The Accuracy of RSS Based Positioning in GSM Networks

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Abstract: This paper deals with performance of positioning in GSM networks based on received signal strength (RSS) measurements. Each mobile station (MS) collects RSS measurements of the downlink control channels transmitted by the surrounding base stations. These measurements can be used to obtain the MS location by means of calculating algorithm. We examine the accuracy of adaptive geometric and least square algorithms by circular error probability (CEP). Although accuracy of RSS positioning is not excellent, the initial costs are minimal. This is the advantage of RSS based positioning.

1. Introduction

Recently, MS location information is important for service provider. If MS location is known, various services based on MS location can be provided. Therefore location information plays important role for the next generation mobile systems. The accuracy of location information is important from the user point of view. Some services require higher accuracy as another services and therefore choosing of positioning method for specific service is important. One of the key parts in the cellular wireless location systems is location algorithm. Generally, a number of receivers distributed separately are used to receive the transmitted signals from sources and make measurement of parameters for the next processing.

One viewpoint for examining positioning systems is to consider where the position measurements are made and where the position information is used for position calculation. Three broad classifications are made: self-positioning (mobile-based positioning), remote positioning and hybrid positioning [4].

- Self-positioning – positioning receiver (MS) makes the necessary signal measurements from geographically distributed transmitters (BSs) and uses these measurements to determine actual position.
- Remote-positioning – receivers (BSs) measure a signal originating from the positioned station (MS). These measurements are transferred into a central site and they are combined to give an estimate of MS location.
- Hybrid positioning – it is possible to send the location measurement data from self-positioning receiver into a remote site and there is realized calculation process or vice versa.

The type of measured location parameters depends on the positioning method, e.g. for RSS method it is signal strength, for time based methods it is time of arrival. We discuss the RSS based positioning therefore received signal strength is important for us.

In the RSS method the propagation path losses from the MS to the BSs are measured and converted to distances between them. For two-dimensional positioning each RSS measurement will provide a circle centred at the corresponding BS and MS lies on this circle. In the absence of measurement error, the MS position is given by the intersection of circles from at least three BSs in order to resolve ambiguities arising from multiple crossings of the lines of position (circles).

The problem of location estimation accuracy may be caused by mutual deployment of sources and receivers. Signal propagation conditions and environment has the significant impact on accuracy, e.g. non line of sight (NLoS) propagation.

The changes in the transmission path are characterized by various influences, e.g. shadowing, multipath fading and path loss. The shadowing is characterised by long-term fading or lognormal fading and its variations are due to terrain contour between base station and mobile station. It represents a slow variation in the mean envelope over a distance. The multipath fading is caused by NLoS propagation. NLoS propagation always exists in cities or other built-up environments i.e. the signals arrive to the receiver via NLoS propagation. The multipath fading or short-term fading is characterized by the fast variation of received signal strength over a short distance on the order of a few wavelengths or over short time durations on the order of seconds [5]. The path loss means signal power attenuation with the increasing distance between the transmitter and the receiver. These influences cause deviation of signal strength measurement and degrade the location accuracy. The variations of received signal strength can acquire values up to 30 ÷ 40 dB.

This paper provides detailed analysis of accuracy in terms of circular error probability (CEP) as a function of various parameters:

- the number of BSs used for positioning,
- MS location regarding BSs distribution,
- cell radius,
- channel parameters.
2. Problem formulation

The principle of RSS based mobile positioning is shown at the following figure.

\[
RSS = T_x - \left( L_{LS} + L_{MS} + L_{SS} \right),
\]

where RSS is received signal strength, \( T_x \) is transmitted signal strength.

Signal attenuation is influenced by the following parameters: \( L_{LS} \) is signal degradation, caused by large-scale propagation (path loss), \( L_{MS} \) is signal degradation, caused by medium-scale propagation (shadowing) and finally \( L_{SS} \) is signal degradation, caused by small-scale propagation (multipath propagation). All of the parameters are in [dB].

\( L_{LS} \) is modelled by Hata’s model. Hata [6] developed a useful model for path loss in macrocells on the experimental results of Okumura. The model expresses the path loss as a function of BS height, MS height, carrier frequency and the type of environment (urban, suburban or rural). Medium-scale variations of \( L_{MS} \) take into consideration Gaussian statistics. In general, the \( L_{SS} \) of channel with a large number of paths can be modelled as a Rayleigh channel. The signal amplitude is modelled by Rayleigh distribution in a case of large number of obstacles and dominant reflected waves (NLOS environment – Non Line of Sight).

We consider the location in a two-dimensional (2-D) plane. Let the true location of MS is \( [x_s, y_s]^T \) (receiver) and the coordinates of the \( i^{th} \) BS is \( [x_i, y_i]^T \) (source), \( i=1,2,\ldots,N \). The distance between MS and the \( i^{th} \) BS, denoted by \( d_i \), is given by

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

In the presence of disturbance we denote a measured distance \( r_i \)

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

where \( n_i \) is the noise or range error at the \( i^{th} \) BS. For the simplification we assume that the measurement errors \( \{n_i\} \) are zero mean Gaussian variables with known variance \( \sigma^2 \).

The distance \( r_i \) determine the circle radius. If we use at least three BSs to resolve ambiguities, position of MS is given by the intersection of circles. The circles are given by equations

\[
(x_s - x_i)^2 + (y_s - y_i)^2 = r_i^2, \quad i=1,2,\ldots,N.
\]

In general, calculation of MS location by means of circles intersection can be done by various calculating algorithm. Basic geometric algorithm (GA) is based on calculation of circles intersections. Subsequently, relevant intersections are selected from all the intersections and they are suitable for final calculation (Fig. 2 a, b and c). The adaptive geometric algorithm (AGA) is an improvement of basic GA algorithm. The principle of
AGA bases on decreasing of delimited area of chosen intersections (See Fig. 2). The AGA algorithm is proposed in [1]. The LS is conventional algorithm [2], [3] and results of this algorithm are compared to the AGA algorithm.

3. Simulation Environment

We introduce the proposed system model. We assume the system model as following:
- the number of BS is N,
- signals from BSs are measured at MS,
- received signal strength from each BS is independent to each other,
- hexagonal base stations configuration (Fig. 3),
- all cells in the system are deployed with omni directional antennas.

![Fig. 3. Allocation of the MS.](image)

Note that the accuracy of the method depends on:
- the MS and base stations’ geometry,
- the channel parameters i.e. statistical characteristic of received signal amplitude changes,
- cell radius.

4. Simulation Results

In this section, we obtain numerical results for the expected accuracy of the location-determination method described in the previous sections. Here, we use the concept of CEP. The CEP is defined as the radius of the circle that has its centre at the true location and contains the location estimates with probability $P_{\text{CEP}}$. We will focus on 50 % (marked CEP50) and 67 % (marked CEP67) since these probabilities are the most used.

Three BSs are used for position calculation. In [1], [2] is demonstrated, that the highest accuracy is obtained just by using three BSs.

For illustration, we show the following example. In case of use $n$ BSs for positioning are selected $n$ BSs which are the closest to the MS. If the distance between BS and MS is longer, error of estimated distance (according to propagation model) is also bigger (See Fig. 4). For each RSS value (-50, -60 ... ) is established identical error (1 dBm). The error 1 dBm causes different distance error at the estimation of the distance between MS and BS. Fig. 4 demonstrates the fact that the decreasing value of RSS means increasing of the distance error. On the basic of this fact, we can assume that the using more BSs for positioning does not bring accuracy increase. In the case of using three BSs for positioning, the accuracy should be the highest and the error should be the lowest. This observation has more important impact in the environment with larger cells (rural area).

On the basis of this fact, the adaptive geometric algorithm AGA was applied just for three BSs and its performance is compared with LS algorithm (also using three BSs).

![Fig. 4. Distance error [km] versus RSS in the presence of RSS error [dBm].](image)
The simulations are carried to evaluate the performance of the proposed AGA location algorithms. The performance is compared with conventional LS algorithm. The simulations are realized for two cases of MS location (See Fig. 3). Simulation parameters are defined: \( r = 5 \text{ km}, \sigma = 4 \text{ dB} \). The choice of parameters represents realistic case. All results are based on 5000 independent runs.

In the first case MS location is randomly generated in the centre cell. The accuracy (CEP) is observed according to received signal amplitude \( \sigma \) standard deviation changes and cell radius.

![CEP vs. \( \sigma \) (r=5 km)](image1)

![CEP vs. \( r \) (\( \sigma =4 \text{ dB} \))] (image2)

Fig. 5. a) CEP versus standard deviation \( \sigma \) [dB], b) CEP versus cell radius \( r \) [km]

Fig. 5 depicts CEP properties in the case of MS location according to Fig. 3 a). Fig. 5 a) shows the accuracy decline with the increase of standard deviation. The standard deviation play important role particularly in rural environment where hostile surrounding environment has greater impact on the radio channels and causes deeper fading. On a basis of obtained results we conclude that the AGA algorithm achieves more accurate results comparing to conventional LS algorithm. The CEP is a linear function of standard deviation \( \sigma \) of received signal amplitude.

Fig. 6. a) CEP versus standard deviation \( \sigma \) [dB], b) CEP versus cell radius \( r \) [km]

Fig. 6 depicts CEP properties in the case of MS location according to Fig. 3 b). Fig. 6 a) shows the CEP as a function of the amplitude standard deviation of received signal. The accuracy is approximately linear function of standard deviation \( \sigma \). Fig. 6 b) plots the CEP versus cell radius. The accuracy decreases linearly with the cell radius up to value of 9 km. The accuracy is rather poor for large cells.

5. Conclusion

We discussed a method for location determination based on RSS positioning. The MS collects RSS data of the surrounding base stations. We presented the results in terms of CEP of 50 % and 67 % probability. The method is not accurate in comparison with the time based methods, but it is sufficient for the commercial location based services.

In the article we proposed novel adaptive geometric algorithm. It is possible to increase the performance of RSS method by means of using this algorithm. The results of this algorithm are more accurate in comparison to LS algorithm.

REFERENCES