS BY NATIONAL MOBILE PHONE OPERATOR IN EACH STATE OF BRAZIL

STATE	INHABI-TANTS x 1000	MS TOTAL (x1000)	NUMBER OF BTS'S / MOBILE PHONE OPERATOR				BTSs TOTAL
			VIVO	TIM	CLARO	OI	
AC	739	953	57	25	44	49	175
AL	3301	3806	188	246	183	150	767
AP	682	949	43	42	24	30	139
AM	3624	4131	290	187	149	138	764
BA	15104	17169	664	557	771	624	2616
CE	8856	10291	337	472	464	442	1715
DF	2705	5946	261	290	362	382	1295
ES	3575	4575	371	260	276	255	1162
GO	6193	8949	396	344	605	525	1870
MA	6675	6040	196	254	216	269	935
MT	3199	4503	317	174	280	220	991
MS	2480	3704	251	158	221	177	807
MG	20638	25542	1653	1198	1440	1549	5840
PA	7808	8807	368	438	308	279	1393
PB	3920	4667	196	265	198	230	889
PR	10983	14241	699	930	863	817	3309
PE	9043	11837	474	570	548	476	2068
PI	3280	3754	177	176	242	111	706
RJ	16148	23173	1265	1303	1462	1373	5403
RN	3292	4379	167	252	208	197	824
RS	11086	15603	1178	858	1101	1156	4293
RO	1567	2358	81	67	118	100	366
RR	458	525	32	29	16	15	92
SC	6362	8472	499	635	542	530	2206
SP	42090	63371	3496	2948	3580	3280	13304
SE	2120	2683	175	81	102	125	483
TO	1355	1830	88	61	123	140	412
Total	197283	262258	13919	12820	14446	13639	54824
%	100%	100%	25.20%	23.70%	26.30%	24.90%	100%

TABLE III
NUMBER OF MOBILE PHONE OPERATORS IN EACH CITY OF BRAZIL

NUMBER OF MOBILE PHONE OPERATORS IN THE CITY	NUMBER OF CITIES
1	2059
2	781
3	454
4	2185
5	86
Total	5565

B. Received Signal Strength (RSS) and Signal Quality Techniques

The location techniques through power measurement (Received Signal Strength – RSS) or by quality signal were grouped because of their common characteristics, such as:

- a measure of directly or indirectly received signal strength (electromagnetic field);
- a better result in case of Line-of-sight (LOS);
- a better accuracy precision in triangulation process;
- a network based technique.

These following techniques are:

- RSS – Received Signal Strength or RXLEV - Received Signal Level [*20*], [*21*], [*22*];
- Received Signal Quality [13];

C. Location technique by time measurements of the signal between BTS and MS

The location methods by time measurements of the signal between the BTS and MS were grouped due to their common features, such as:

- a better result in case of Line-of-sight (LOS);
- a better accuracy precision in triangulation process;
- a network based technique.

These following techniques are:

- CID + RTT – cell identity with round trip time measurements. It is the time measurement of sending and receiving signal from the BTS to the MS or contrariwise (Round Time Trip – RTT). It is also called Time of Arrival (TOA). It is described that the outcomes of TOA technique, generally, provides better accuracy than AOA or RSS [*23*].
- Time Advance (TA) [13].
- Multiple-Input/ Multiple-Output Time of Arrival (MINO TOA) [*24*], [*25*].
- Hello Message Delay Method [*26*].
- Time Difference of Arrival (TDOA), Uplink TDOA (UTDOA) and Enhanced Observed Time Difference (EOTD) [*27*].

D. Combination of Location Techniques

The use or combination of more than one position calculation technique has been deploying in order to reduce the minimum amount of sectors required to estimate the MS position and to reduce the positioning error [1].

In Table IV, we list the network based techniques that use more than one network parameters and do not require the installation of additional elements for the RAN.

TABLE IV
NETWORK BASED POSITIONING TECHNIQUE

ESTIMATION TECHNIQUE	NETWORK PARAMETERS USED	MINIMUM AMOUNT OF SECTORS	BEST RESULT IN LOS
Centroid (C-GEOM or C-AVG)	CID	3	No
Centroid Area with best RTT Server (Cpred)	CID+RTT	1	No
Centroid Section (Csection)	CID+TA	1	No
Triangulation by circular multilateration with call quality	CID+ RXQUAL	3	Yes
Triangulation by circular multilateration with propagation loss	CID+RSS	3	Yes
Triangulation by circular multilateration with RTT	CID+RTT	3	Yes
Weather Coverage and time measures (RTT, RTD or TOA	CID+RSS+ RSS/RTD/TOA	3	Yes

Researchers are studying methods that can link information from RTT methods or RTD (Round Trip Delay) method with the RSS, this process is called RTT + RSS or RTD-PRED [28], [29], [30]. The combination of CI-PRED method with the CI+TA method resulted in CI+TA-PRED method with improved results [13].

It should be examined if systematic errors can occur when the LOS condition does not apply [21], [32], [38], so others computational techniques, like the Fuzzy-based Interacting Multiple Model (IMM) [30], could be used.

After the network parameter acquirement, it is necessary to apply computational algorithms to estimate the location of the MS. It is done in two steps. First, it is important to provide a quick location of MS and it is done with the techniques explained in this Section III using the parameters obtained from the network. Then, it is necessary to improve the location accuracy by the explained methods in the next Section.

IV. Computational Methods for Accuracy Improvement

In this Section, we present several computational algorithms that improve the accuracy, with focus on the Data Correlation Method (DCM) or fingerprinting. The network based techniques have the advantage of be implemented for any mobile station (MS) [1], [13], [28]. Besides the parameters obtained from the network, it is essential to incorporate the location computational system for increasing the accuracy location. We compare and analyze the precision obtained in several experiments, most of them based on Data Correlation Method (DCM) [28], [32], [34], [35], [38].

It is also important that the mobile location system must be integrated with the mobile based method, including the software to find its geographic coordinate by GPS or other software, such as Google Latitude (http://m.google.com/latitude), for example, if the mobile station has a GPS or if it is a smartphone. It is expected that there will be only smartphones in Brazil by the year of 2016 [31].

Others computational algorithms are deployed to improve accuracy location and they may require a longer processing or a more complex program. Generally, the complexity of the algorithm is inversely proportional to the accuracy location. The objective is to get a computer program with low response time, low latency time and an expected accuracy.

A. Database Correlation Method – DCM

Generally, DCM involves three steps: obtaining radio signatures (fingerprinting), database preparation and location estimation [32]. This method was first proposed in 2001 [33]. So it is consisted in create a database with historical parameters that can be correlated, already geo-referenced with the parameters obtained by the network. The data analysis can be done by the minimum square average (LMS - Least Mean Square) or by the Gaussian probability distribution which is based on the exponential function, these methods are called, respectively, DCM-LMS and DCM-EXP [34]. Another method is to associate the MS to the closest coordinate of the radio signature stored in DCM-NN (Nearest Neighbor Method) for urban environments and DCM-WkNN (Weighted k-Nearest Neighbor Method) to suburban and rural environments [36]. DCM is widely used together with others techniques based on the network and assisted systems by MS [34], [35], [36], [37].

B. Geographical Information Systems (GIS) Tool

The GIS tool can be used to improve the location accuracy of the electromagnetic field prediction received by the MS [39] and it can notice place as roads, streets and stores. In Japan up to 70% of the calls can be located using GPS of the mobile phone [7]. As Brazil has large rural area, applications that connect to the MS and turn on the GPS must be considered when the system is deployed. The analysis of the positioning measurement of the mobile phone, user's information and the support of Geographic Information Systems (GIS) [39] increase the accuracy of its localization.

C. Others Computational Methods for Accuracy Improvement

Others computational methods for accuracy improvement have been developed, showing improvement in the accuracy of estimated results:

- Kalman Filter Method, also called Kalman Predictive Filter or Cubature Kalman Filter (CKF) [38], [39];
- "Spatial Triggers" Method that has the aim of storing the measured parameters by the network at the moments close to the transition between a serving BTS and a neighboring BTS which can obtain the condition of being server (handover) [40];
- Fuzzy-Based Interacting Multiple Model Algorithm (IMM), applied to situations that the MS is in a position of transition between LOS and NLOS [30];
- Signal Strengthen Dynamic Value Scheme (SSDV) [20] – Algorithm with the same logical base of DCM that creates a database with measurements of electromagnetic field from the MS to different Base transmission stations;
- Support Vector Machine (SVM) - algorithm with relatively low complexity and average latency (execution) of 2.45 seconds on a Pentium 4 computer [41];
- Simulated Annealing with Changeable Neighborhood (SA-CN) [42];

Computer systems which can rate the condition of the MS's movement must also be considered [43], [44].

V. Emergency Call System by SMS in Brazil

In Brazil, the National Telecommunication Agency (Anatel) regulated the Short Message Service (SMS) system to the public emergency calls in 2011 and one of the main advantages was the accessibility of the deaf-mute to the Emergency Call System.

The SMS (Short Message Service) is a mean of short messages sending to and from mobile phones. It was originally defined as part of the GSM standard (Global System for Mobile Communications) in 1985 as a way to send messages up to 160 characters to and from GSM mobile devices [45]. Ever since the support service has expanded to include alternative mobile standards.

The deployment of the Emergency Call System by SMS in Brazil has been conducted by a Working Group (WG – SMS) composed by Anatel, the network operators and the responsible institutions for the public emergency services in each state or city, that makes his interest [46].

In order to deploy the system, the WG-SMS studies the technical and operational aspects related to the SMS emergency service [47]. Among the technical and operational aspects to be attended by the group, it may include deployment deadlines, network topology, minimum quality requirement of the messages delivered, location parameters of the SMS sender and the granularity of the delivery places to these messages, defined with the responsible for the public emergency service [11].

VI. Specification of the Localization System of Mobile Phones Depending on the Accuracy and the Location Time

The mobile location time is related to the localization accuracy and to the mobile's place (urban, suburban or rural).

The specification of the Mobile Location System can be done studying the published results of scientific experiments. The Tables V and VI show the localization accuracy according to the techniques or methods used, to the urban (Table V) and suburban/rural (Table VI) environments.

Studying these tables and the techniques applied, it can be observed that the measure in urban environments have an accuracy close to the specified by the FCC (100 meters in 67% of the calls and 300 meters in 95% of the calls in network-based). However, the results are so much worst in suburban or rural environments.

TABLE V
Published Results Regarding to the Accuracy Techniques in Urban Environments

TECHNIQUE OR METHOD	AVERAGE ERROR	IN 67% OF THE MEASURES	IN 95% OF THE MEASURES	IN 100% OF THE MEASURES (MAXIMUM ERROR)
CI-GEOM [32].	283 m			2098 m
CI-GEOM [48]	209 m	262 m	332 m	
CI-GEOM [36]	242 m	277 m	624 m	1225 m
CI-AVG [13]	171 m			814 m
CI+TA-PRED [13]	139 m			646 m
E-OTD [33]		141 m	237 m*	
DCM [13]	136 m			567 m
DCM RTD-PRED Fullset [28]	134 m	155 m	297 m	400 m
DCM RTD-PRED Subset [28]	106 m	122 m	245 m	
DCM [32].	112 m			701 m
DCM [33]		44 m	90 m*	
DCM [36]	137 m	150 m	296 m	1682.8 m
DCM LMS [48]	99 m	98 m	282 m	
DCM EXP [48]	75 m	83 m	192m	
DCM Route A [34]	99 m	100 m	257 m	
DCM-NN [36]	101 m	112 m	276 m	701.3 m
Average DCM **	111 m	108 m	242 m	810 m

*Result obtained in 90% of the measures.
** Average calculation of DCM above.

TABLE VI
Published Results Regarding to the Accuracy Techniques in Suburban Environments

TECHNIQUE OR METHOD	AVERAGE ERROR	IN 67% OF THE MEASURES	IN 95% OF THE MEASURES	IN 100% OF THE MEASURES (MAXIMUM ERROR)
CI-GEOM [32].	970 m			12476 m
CI-GEOM [48]	1238 m	1142 m	4927 m	
CI-GEOM [36]	894 m	1033 m	1956 m	3782 m
CI-AVG [13]	2200 m			7700 m
CI+TA-PRED [13]	1000 m			8200 m
E-OTD [33]		125 m	231 m*	
DCM [13]	1200 m			7600 m
DCM RTD-PRED Fullset [28]	876 m	969 m	1982 m	
DCM RTD-PRED Subset [28]	705 m	850 m	1567 m	
DCM [32].	242 m			1176 m
DCM [33]		74 m	190 m*	
DCM [36]	296 m	330 m	849 m	1255 m
DCM LMS [34]	532 m	602 m	1023 m	
DCM EXP [34]	524 m	607 m	1021 m	
DCM-WkNN [36]	255 m	299 m	626 m	1181 m
Average DCM **	579 m	533 m	1037 m	2803 m

*Result obtained in 90% of the measures.
** Average calculation of DCM above.

Considering the evaluation of the urban, suburban and rural environments, the result is that the number of available base transmission stations increases considerably the calculation accuracy, as evidenced also in some papers [28]. In this approach, analyzing this issue together with Table II, it evidences the great relevance for the location systems of legacy MS, if it is possible to analyze data from all BTSs in the MS's coverage area, from all available mobile phone operators.

Considering the data in Tables V and VI, technology advances in mobile location techniques and the focus on the continuous improvement, it is proposed, in Table VII, the specification of time and accuracy of mobile location systems which could be used in some countries.

TABLE VII
Suggestion Of Time Location And Accuracy Location For Emergency Calls in some countries

PHASE	LATENCY TIME LOCATION	ACCURACY IN URBAN AREAS OR TRAFFIC CORRIDORS	ACCURACY IN RURAL AREAS
Phase 1 (Network-based)	Immediate (as quickly as possible)	The best possible	The best possible
Phase 2 (Network-based and Handset-based)	Until 30 seconds	Less than 100m in 65% of the call and less than 300m in 95% of the calls (FCC Standard for Network-based)	Indicators per State (or Province) should be evaluated, depending on the number of BTSs
Phase 3 (GIS Analysis, interview, GPS, handset-based, etc.)	Until 5 minutes	The best possible with control by targets and indicators	The best possible with control by targets and indicators

The three proposed phases for the localization process for emergency calls are described below:

- Phase 1: It should be done immediately as fast as possible, without worrying about the accuracy measurement in order to be initiated the answer process of the emergency and forwarding to the location. This latency time should be less than 5 seconds.
- Phase 2: In the following period, the methods described in Section III and IV can be used, but with the latency time of less than 30 seconds. The accuracy proposal for urban environments is the same of FCC (Table I: Network-based);
- Phase 3: In some cases, such as rural areas with few cells or in the need of application software which starts the GPS´s mobile device, the response time can reach up to 5 minutes. It may be even waiting until the user moves to an open area to allow the GPS coverage. The time management in this phase should be done by controlling the proposed indicators and deploying a continuous improvement process.

VII. Conclusion

As a result of this work, it is verified that the Data Correlation Method improves the location accuracy and it is an important tool to be considered in the mobile location estimation for emergency calls. The measures using DCM in urban areas from many experiments from the literature has a slightly degree of precision higher than specified by the FCC. However, the average error doubles at least in suburban or rural environments and it can be more than seven times worse compared to urban areas.

Studying urban and rural environments, it can be asseverated that in rural areas the number of Base transmission stations increases the estimate accuracy much more than others computational methods. So, it is essential to increase the accuracy system in suburban and rural environments that the base transmission station's data of all available carriers, within the range of MS, should be analyzed together, specially in large countries, such as Brazil.

The BTS number of each Brazilian Mobile Operator is presented to show that is very important that all the parameters of all neighbors BTS, independent of which mobile phone operator and manufacturer, should be integrated in the same computational system to improve the mobile location estimation. One issue is that the BTS´s network parameters of the operators have confidential information of the coverage and planning network. The proposed solution by us is that for each emergency call, the network parameters would be requested to the others operators and would be processed together. Also, it's important to include the tool to find its coordinate by GPS or by any other assisted software by the MS, if the mobile phone makes it possible.

Therefore, considering that there are four national carriers of Mobile Service in Brazil with market share between 18.85% and 28.91% and they are expanding their services, this integration proposal of the emergency call tracking system by the base transmission stations of all operators will increase the location accuracy through triangulation process in small cities and rural areas of Brazil.

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