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Full Length Research Paper

On the accuracy of AGA positioning algorithm in multipath environment

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The quality of location-based services (LBS) services depends on the available accuracy of the used positioning method. There are generally several ones for wireless 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 (RSS) method, which is described below, belongs to the latter case. The purpose of this paper is to describe a performance of adaptive geometric algorithm (AGA) for estimation of mobile station position in multipath environment. 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 a simulation and experimental scenario. Both scenarios are implemented in typical multipath conditions, which are crucial in wireless communication.

Key words: Adaptive geometric algorithm, mobile positioning, received signal strength method, wireless networks.

INTRODUCTION

Mobile station (MS) location is important information for a large numbers of applications, example, personal navigation or friend finder. Known MS location facilitates provision of various services based on the current position. Therefore, location information plays an important role in the present and next generation mobile systems. The positioning accuracy is also an important factor and it depends on service requirements. The requirements can be fulfilled by various positioning methods. The selected positioning method is significant part of the position estimation process. The final position estimation is performed by a positioning method.

The common localization methods in cellular networks are Cell Identification (Cell ID), received signal strength (RSS), angle of arrival (AoA) and time-based methods (Caffery, 1999; Cheung, 2004; Deligiannis and Kotsopoulos, 2007; Drane et al., 1998; Krejcar, 2006; Pent et al., 1997; Wang et al., 2003). There are different types of measured parameters dependent on the positioning method, example, signal strength is used by the RSS method, time advance or time of arrival are used by time-based methods etc.

The cellular network ability to locate a MS depends on network itself as well as on MS equipment. It is quite difficult to provide precise MS location without network assistance or MS modifications. Furthermore, users do not prefer expensive solutions. Hence, the network provider wants to avoid exhaustive and costly modifications. It is then important and efficient to improve simple methods, which are sufficiently precise. Therefore the paper is focused on enhancement of basic positioning method which does not need significant modifications.

We focused on improvement of RSS-based method. The proposal is implemented as mobile-assisted positioning solution, that is, MS measures the signal strength from each base station (BS) in range and forwards this information to the localization server for further processing. The MS position is estimated based on the measured data.

For the RSS method the propagation path loss from the MS to the BS (or vice versa) is measured and converted

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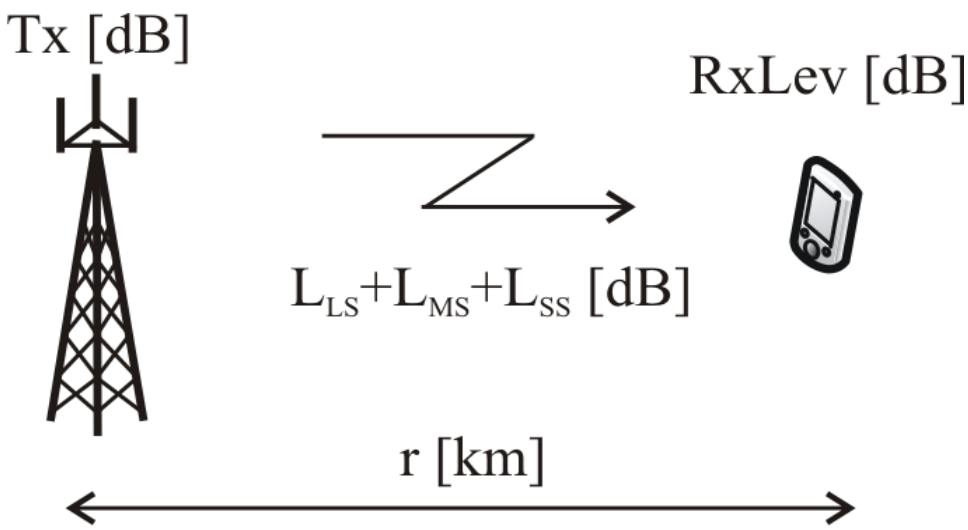

Figure 1. RSS measurement model.

to a distance between them. However, there are many limiting factors that impact on method effectiveness. For example, the distance between MS and BS is not the only factor that affects radio-frequency (RF) waveform propagation. The terrain characteristics between transmitter and receiver have significant impact on this measurement as well. The transmission path modifications are characterized by various influences, example, shadowing, multipath fading and path loss (Calhoun, 1988; Dobos et al., 2002; Lee, 1995; Prasad, 1998). Moreover, individual BS distances, cell radius, and mutual deployment of sources and receivers have also significant impact on positioning accuracy (Brida et al., 2006).

Attention of many researchers has been paid to RSS positioning (Brida et al., 2006, 2008; Hata and Nagatsu, 1980; Khalaf-Allah and Kyamakya, 2006; Laitinen et al., 2000, 2001; Takenga et al., 2006; Wong et al., 2000). This interest can be based on fact that signal strength information can be simply measured by MS and does not require additional implementation costs compared to other methods. The RSS information can be processed in various ways. There are two basic ones which are trilateration (Brida et al., 2005, 2008; Hata and Nagatsu, 1980; Krejcar, 2009; Wong et al., 2000) and fingerprinting method (Anne et al., 2004; Benikovsky and Brida, 2009; Brida et al., 2006; Khalaf-Allah and Kyamakya, 2006; Laitinen et al., 2000, 2001; Takenga et al., 2006; Takenga and Kyamakya, 2006).

Generally, there are several ways to improve the positioning accuracy of RSS method. In this paper, we present modification of basic geometric calculation algorithm for position estimation, which we called adaptive geometric algorithm (AGA). The properties of proposed algorithm are evaluated in simulation and experimental scenarios. Both scenarios are implemented in typical multipath conditions, which are crucial in wireless communication. The results are compared to the basic geometric algorithm (GA) and standard least squares algorithm (LS).

The nature of AGA originates from basic geometric algorithm and it is improved in a way that minimizes additional calculation capacities.

RSS POSITIONING

The principle of RSS positioning is shown in Figure 1. The received signal strength (RxLev) is defined as:

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

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). The shadowing is characterized by long-term fading or lognormal fading and its variations due to terrain contour between base station and mobile station. It represents a slow variation in the mean signal envelope over a distance. L_{SS} is the signal attenuation caused by small-scale propagation (multipath propagation). The multipath fading or short-term fading is caused by multipath propagations and it is characterized by the fast variation of received signal strength over a short distance by a few wavelengths order of magnitude and over short time durations by second order of magnitude (Pent et al., 1997). 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 (Dobos et al., 2002; Garg and Wilkes, 1996; Prasad, 1998). All these

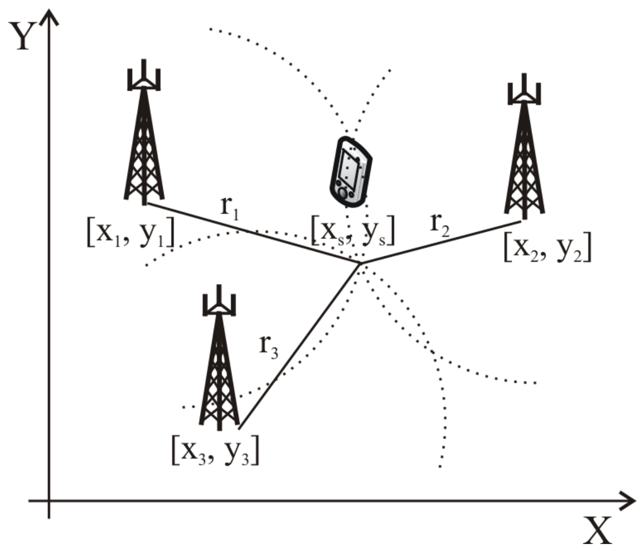

Figure 2. The three-circle intersection scenario.

parameters can be modified to simulate different scenarios, but we only focused on investigation of L_{LS} parameter impact. Hence, the distance between MS and BS is calculated based on this parameter. The CCIR (Comité Consultatif International des Radio-Communication) propagation model is used in our experiments (WCTG, 2002). The CCIR model is an empirical form for combined effects of free space path loss and terrain inducted path loss. This is given by:

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

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:

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

The CCIR propagation model is Hata model for small or medium city propagation conditions (Hata, 1980), supplemented with a correction Factor B defined by:

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

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

Problem formulation

It is assumed two-dimensional (2-D) plane is used. Let the true location of MS 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 exact distance d_i, between MS and the i^{th} BS is given by:

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

The distance between MS and i^{th} BS with reference error range n_i is defined by:

$$r_i = d_i + n_i = \sqrt{(x_s - x_i)^2 + (y_s - y_i)^2} + n_i, \quad i = 1,2,\ldots N. \quad (6)$$

For the simplicity, we assume that the measurement errors $\{n_i\}$ are zero mean Gaussian variables with known variance σ^2.

The received signal strength measurement determines a circle centered 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 (Figure 2). Then MS position can be estimated by the intersection of at least three circles.

MOBILE LOCATION CALCULATING ALGORITHMS

In general, there are two different kinds of proposed approaches to determine MS location based on the signal strength measurements (Caffery, 1999) as follows:

(i) The geometric approach based on geometric algorithm (GA) (Brida et al., 2005).
(ii) The statistical approach based on least square (LS) algorithm (Caffery, 1999; Cheung, 2004; Pent et al., 1997; Wang et al., 2003).

The principles of geometric algorithms are described in the next chapters of the paper.

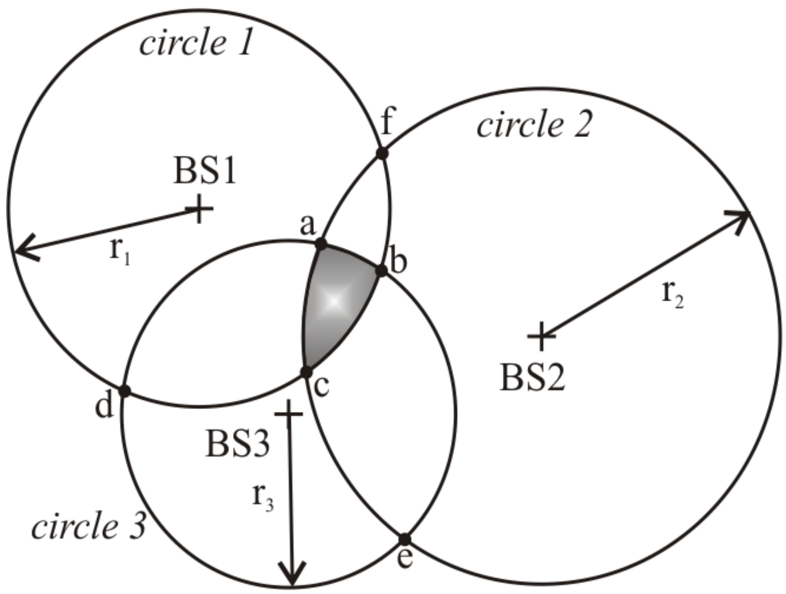

Figure 3. Situation 1: There is area which belongs to all three circles.

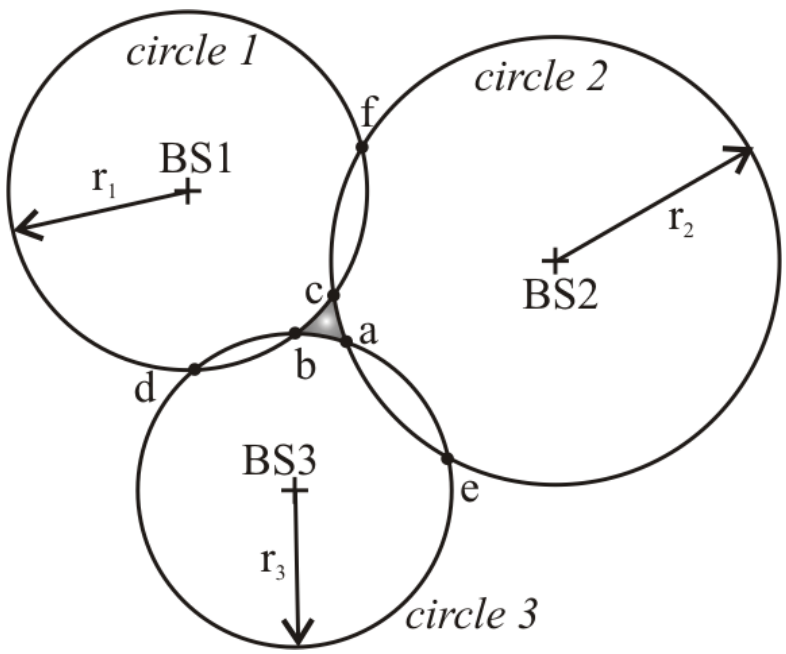

Figure 4. Situation 2: There is no area which belongs to all three circles.

Geometric algorithm (GA)

In ideal case, there is only one intersection of all involved circles (Figure 2). 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 real situations, which are analyzed and used for estimation of MS position in this paper, are depicted in Figures 3 and 4. As can be seen, there are a few intersections of all circles. The first situation is depicted in Figure 3. Each two circles intersect in two different points (example, the Circles 1 and 2 intersect in c and f points). An intersection of any two circles, which lies inside the Circle 3, is an interior intersection. An interior intersection is used for MS position estimation and therefore it is called a relevant intersection. For each combination of two circles there is one relevant intersection. Three-circles BS model determines 3 different relevant intersections, example, there are a, b, c relevant intersection in Figure 3. These relevant intersections determine an area which belongs to all circles. It

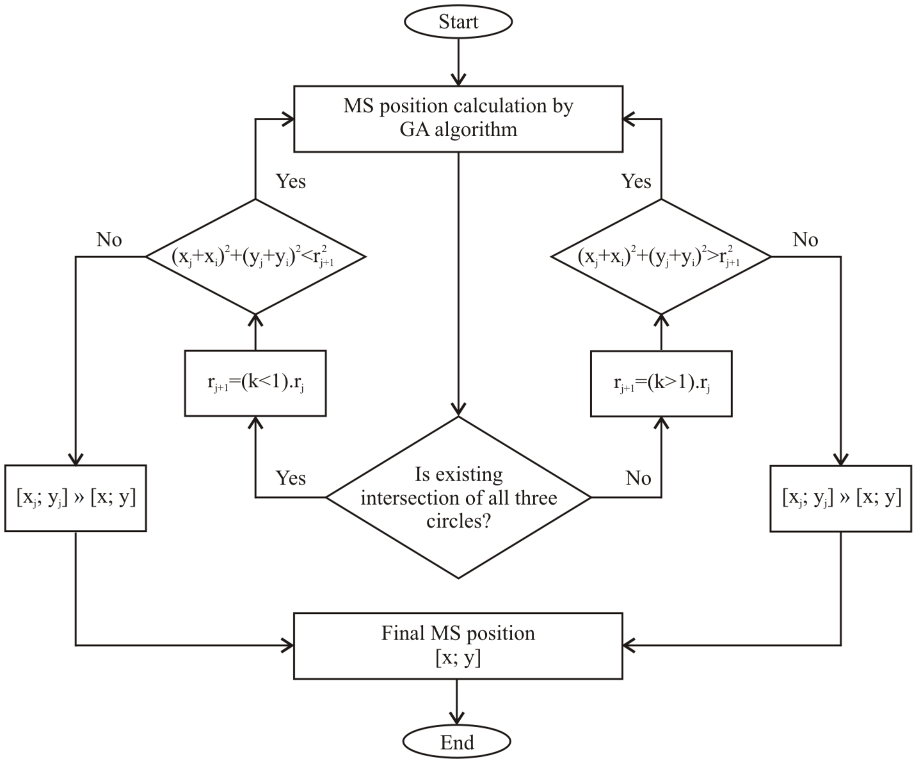

Figure 5. Adaptive geometric algorithm flowchart.

is called a relevant area. The exact location of MS is expected to be inside the relevant area.

The second situation is shown in Figure 4. This is more complicated scenario compared to previous one, because there are no interior intersections. Consequently, the relevant intersections are chosen by different way. Each two circles have two intersections. For example, there are c and f points between Circles 1 and 2. Only one point of this pair with shorter mutual distance is taken into consideration. Hence, three relevant pairs of intersection are obtained. As shown in Figure 4, the relevant intersections are a, b and c. These relevant intersections also determine relevant area. The exact location of MS is expected to be inside this 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. In general 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:

$$x = \frac{1}{K}\sum_{l=1}^{K} x_l \ , \ \ y = \frac{1}{K}\sum_{l=1}^{K} y_l \ , \ l = 1, 2,..., K \ , \qquad (7)$$

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

Adaptive geometric algorithm (AGA)

The main idea of AGA comes from the basic GA described above. 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. The purpose of AGA is to reduce the relevant area and to finally determine the specific coordinates of MS. AGA process is shown in Figure 5.

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 (Figure 3), Factor k is less than one and for the second situation (Figure 4). 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 algorithm is applied in the last iteration, but now potentially on way more reduced area compared to the first iteration.

The performance of the proposed algorithm is compared to conventional GA and LS algorithms subsequently in this paper. The basic LS algorithm is well-known, as such, it is not explained here. It is described in details in Caffery (1999), Cheung (2004), Pent et al. (1997), Wang et al. (2003). The performance of AGA is evaluated by simulation and practical experiments.

SIMULATION AND EXPERIMENTAL SCENARIOS

As mentioned previously, it is assumed that only multipath urban environment is used. The simulation parameters were defined in order to correspond to experimental scenario.

For the purpose of simulations, radio channel is modeled by means of the Equation (1). Simulation parameters are shown in Table 1. The cell radius is 1 km, what corresponds to urban areas. MS moves uniformly in the area -2 km ≤ x_s, y_s ≤ 2 km.The experimental scenario

Table 1. Radio channel statistical parameters.

Fading	L_{MS} - Shadowing	L_{SS} - Short-term
Distribution	Normal	Rayleigh
σ[dB]	6	7
µ [dB]	0	-3

Table 2. RMSE vs. number of BSs for simulation scenario.

BSs number	AGA		GA		LS	
	RMSE [km]					
	µ	σ	µ	σ	µ	σ
3	0.286	0.340	0.325	0.367	0.456	0.571
4	—	—	0.466	0.369	0.515	0.467
5	—	—	0.527	0.355	0.737	0.531
6	—	—	0.620	0.411	0.815	0.628
7	—	—	0.676	0.463	0.864	0.782

was represented by Zilina city centre (in Slovakia). This environment is typical multipath environment with many buildings and obstacles in motion. The environment was chosen purposely because of its bad propagation properties - a hostile shadowing and multipath.

The experiment was implemented in real GSM network which operates in 900 MHz band. Various parameters which characterize properties of the network have been defined, because these parameters are inputs to propagation model (Equation 2). These parameters are height of mobile antenna h_m = 1.5 m and height of base station h_b = 40 m. The value of frequency was calculated as average value of downlink channel frequency, that is, f = 947.5 MHz. The correction factor B depends on the χ. The parameter χ was defined particularly for individual cells; values were from 20 to 90%.

The measurements were realized by means of movable measuring station. The station consists of GSM/GPS module and localization server (Fargo, 2005; Garmin, 2005). The localization server provides the communication and data collection service for the module. However, as a server, it is designed to handle multiple clients (GSM/GPS modules). It also records measured data and computes MS position estimation. The function of GSM module is to measure received signal strength (RxLev) and cell identifier (Cell ID) from all available BSs by means of AT commands (ETSI, 1999). The maximum number of monitored BSs is seven, that is, one serving BS and six neighbour BSs at the same moment. GPS module is utilized to monitor current (precise) coordinates of MS position. These coordinates are used later on for calculation of position estimation error. The system architecture of the measuring station is shown in Figure 6.

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

$$\overline{RSS} = \frac{1}{N_s} \sum_{i=0}^{N_s - 1} RSS_i \ , \tag{8}$$

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

RESULTS AND INTERPRETATION

In the following part, results obtained in two aforementioned scenarios by means of above described algorithms are compared. The results provide detailed analysis of positioning accuracy in terms of root mean square error (RMSE) as a function of the number of BSs used for positioning. The RMSE is calculated as follows:

$$RMSE = \sqrt{(x_s - x)^2 + (y_s - y)^2} \ \text{[km]}, \tag{9}$$

where [x_s; y_s] are coordinates of MS actual location and [x; y] are coordinates of MS estimated location.

The reference (actual) coordinates of MS position were obtained by means of GPS module in the experimental scenario. Thus the final position estimation (utilizing AGA) was expressed in WGS84 coordinate system in order to be able to compare results with data from GPS module.

Table 2 shows positioning results for simulation scenario. The statistical parameters µ (mean value) and σ (standard deviation) characterize RMSE. Both parameters µ and σ are calculated from all 1000 independent trials of simulations.

There were from three to seven BSs utilized for position estimation in case of GA and LS algorithm. In case of decreased number of BSs in range, transmitters with higher signal strength were preferred.

In the light of obtained results it is possible to note that the higher the number of BSs used for position calculation the lower the accuracy of both algorithms (GA and LS). The most accurate results are obtained only when three BSs are involved in position estimation.

Hence, only three BSs are supported by AGA algorithm. The three nearest BSs to the MS are used for position estimation, because farther BSs bring errors into the position estimation. It is caused by the fact that RxLev

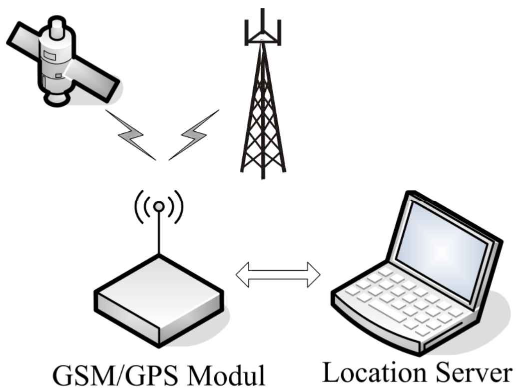

Figure 6. System architecture.

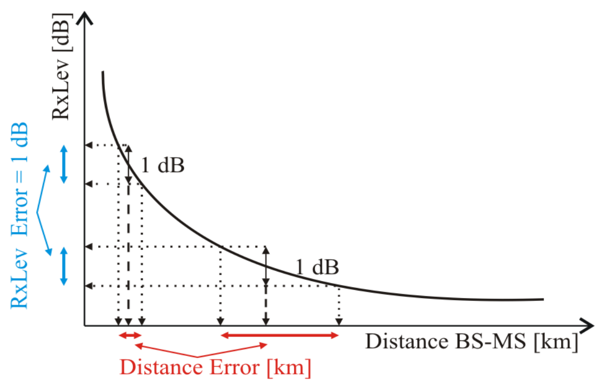

Figure 7. The error in distance estimates caused by RxLev variations.

variation of 1 dB could introduce error related to distance estimation (Figure 7).

The dashed arrows indicate the true distance and the dotted arrows denote over or under estimated distance due to signal strength. The blue lines denote RxLev Error and red lines represent adequate distance error.

Variation probability of RxLev is same in all cases, that is, it does not depend on BS-MS distance. However, distance error depends on BS-MS distance (see blue and red lines in Figure 7). In the case when BS-MS distance is smaller, the error of estimated BS-MS distance should be smaller as well. Correspondingly, greater value of BS-MS distance introduces greater error of the estimated distance. Therefore only three nearest BSs are used for position estimation.

AGA algorithm has achieved the most accurate results in comparison to the other algorithms. The smallest accuracy was achieved with LS algorithm. LS algorithm, also got highest error in case when seven BSs were used for position estimation.

Experimental verification of achieved simulation results was necessary to be performed. The basic problem of the RSS positioning is conversion of measured data (RxLev) into BS-MS distance. As mentioned above, we decided to use CCIR model because its properties can be customized based on the relevant environment. Therefore, preparatory measurements were performed at the beginning. GSM module was calibrated and CCIR model was created.

As mentioned above, the measurements in experimental scenario were realised in city centre. There is sufficient multipath environment with many buildings and movable obstacles. These parameters were taken into account in radio channel modelling for simulations (Table 1). The statistical parameters (histogram, standard deviation, etc.) were calculated from the measured and computed data.

The RxLev has significant impact on estimation of BS-MS distance (Figure 7). The measuring station was monitoring RxLev from all available BSs. The nearest BS belonged to serving cell and the remaining ones to neighbour cells. Figure 8 shows the histograms of RxLev for serving cell and neighbour cells in the urban environment. The mean value of serving cell RxLev 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. 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] is obtained from real GPS coordinates. The comparison of the distances is expressed as deviation in [km]. The deviation is calculated as follows:

$$deviation = d - r \, . \qquad (10)$$

Figure 9 depicts the histogram of the deviations. At first, it is necessary to note a few important facts. Probability of an incorrect distance determination is the same for serving cell as well as for neighbour cells.

On the basis of Figure 9, 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.

The obtained positioning results are shown in Table 3. The availability in [%] expresses probability of using data from a given number of BSs. 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 when more

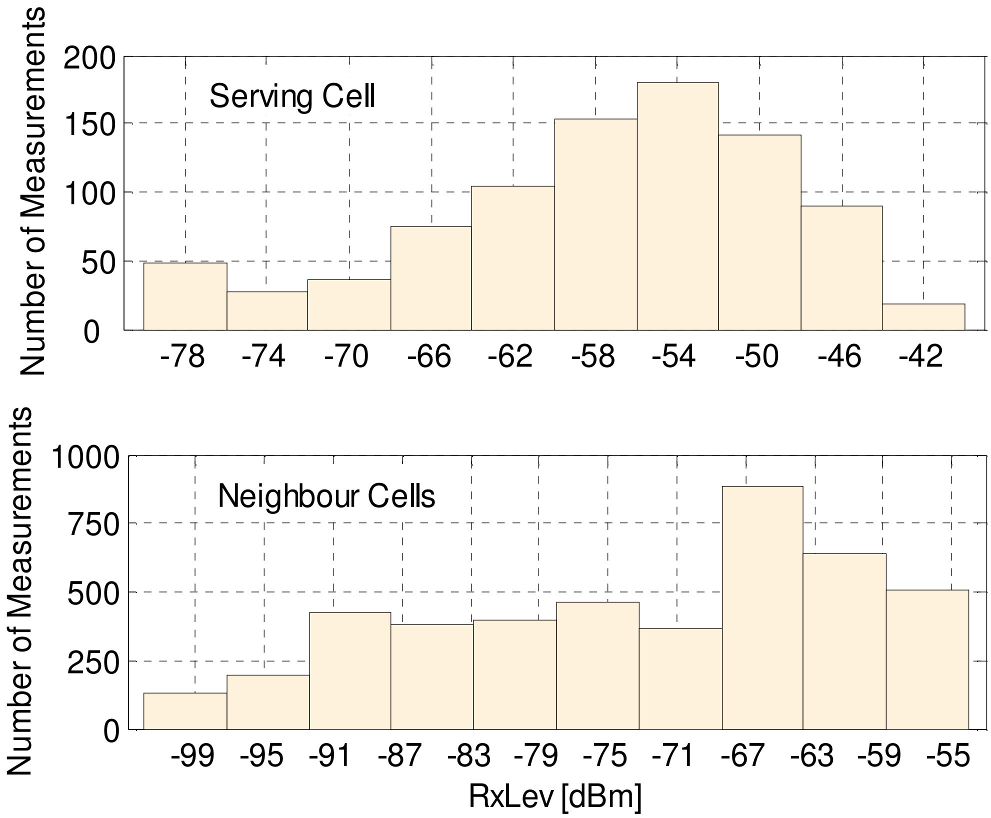

Figure 8. Histogram of RxLev for serving cell and neighbour cells for experimental scenario.

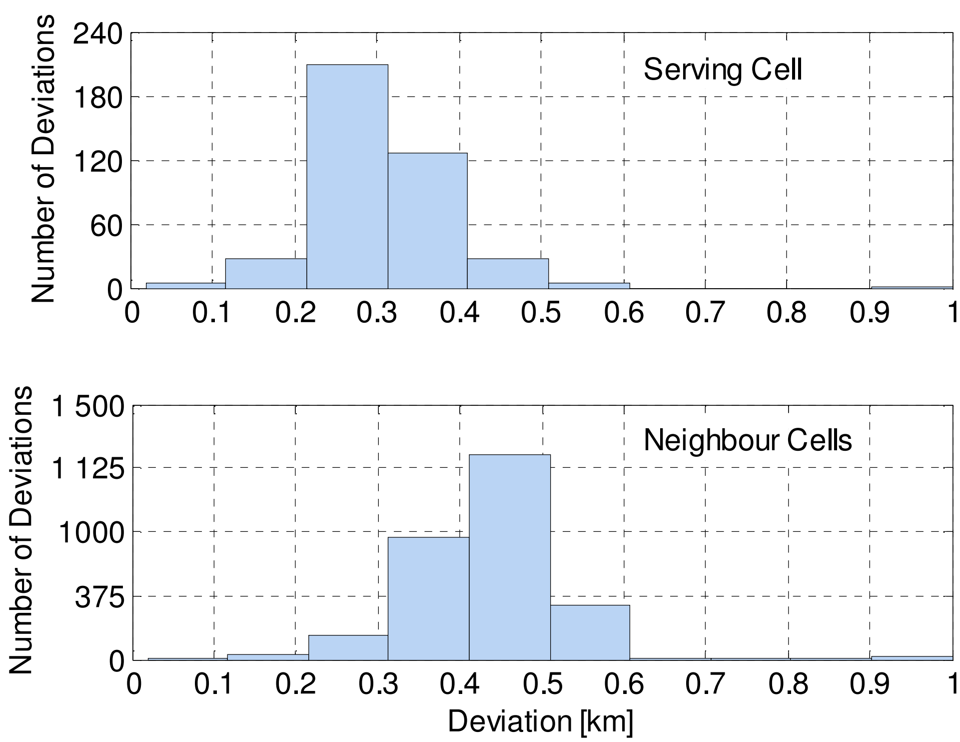

Figure 9. Histogram showing the distribution of deviations for serving cell and neighbour cells for experimental scenario.

Table 3. RMSE vs. number of BSs for experimental scenario.

BSs number	Availability [%]	AGA		GA		LS	
		RMSE [km]					
		μ	σ	μ	σ	μ	σ
3	100	0.264	0.241	0.358	0.264	0.391	0.273
4	100	—	—	0.472	0.252	0.361	0.265
5	92.7	—	—	0.516	0.279	0.607	0.343
6	24.6	—	—	0.569	0.345	0.752	0.398
7	3.9	—	—	0.715	0.369	0.817	0.465

than one sector of a base station was used. In that kind of situation, sector with the highest RxLev was selected for the position estimation. We assume that the chosen sector has the most direct contact with MS (compared to other sectors). This situation is illustrated in Figure 10.

The particular cells are numbered according to their *RxLev*. Blue cells have been selected for position estimation. $Cell_1$ is the cell with the highest signal strength and $Cell_4$ is the cell with the lowest signal strength. In our scenario it is not possible to utilize $Cell_1$ and $Cell_2$ simultaneously in spite of that these two cells have the best conditions for the most accurate calculation. It is necessary to use $Cell_4$ instead of $Cell_2$. $Cell_1$ and $Cell_2$ cannot be used simultaneously, because they have same BSs coordinates (centre of circles) and it is not possible to calculate intersection of two centred circles.

On the basis of Table 3, it can be concluded that the increasing number of BSs used for position estimation reached lower accuracy. It confirms results from simulation scenario. 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 AGA is more precise compared to basic GA algorithm (approx. 26% accuracy increase). This improvement is caused by the modification of basic calculation algorithm. In comparison to LS algorithm, AGA results are also more accurate (approx. 35% increase of accuracy).

Our assumption that AGA algorithm is more accurate in comparison with other algorithms was verified in both scenarios. The obtained positioning results from experimental scenario measurements are similar to simulation results. The differences are acceptable and could be caused by different parameters of propagation model (correction factor, height of BS…) compared to real parameters.

Conclusions

We discussed and verified simple and efficient positioning algorithm using RSS measurement. The MS collects RSS data (RxLev) of the surrounding base stations. The measured data are sent from MS to the localization server for position estimation.

The properties of proposed AGA algorithm were evaluated in two scenarios - simulation and experimental. Both scenarios modelled multipath radio channel with hostile shadowing and multipath. Therefore, we can conclude that the performance of calculating algorithm was validated in the unfavourable conditions.

We compared performance of the novel adaptive geometric algorithm (AGA), basic geometric algorithm (GA) and standard least square (LS) algorithm. The results are presented by means of the root mean square error (RMSE). According to the results, performance of the novel algorithm is better in comparison to the conventional algorithms.

The increase of positioning accuracy was approximately 26% compared to basic GA and 35% compared to LS. Therefore an implementation of AGA algorithm increases accuracy of RSS based positioning. As explained above, the positioning accuracy was improved by modification of basic algorithm.

The proposed positioning solution based on RSS method and AGA algorithm brings more accurate positioning results compared to most utilized and conventional Cell Identification method. Necessary costs for implementation of both solutions are same in practice. In the case of RSS implementation only localization server has to be added to the network. Compared with the most accurate time based methods, the time synchronization is not essential and it is very significant from engineering and financial point of view.

The implementation of AGA algorithm based on circular trilateration (example, Time of Arrival) may also introduce an accuracy increase. The accuracy of RSS method is smaller in comparison to the time-based methods, but it is satisfactory for the purpose of commercial location-based services. On the other hand the initial implementation costs for the time-based positioning are higher compared to the RSS-based positioning.

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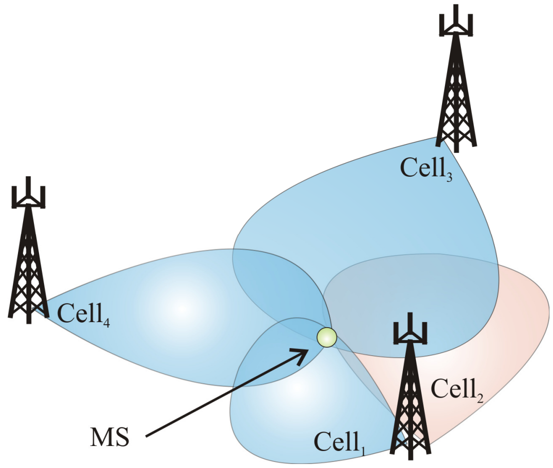

Figure 10. The adverse situation in RSS based mobile positioning.

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