LOCALIZATION SYSTEM IN GSM AND GPS NETWORKS

Lukáš Klozar

Doctoral Degree Programme (2), FEEC BUT

E-mail: xkloza00@stud.feec.vutbr.cz

Supervised by: Jan Prokopec

E-mail: prokopec@fekt.vutbr.cz

Abstract: This paper deals with localization in wireless networks. The mobile localization unit is designed, and tested in a real network measurement. The received localization data were sent on a remote server, where were post processed. We compared the position received from the satellite navigation system and the position estimated according to the received signal power in the cellular network measurement. The optimized multislope log-distance path loss model predicts the propagation distance from the received power. However, an ambiguous position data were estimated this way, thus further optimization is applied. The precision depends on the number and the constellation of the base stations. The lowest error was achieved with a triangular constellation and takes values around tens of meters.

Keywords: Channel modeling, localization, optimization, propagation, wireless networks.

1. INTRODUCTION

Localization in wireless networks is very perspective task. Wireless mobile communication networks are widely spread all around the World and new sites are built contemporary. In addition, sensor and cooperative wireless networks have become very popular and useful in many spheres of industry and every day live. Many techniques were developed for localization in wireless networks [1]. In addition, dedicated wireless satellite networks like GPS (Global Positioning System), GLONASS or GALILEO provide localization and navigation services [2].

We have measured parameters in GPS and GSM (Global System for Mobile Communications) networks and estimated our position. The combined GPS/GSM module XT65 [3] was used for our experiment. With this module, we carried out an urban measurement in Brno city. We have collected localization data from GPS and GSM network (latitude, longitude, received signal strength, timing advance, cell identity, signal frequency) and processed them in Matlab. We applied appropriate propagation models and use our optimization algorithm and geometric-based technique to estimate the Mobile Station (MS) position in two-dimensional space. To evaluate usability and precision of proposed localization techniques we compared results with the MS positions received from GPS.

2. LOCALIZATION IN GPS NETWORK

GPS uses the physical model of the Earth called WGS 84 [2]. Thanks to the precise atomic-clock based time synchronization, GPS receiver uses the TOA (Time of Arrival) technique [2][3]. The signals, received from at least four satellites, are correlated in a receiver and corrected by SBAS (Satellite Based Augmentation Systems). Its accuracy depends on the constellation and the number of visible satellites. With the SBAS is the XT65's CEP (Circular Error Probable) 2 m and SEP (Spherical Error Probable) 3 m [3].

3. LOCALIZATION IN GSM NETWORK

GSM is the wireless network with a cellular architecture (Figure 1). There are many techniques developed for localization [1]. However, the precise position data of BSs (Base Stations) are mandatory for all of them.

3.1. Cell Identity Localization Technique

The CI code uniquely identifies each sector in the network as illustrated in Figure 1. CI is a part of the service information transmitted in the BCCH (broadcast control channel) [1] and it is expressed in hexadecimal format. With the database of identification and position information of BSs it is possible to track MS moving in a network according to the CI value i.e., trace connected sectors of BSs. Other codes used for an identification of MS in the network: LAC (Location Area Code), MNC (Mobile Network Code), MCC (Mobile Country Code) [1].

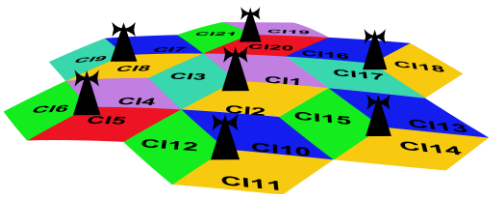

Figure 1: Cell identity of the sectors in a cellular network.

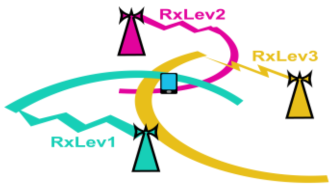

Figure 2: Triangulation localization technique based on the received signal strength.

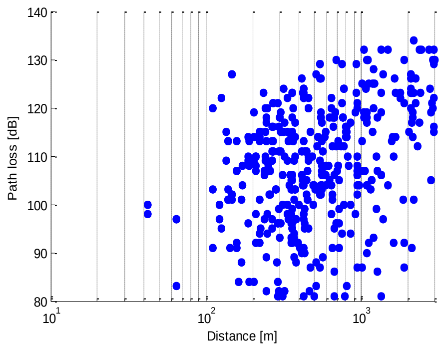

Figure 3: Outdoor urban measurement of the received power in a real GSM network. The distance is determined according to the GPS coordinates in the measurement points and the known position of base stations.

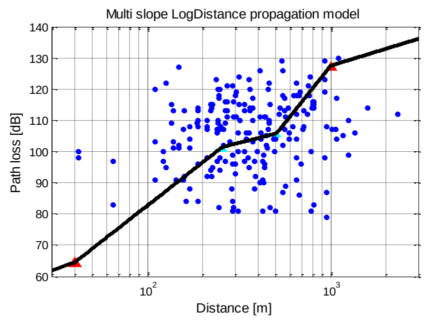

Figure 4: Optimized multislope log-distance model with the deviation error of 12 dB. Break point positions are bp0=[40 m; 64 dB], bp1=[253 m; 100 dB] , bp2=[542 m; 104 dB] , bp3=[1000 m; 127 dB].

3.2. Timing Advance Localization Technique

The TA (Timing Advance) information transmitted in BCCH corresponds with a propagation delay of the transmitted signal. The TA interval in GSM primarily avoids an overlapping of the bursts transmitted by different users to single BS. TA is expressed as a natural number from 0 to 63. Each value determines the distance from BS up to 34 km with a 550 m width step [1].

3.3. Received Signal Level Localization Technique

RxLev (Received Signal Level) represents the power of BCCH received by MS from a network [3]. The RxLev value depends on the length and the conditions of a propagation path. The free space path loss describes formula (1) as

$$PL_{FS} = \left(\frac{4\pi df}{c}\right)^2, \tag{1}$$

where d is the propagation distance in [m], f is the signal frequency in [Hz], c is the speed of light ($3 \cdot 10^8$ m/s). Figure 2 describes the basic principle of triangulation technique used for the MS position estimation. The character of a propagation environment influences path losses, therefore using the feasible propagation model is mandatory.

4. MEASUREMENT

We designed the SQL (Structured Query Language) database containing position data and identification of BSs (latitude, longitude, CI, LAC, MNC and MCC). Next, we performed measurement in the real network in Brno city with the combined GSM/GPS module [3]. Measured BSs transmitted in the 900 MHz GSM frequency band [1]. Collected service information and position data were sent via GPRS data service on the http server. Next, the PHP script running on this server stored and processed incoming data in to the SQL database. Incoming data were CI, LAC, MNC, MCC, TA, RxLev, ARFCN (Absolute Radio Frequency Channel Number)) for each connected BS, and GPS latitude and longitude for each measuring point. Next, we determined the propagation distance for every connected BS. The path loss depends on a propagation distance as described by propagation models [1][4][5][6]. Figure 3 shows path losses in the experimental measurement points.

5. CHANNEL MODELING

Channel modeling is complex process influenced by an individual propagation conditions. We have modeled path losses by some widely used path loss models (COST 231 [4], Okumura Hata [5], ECC 131 [6]) and adjust their parameters to fit our measurement [8]. According to the results [8] we proposed the adaptable optimization technique. It uses the multislope modeling approach [7][9] and describes the log-distance dependency of path loses (2) [10] as

$$PL_{LD}(d) = PL_{d0} + 10 \cdot n \cdot \log_{10}\left(\frac{d}{d_0}\right), \tag{2}$$

where n is the path loss exponent setting the slope of the model ($n_{FREE\ SPACE} = 2$), d is the propagation distance, d_0 is the reference distance (typically $d_0 = 1$ m) and $PL_{(d0)}$ is the frequency dependent parameter describing the free space path loss (1) at the reference distance $d_0 = 1$ m.

We enhanced the log-distance model (2) with the multislope adaptation as described in [9]. The break point positions of a multislope model we optimized according to the mean square error (MSE) estimation to achieve the best fit with the measurement (Figure 4). Our adaptable modeling algorithm uses PSO (Particle Swarm Optimization) to adapt position of break points. The first break point bp0 is static and its position is determined as the free space path loss (1) at the distance 40 m. This distance represents correction of the BS height for macro cell in an urban area. The position of the rest three break points (bp1, bp2, bp3) estimates the optimization algorithm in the range from 40 m to 1000 m. We use the model shown in Figure 3 with parameters: bp0= [40 m; 64 dB], bp1= [253 m; 100 dB], bp2= [542 m; 104 dB], p3= [1000 m; 127 dB]. The standard deviation is 12 dB.

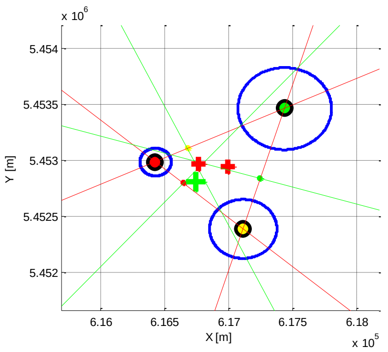

Figure 5: Geometric localization technique (localization error is 165 m).

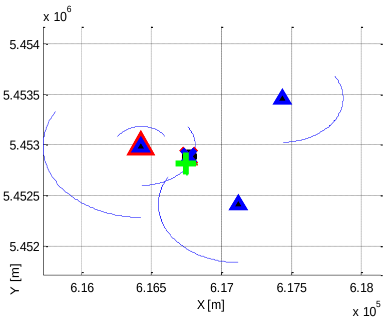

Figure 6: Localization technique with optimization algorithm (localization error is 65 m).

6. LOCALIZATION APPROACH

The visual presentation is performed in the UTM coordinate system. Displayed blue circles and circular arcs in Figure 5 and Figure 6 represent the propagation distance of measured signal. In Figure 6 are considered the sectors of the cells.

The measured RxLev value determines the propagation distance in each sector of BS using channel models (COST 231, ECC 131, our optimized multislope log-distance model). Because of ambiguity of RxLev localization technique, the curve arcs do not intersect in a single point. Heterogeneous environment with places like parks, squares, wide streets, crossroads cause spatial ambiguity and an inaccuracy of used propagation model. Moreover, relative MS position, reflections and interferences (co-channel, adjacent channel, intersystem) can cause degradation of measured RxLev value. We represent two localization approaches for prediction of the MS position with ambiguous localization data.

6.1. GEOMETRIC LOCALIZATION TECHNIQUE

This technique can be used only in case the MS is linked with at least three BSs. The triangular constellation of connected BSs is mandatory. The best results were achieved with the constellation conformable to an equilateral triangle (Figure 5).

The basic principle is to link neighboring BS with the lines to create a triangle (red lines in Figure 5). Next, divide these lines according to the ratio of the RxLev value. Through the dividing points are led the perpendicular lines (green lines). Intersections of the green lines create a small triangle. The final MS position is estimated to be in the center of this triangle (the upper red cross on left). The second red cross on right is the triangle’s centroid. The real GPS position of MS is marked with the green cross.

The localization error for the case in Figure 5 is 165 m and the typical error of this technique was about 300m in an urban environment.

6.2. OPTIMIZATION LOCALIZATION TECHNIQUE

This localization technique uses PSO (Particle Swarm Optimization) algorithm with the MSE criteria function estimating the MS position. The propagation distances in the connected sectors are determined by using the optimized channel model (blue circular arcs in Figure 6).

The TA value sets boundaries of the searched space. Twelve PSO agents move inside the defined space with the global scaling factor g=2.49 and the personal scaling factor p=1.5. The optimization algorithm has 25 iteration loops. In each loop the criteria function compares the Euclidean distance A_i between the agent's position and the blue circular arcs for each agent. Equation (3) describes the output of the criteria function for every single agent as

$$K = \sum_{i}^{nBS} \left(\left(1 + \frac{1}{(R_i / 1000)} \right) \cdot A_i \right), \tag{3}$$

where R_i [m] is the modeled propagation distance between BS and MS (blue arcs in Figure 6) and A_i [m] is the Euclidean distance. The nBS is the number of connected BSs. The first part of (3) describes the dependency on the modeled propagation distance R_i, where the shorter distance is favored.

7. CONCLUSION

We have presented capabilities of localization in cellular wireless networks. We carried out measurement of RxLev in real GSM network in Brno. The post processing of the measured data predicts the propagation distance. However, the propagation models are not capable to involve every individual propagation scenarios. Therefore, the additional processing is applied to reduce an ambiguity of the MS position. Two methods, estimating the finite MS location, are described and compared. The first approach is a simple geometric technique. The position is estimated as the ratio of RxLev received from three BSs in the triangle constellation (Figure 5). The positioning error is about 300 m, but it is very strongly dependent on the constellation of BSs (some cases gives unreasonably high errors). The second technique uses the PSO algorithm (Figure 6). In some cases was achieved the localization error of a few meters. Average error was in tens of meters for scenarios with connected at least three BSs. The mean localization error achieved by the geometric technique was about 300 m, the mean error achieved by the PSO technique was about 80 m.

Further work on a comparison of propagation models for serving and neighboring BSs and improving of the optimization algorithm. The further improvements in PSO technique should be done in the defining closer space. We proved capabilities of the PSO technique in localization tasks.

ACKNOWLEDGEMENT

This paper was jointly supported by the Czech Ministry of Education, Youth and Sports through the research program of Brno University of Technology, Electronic Communication Systems and New Generation Technology (ELKOM) MSM0021630513, internal project FEKT-S-11-12 MOBYS and through the project Systems of Wireless Internet Communication (SYWIC) LD11081 in frame of COST IC 0906.

REFERENCES

[1] T. Halonen, J. Romero, and J. Melero, GSM, GPRS and EDGE Performance : Evolution Towards 3G/UMTS, 2nd ed. England: John Wiley & Sons, Ltd, 2003.

[2] E. D. Kaplan, Understanding GPS: Principles and applications. Norwood: Artech house inc., 1996.

[3] XT65/XT75 - Hardware Interface Description. Siemens, Cinterion, Germany, 2007.

[4] COST Action 231: Digital mobile radio towards future generation systems, Brüssel, 1999

[5] M. Hata, "Empirical formula for propagation loss in land mobile land mobile radio services," IEEE Trans. on Vehicular Tech., vol. 29, no. 12, pp. 317-325, August 1980, doi: 10.1109/T-VT.1980.23859.

[6] ECC Report 131, Denmark, [Online] Cited, June 2009, Available at: http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP131.PDF.

[7] European Radiocommunications Office, "SEAMCAT user manual (Software ver. 2.1)," February 2004.

[8] L. Klozar and J. Prokopec, "Propagation Path Loss Models for Mobile Communication," Proc. of 21st International Conference Radioelektronika 2011, Brno, 2011, pp. 287-290, doi: 10.1109/RADIOELEK.2011.5936478.

[9] L. Klozar, J. Prokopec and O. Kaller, "Multislope Channel Model Optimization Processing". In 19th Proceedings of Technical Computing Prague 2011. Prague, 2011, pp. 66-66.

[10] T. S. Rappaport, Wireless Communications: Principles and Practice (2nd Edition). USA: Prentice Hall, 2002