ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2010. No. 8(104)
ELEKTRONIKA IR ELEKTROTECHNIKA

TELECOMMUNICATIONS ENGINEERING
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TELEKOMUNIKACIJŲ INŽINERIJA

An Experimental Evaluation of AGA Algorithm for RSS Positioning in GSM Networks

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Introduction

The cellular network ability to locate a Mobile Station (MS) depends on network itself as well as on MS equipment. Generally, it is quite difficult to provide fine MS location without implementation of necessary changes either in network or in MS. These changes depend on implemented positioning method. The fundamental Cell Identification (Cell ID) method does not need any changes, but its accuracy is very poor. On the other hand, time-based methods belong to the most accurate methods, but they require very precise time synchronization, which is not present in the GSM (Global System for Mobile Communications) network. Therefore, modifications resulting from this requirement should be implemented.

Generally, we can say that more accurate methods need more significant changes. We focus on simple positioning method based on Received Signal Strength (RSS). The monitoring of RSS is performed for basic network operation. Therefore, it can be easily utilized for MS positioning. The accuracy is not excellent, but its implementation does not require big changes. This solution saves initial costs for implementation of new components to the network or MS.

The MS continuously measures the signal strength from surrounding Base Stations (BSs) and reports this information to the location server. With this information, it is possible to calculate the MS position utilizing the fact that RSS degrades as the distance between the transmitter and receiver increases. However there are number of factors that limit the effectiveness of this method. Distance between MS and BS is not the only factor to affect RF waveform propagation. The terrain characteristic between the transmitter and receiver as well as the issue of indoor attenuation has significant impact upon this measurement. Cell radius and distance between BSs have an important impact on accuracy as well.

Attention of many researchers has been paid to RSS positioning [1 - 7]. This interest can be based on fact that signal strength information can be simply measured by MS and does not require any additional implementation costs.

The way to increase accuracy of RSS could consist in improvement of calculating algorithm. This solution was proposed in [6] and it is called Adaptive Geometric Algorithm (AGA). In this paper, the performance of AGA is experimentally evaluated in real GSM network.

The rest of the paper is structured as follows. At first, RSS positioning is briefly discussed. Then, the existing calculation algorithms are mathematically described. Experimental setup and particular scenarios are presented. At last, the obtained results are discussed. The contributions are finally concluded in the conclusion.

RSS Positioning

The principle of RSS positioning is based on monitoring of signal strength variation. The received signal level (*RxLev*) could be defined as

$$RxLev = T_x - \left(L_{LS} + L_{MS} + L_{SS}\right), \tag{1}$$

where T_x is the transmitted signal strength, L_{LS} is the signal attenuation caused by large-scale propagation (path loss) and L_{MS} is the signal attenuation caused by medium-scale propagation (shadowing - long-term fading). L_{SS} is the signal attenuation caused by small-scale propagation (multipath propagation - short-term fading). All these parameters are expressed in [dB]. The aforementioned influences cause deviation of signal level and degrade the location accuracy. The received signal strength variation can acquire values up to 40 dB [8].

All these parameters can be modified to simulate different scenarios. We only focused on investigation of L_{LS} parameter impact, because it is not easy to precisely (reliably) predict behaviour of long and short-term fading. Hence, the distance between MS and BS is calculated based on this parameter. The CCIR propagation model is used in our experiments [9]. The CCIR model is an empirical form for combined effects of free space path loss and terrain inducted path loss. This is given by

$$\begin{aligned} L_{LS} &= 69.55 + 26.16\log(f_{MHz}) - 13.82\log(h_b) - \\ &- a(h_m) + [44.9 - 6.55\log(h_b)]\log(d_{km}) - B, \end{aligned} \tag{2}$$

where h_b and h_m stand for antenna height of base station and mobile station respectively and it is defined in meters. The d_{km} is the link distance in kilometres and f_{MHz} is the center frequency in MHz. The $a(h_m)$ parameter can be calculated as follows

$$a(h_m) = [1.1\log(f_{MHz}) - 0.7]h_m - 1.56\log(f_{MHz}) + 0.8\,. \qquad (3)$$

The CCIR propagation model is Hata model for small or medium city propagation conditions, supplemented with a correction factor B defined by

$$B = 30 - 25\log(\chi), \qquad (4)$$

where χ stands for ratio of built-up area to full observed area in [%].

Problem Formulation

It is assumed 2D plane is used. Let the true MS location be given by $[x_s;y_s]^T$ and the coordinates of the i^{th} BS be defined by $[x_i;y_i]^T$, $i=1,2,\ldots,N$, where N is the number of BSs. The distance r_i, between MS and the i^{th} BS is

$$r_i = \sqrt{(x_s - x_i)^2 + (y_s - y_i)^2}, \quad i = 1, 2, \ldots, N\,. \qquad (5)$$

The *RxLev* measurement determines a circle centred at the corresponding BS with MS located on the circle. Note that the radius r_i of the circle expresses the distance between MS a BS. Then MS position can be estimated by the intersection of at least three circles. It could be done by Geometric Algorithm (GA). Principle of GA is explained in following part.

In ideal case, there is only one intersection of all involved circles. The MS location is uniquely defined by this intersection. However, this does not happen in real environments. Furthermore, there are some situations where MS position can not be estimated. These situations are not explained, because positioning process uses only BSs which allow to determine MS position.

Two situations, which are analyzed and used for MS position estimation in this paper, are depicted in Fig. 1. As can be seen, there are a few intersections of all circles.

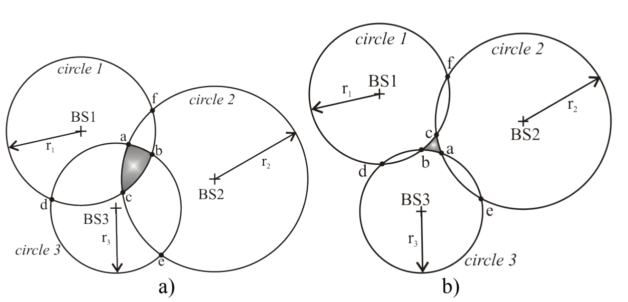

Fig. 1. Situations used by GA for MS position estimation

The first situation is depicted in Fig. 1 - a). A one intersection of any two circles, which lies inside the third circle, is an interior intersection. An interior intersection is used for MS position estimation and therefore we called it a relevant intersection. Three-circles BS model determines 3 different relevant intersections, e.g., there are *a*, *b*, *c* relevant intersection in Fig. 1 - a). These relevant intersections determine an area which belongs to all circles. It is called a relevant area. The exact location of MS is expected to be inside the relevant area.

The second situation is shown in Fig. 1 - b). This is more complicated scenario compared to previous one, because there are no interior intersections. Consequently, the relevant intersections are chosen by different way. Only one point of the intersection pair with shorter mutual distance is taken into consideration. Hence, three relevant intersections are obtained. As shown in Fig. 1 - b), the relevant intersections are *a*, *b* and *c*. These relevant intersections also determine relevant area.

For both previous situations, relevant intersections *a*, *b* and *c* determine the relevant area, where MS should be situated. A size of the relevant area depends on particular situation. Generally, it can be said that the relevant area should be as small as possible in order to allow precise estimation.

The final estimation of MS position is defined as centroid or centre of gravity of polygon created from all relevant intersections. The estimated coordinates of MS are calculated as follows

$$x = \frac{1}{K}\sum_{l=1}^{K} x_l\,,\ y = \frac{1}{K}\sum_{l=1}^{K} y_l\,,\ l = 1, 2, \ldots, K\,, \qquad (6)$$

where K is the number of relevant intersections. For three circles $K = 3$.

The positioning accuracy could be improved by reduction of the relevant area. Therefore, AGA algorithm was proposed [6].

The main idea of AGA comes from the basic GA described above and its purpose is to reduce the relevant area and to finally determine the specific coordinates of MS. The AGA is implemented as iterative process. In fact, GA is the first iteration of AGA. Thanks to the first iteration, the coordinates of relevant intersections and aforementioned relevant area are determined. The relevant area is then being reduced over all following iterations. AGA process is explained in detail in [6].

The relevant area reduction is done by decreasing or increasing circle radiuses. The circle radiuses are multiplied by a factor *k*. All of these circles are reduced (enlarged) proportionally. The factor *k* can be less (k<1) or greater than one (k>1). For the first situation (Fig. 1 - a), factor *k* is less than one and for the second situation (Fig. 1 - b) factor *k* is greater than one. This iterative process continues until the target relevant area is found. The target relevant area is found in the iteration when the smallest area for all three circles exists. Finally, GA is applied in the last iteration, but now potentially on a way more reduced area compared to the first iteration.

The performance of the proposed algorithm is compared to conventional GA and LS algorithms. Basic LS algorithm is well-known [10 - 11], therefore it is not explained here. The performance of AGA is evaluated by practical experiments in two different environments.

Experimental Setup

We performed extensive outdoor experiments in two different environments:

1. Urban – dominant NLoS (Non Line of Sight), multipath propagation.
2. Rural – dominant LoS (Line of Sight) propagation.

The urban environment is represented by Zilina city centre. This environment is typical multipath environment with a lot of buildings and movable obstacles. The rural environment is represented by almost open area near the University of Zilina (surrounded by a few buildings). These two environments were chosen purposely because of their different properties. The environments have absolutely different signal propagation conditions. Thus there is a hostile shadowing and multipath on the one hand and almost ideal radio channel (without reflections) on the other hand. Therefore it can be said that the performance of calculation algorithm was validated in the representative samples of environment.

The experiment was implemented in real GSM network which operates in 900 MHz band. Various parameters which characterize properties of the network have to be defined, because these parameters are inputs to propagation model, see equation (2). The parameters were following: MS height $h_m = 1.5$ m, BS height $h_b = 40$ m. The average value of downlink channel frequency was used, because the *RxLev* was measured in MS, i.e. $f = 947.5$ MHz. The correction factor B depends on the χ. The parameter χ was defined particularly for individual cells; i.e. from 20 to 90 %.

The measurements were realised by movable measuring station. This station consisted of GSM/GPS module and location server. The location server provided the communication and data collection from the modules. It also recorded measured data and computed estimation of MS position [12 - 14]. The role of GSM part was to measure *RxLev* and *cell ID* from all available BSs. The maximum number of monitored cells is seven, i.e. one serving cell and six neighbour cells at the same moment. GPS module monitored current (precise) coordinates of MS position. The communication architecture of the measuring station, GPS and cellular network is shown in Fig. 2.

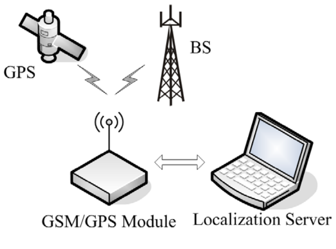

Fig. 2. Communication architecture

The problem of fading was partially eliminated by estimation of local average power in both scenarios. It is calculated as

$$\overline{RxLev} = \frac{1}{N_s} \sum_{i=1}^{N_S} RxLev_i \, , \tag{7}$$

where N_s is number of samples (in this case $N_s = 10$).

The basic problem of the RSS positioning is conversion of measured data (*RxLev*) into the distance between BS and MS. This problem consists of appropriate propagation model selection and it is very important. We decided to use CCIR model because its properties can be customized based on the relevant environment. The preliminary measurements were performed to define the model parameters for particular environment.

The *RxLev* is not only parameter affecting the calculation of MS-BS distance. Positioning environment plays also very important role in localization process. Unfortunately, this factor can not be changed. Thus, the selection of BSs has significant impact on positioning accuracy. BSs situated nearer the MS bring smaller error into positioning. Hence we optimized the process of BSs selection for final position estimation.

The positioning environment is very important factor and is clearly defined by correction factor B in CCIR model (4). The higher the density of surrounding buildings the higher the value of B. Hence, it is important fact in the calculation of MS-BS distance. Therefore it is necessary to observe this impact on the positioning accuracy. We decided to validate this important issue by simulation.

Table 1 shows the impact of B factor on distance d (MS-BS); $B = f(\chi)$. The distance d is expressed for various values of correction factor $B(\chi)$ while *RxLev* is constant.

Table 1. Dependence of MS-BS distance on factor χ

χ [%]	5	10	20	40	80
***RxLev* [dBm]**	-60	-60	-60	-60	-60
d [km]	1.689	1.011	0.605	0.362	0.217

It is obvious that $B(\chi)$ correction factor has an important impact on the conversion of *RxLev* to the MS-BS distance. Therefore, BSs with higher value of $B(\chi)$ are preferred for positioning. In a case of two BSs with same *RxLev*, positioning algorithm chooses BS with higher B factor.

Both parameters *RxLev* and B factor have an important impact for definition of MS-BS distance. As the distance between BS and MS increases, the estimated error also increases [16]. Therefore, BSs with the shortest distance MS-BS are more appropriate to use.

According to the previous example, there was optimized positioning algorithm based on implementation of BSs selection for position estimation. Priority of B factor and *RxLev* value for BS selection were same.

It is obvious, that each BS (cell) is described with different correction factor $B(\chi)$. The B factor depends on the environment properties, especially amount of buildings. In the light of previous fact, correction factor was assigned for particular cells. Thus, each cell is defined by coordinates of serving BS and correction factor $B(\chi)$.

Results and Interpretation

In the following part, we discuss results obtained in two different environments by means of above described algorithms. The results provide detailed analysis of positioning accuracy in terms of Circular Error Probability (CEP) as a function of the number of BSs used for positioning. The CEP is defined as the radius of circle that has its centre at the final estimated location and contains the location estimates with probability P_{CEP}. We focused on 67 % (marked CEP67).

Experimental Results for Urban Environment

As mentioned above, the measurements in urban environment were realised in Zilina city centre. There is sufficient multipath environment with a lot of buildings and movable obstacles. The final position estimation was computed by means of three calculating algorithms - AGA, GA and LS respectively.

The *RxLev* has significant impact on estimation of BS-MS distance [16]. The measuring station was monitoring *RxLev* from all available BSs. The nearest BS belonged to serving cell and the remaining ones to neighbour cells. Fig. 3 shows the histograms of *RxLev* for serving cell and neighbour cells in the urban environment. The *RxLev* mean of serving cell was approx. -54 dBm and the mean value for neighbour cell was approx. - 67 dBm. The difference is caused by longer BS-MS distance in a case of neighbour cell and correspondingly greater signal attenuation. Therefore we utilized only the nearest neighbour cell BSs for positioning.

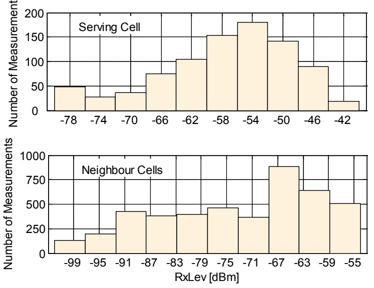

Fig. 3. Histograms of *RxLev* for urban environment

The next key factor affecting RSS based positioning accuracy is an ability to determine precise MS-BS distance on the basis of measured *RxLev*. Therefore it is important to observe this factor. Precise specification of the distance is rather difficult in real conditions. This determination especially depends on current signal propagation conditions.

The distance calculated from measured *RxLev* is represented by r in [*km*]. The precise distance d [*km*] was obtained from real GPS coordinates. The comparison of the distances is expressed as *deviation* in [*km*]. The *deviation* is calculated as follows

$$deviation = d - r\,. \tag{8}$$

Fig. 4 depicts the histogram of the deviations. Firstly, it is necessary to note a few important facts. Probability of an incorrect distance determination is the same for all situations, i.e. for serving cell and also for neighbour cells. The correction factor B is similar for serving and neighbour cells. It is caused by urban environment situation. The distance between BSs is relatively short and the changes of environment (density of buildings) are not significant. The deviations can be caused by signal strength variation, because it is very difficult to make a precise signal strength prediction.

On the basis of Fig. 4, it can be concluded that there is greater deviation in neighbour cells compared to serving cell. The reason is the longer BS-MS distance in the case of neighbour cells. This result confirms that the positioning information from further base station decreases the positioning accuracy. Hence the utilization of minimum number of BSs is optimal for positioning.

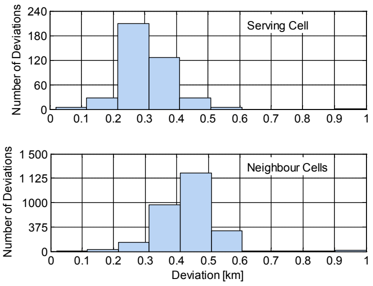

Fig. 4. Histograms of deviations for urban environment

The obtained results are shown in Table 2. The availability in [%] expresses probability of using data from a given number of base stations. The data from seven BSs were always available, but it was not always possible to use these data for the position estimation. The adverse situation occurred in the case where multiple sectors from the one BS (same coordinates) belonged to the seven closest BSs. Then the sector with the highest *RxLev* was used for the position estimation.

Table 2. CEP67 vs. number of used BSs for urban environment

BSs Number	Availability [%]	CEP67 [km]		
		GA	AGA	LS
3	100	0.328	0.243	0.37
4	100	0.528	—	0.353
5	92.7	0.543	—	0.514
6	24.6	0.587	—	0.671
7	3.9	0.718	—	0.763

On the basis of results shown in Table 2, it can be concluded that the increased number of BSs used for MS position estimation yielded lower accuracy. This confirms simulated results obtained in [6]. Therefore AGA algorithm was implemented only for three BSs. The AGA algorithm achieved the most accurate results compared to basic GA and LS algorithms. The results obtained by means of LS algorithm are the most inaccurate. Positioning accuracy obtained by the AGA is more precise compared to basic GA algorithm (approximately 26 % increase of accuracy). This improvement is caused by the modification of basic calculation algorithm. In comparison to LS algorithm, AGA results are also more accurate (approximately 35 % increase of accuracy).

Experimental Results for Rural Environment

The measurements in rural environment were implemented near University of Zilina in Slovak Republic. This is completely different environment compared to the previous one and represents typical rural environment, where LoS propagation is dominant. The final position estimation was again computed by means of three calculating algorithms (AGA, GA and LS).

Fig. 5 shows the histogram of *RxLev* for serving cell and neighbour cells in the rural environment. The histogram has two maximum values for serving cell (approx. - 65 dBm and - 74 dBm). The most often repeated value for neighbour cells is approx. - 89 dBm. Note that *RxLev* from serving cell is about 20 dBm higher than *RxLev* from neighbour cells.

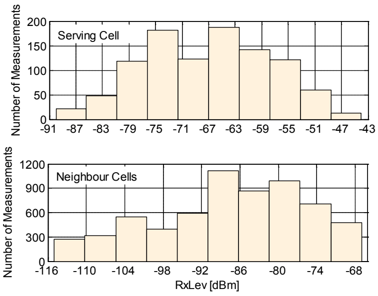

Fig. 5. Histograms of *RxLev* for rural environment

The main difference between urban and rural environment is in the different value of *RxLev*. The difference is caused by longer mutual distances between MS-BSs in rural environment.

Fig. 6 shows the histogram of distance deviations for rural environment. There is higher deviation in the neighbour cells compared to the serving cell. The main difference between observed environments lies in the range of the deviation and it is higher in the rural environment. It is caused by longer distance between MS and surrounding BSs. This result verified that the data from further BSs have greater deviation compared to ones from nearer BSs.

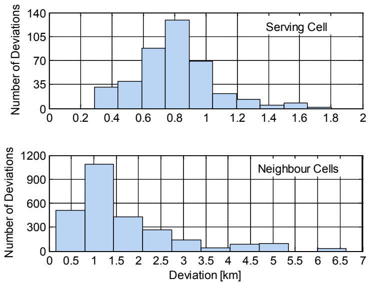

Fig. 6. Histograms of deviations for rural environment

Table 3 shows results for rural environment. AGA algorithm has achieved the most accurate results in comparison with the other algorithms. The results obtained by means of AGA are again more accurate than GA results (approximately 24 % increase of accuracy). In comparison with LS algorithm the AGA algorithm is even more accurate (approximately 49 % increase of accuracy).

Table 3. CEP67 vs. number of used BSs for rural environment

BSs Number	Availability [%]	CEP67 [km]		
		GA	AGA	LS
3	100	1.292	0.982	1.952
4	100	1.542	—	2.982
5	82.7	2.463	—	3.863
6	74.6	3.057	—	5.032
7	29.4	4.718	—	5.732

On the basis of experimental results, it can be concluded that RSS based positioning produces more accurate results in urban environment. This fact is mainly caused by shorter distance between MS and BSs. Therefore, the denser network of BSs has positive impact on positioning accuracy. Mutual distance between BSs has more significant impact on the positioning accuracy compared to signal propagation properties.

The experimental results are comparable with the simulation results from [6, 16]. Our assumption that AGA algorithm is more accurate in comparison with other algorithms was verified in both environments. The obtained data of positioning accuracy from experimental measurements are similar to simulation results. The differences are caused by different propagation model parameters (correction factor, height of BS…) compared to real parameters. It is very difficult to define precise signal propagation model.

Conclusions

We discussed and verified a simple and efficient positioning algorithm using RSS measurement proposed in [6]. The proposal is implemented as mobile-assisted positioning, i.e. MS collects *RxLev* data of the surrounding BSs. The measured data are sent from MS to the localization server for position estimation.

The experiments were realised in absolutely different environments - urban and rural environment. The first can be characterized by hostile shadowing, multipath and on the other hand the second one has almost ideal radio channel. Therefore, it can be concluded that the performance of calculation algorithm was validated in the representative samples of environment.

The performance of the novel Adaptive Geometric Algorithm (AGA) was compared to basic Geometric Algorithm (GA) and standard Least Square (LS) algorithm. The results are presented by means of the circular error probability (CEP). According to the results, performance of the novel algorithm is better in comparison with the conventional algorithms.

The increase of positioning accuracy was approximately 25 % compared to basic GA and 40 % compared to LS in both environments. Therefore an implementation of AGA algorithm increases accuracy of RSS based positioning. As can be seen the positioning accuracy was improved by modification of basic calculation algorithm.

The implementation of AGA algorithm in the positioning methods based on circular trilateration (e.g. ToA) may also bring the accuracy increase. The accuracy of RSS method is smaller in comparison with the time-based methods, but it is satisfactory for the purpose of commercial location based services [17]. On the other hand the initial implementation costs for the time based positioning are higher compared to the RSS based positioning.

Acknowledgments

This work was partially supported by the Slovak Research and Development Agency under contract No. LPP-0126-09; by the Slovak VEGA grant agency, Project No. 1/0392/10 “The research of mobile nodes positioning in wireless sensor networks”; and by the

Centre of excellence for systems and services of intelligent transport, ITMS 26220120028 supported by the Research & Development Operational Programme funded by the ERDF.

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Received 2009 10 15

P. Brida, J. Machaj, J. Benikovsky, J. Duha. An Experimental Evaluation of AGA Algorithm for RSS Positioning in GSM Networks // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 8 (104). – P. 113–118.

The quality of location based services depends on the positioning accuracy of mobile station estimation. Generally, there are several methods suitable for cellular networks. The more accurate methods are way more expensive to implement. On the contrary, there are methods with lower accuracy and much lower costs as well. Received Signal Strength method belongs to the second case. The purpose of this paper is to experimentally evaluate adaptive geometric algorithm implemented into RSS method. The algorithm is an improved version of basic geometric algorithm and it is compared to it as well as to standard Least Squares method. The properties of the proposed algorithm are evaluated in two different environments: urban and rural. The environments have absolutely different signal propagation conditions and the algorithm performance was validated in the representative samples of environment. Ill. 6, bibl. 17, tabl. 3 (in English; abstracts in English, Russian and Lithuanian).

П. Брида, Ю. Махай, И. Бениковски, Я. Дуга. Экспериментальная проверка свойств алгоритма AGA при определении местоположения в сетях GSM методом RSS // Электроника и электротехника – Каунас: Технология, 2010. - №. 8 (104) – С. 113–118.

Качество услуг, основанных на местоположении, зависит от точности вычисления местоположения мобильного телефона. Существует несколько методов определения местоположения, которые можно использовать в сотовых сетях. Применение более точных методов связано с довольно высокими капиталовложениями на их внедрение. С другой стороны существуют менее точные методы, внедрение которых требует существенно меньше капиталовложений. В эту вторую группу входит и метод RSS (напряженность поля принимаемого сигнала). В статье приведены результаты экспериментальной проверки адаптивного геометрического алгоритма использованного для метода RSS. Этот алгоритм вычисления представляет усовершунствование основного геометрического алгоритма и результаты полученные при применении этого метода, в статье сопоставлены с результатами, полученными применением метода LS (минимальных квадратов). Свойства предложенного алгоритма анализируются в двух различных средах: городской и сельской. Эти среды были выбраны преднамеренно, поскольку они сильно отличаются с точки зрения распространения сигнала и свойства алгоритма были проверены на типичных образцах среды. Ил. 6, библ. 17, табл. 3 (на английском языке; рефераты на английском, русском и литовском яз.).

P. Brida, J. Machaj, J. Benikovsky, J. Duha. Eksperimentinis AGA algoritmo patikrinimas, nustatant vietos padėtį GSM tinkluose // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 8(104). – P. 113–118.

Mobiliojo telefono vietos nustatymo metodams tobulinti skiriama daug lėšų. Paprastai vartotojams siūloma taikyti RSS metodą (adaptyvųjį geometrinį algoritmą). Įrodytos šio metodo teigiamybės ir trūkumai. Siūloma taikyti pigesnį LS metodą (minimalių kvadratų algoritmą). Pasiūlytas LS metodas ištirtas miesto ir kaimo vietovėse. Il. 6, bibl. 17, lent. 3 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).