Wireless Network Localization

Optimization Processing

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***Abstract*—This paper deals with localization in wireless cellular networks. We performed measurement of the received signal strength in and around Brno city and stored the collected data. The localization approach uses multislope channel models to estimates the propagation distance from the signal strength. Results are processed by two localization techniques. The first one is geometrically based with a triangular constellation of BSs. The second one is independent on the number of connected BSs, however more linked BSs with a triangular constellation refine the localization precision. This technique uses an optimization algorithm and proves to be universal and more accurate.**

Keywords-Channel; localization; modelling; multislope; optimization; propagation; wireless.

I. INTRODUCTION

Wireless mobile communication networks are widely spread all around the world and new sites are built contemporary. This brings new opportunities for localization. Many techniques were developed for positioning in wireless networks [1][2][10][11][12][13]. In addition, the dedicated wireless satellite networks like GPS, GLONASS or GALILEO provide localization and navigation services [2].

The motivation of this work is to investigate localization capabilities of an optimization approach in wireless networks. We have measured parameters of GPS and GSM networks in an urban environment of Brno city. With the combined GPS/GSM module XT65 [3] we have collected localization data (latitude, longitude, received signal strength, timing advance, cell identity, signal frequency) and processed them in Matlab.

The measurement of the received signal level in the GSM network is influenced by individual propagation conditions. Therefore, the positioning is ambiguous and additional processing is required to increase precision. We applied the adaptable multislope propagation channel model on the measured values of the signal level to estimate the propagation distance. Next, to determine the final position we propose two localization algorithms. The first one is geometric-based and it is strongly dependent on a network constellation. The second one uses an optimization approach with a mean square error (MSE) estimation to find the Mobile Station (MS) position in two-dimensional space.

At the beginning of this paper is a theoretical description of localization principles in dedicated wireless networks (GPS, GSM). Next, the experimental measurement is introduced. An optimization multislope channel modeling technique is presented [9] to estimate a propagation distance. Next, two localization techniques are described and tested. Results are compared with other techniques described in [11][12]. In conclusion, the results are summarized and further improvements are proposed.

II. GPS LOCALIZATION

GPS uses the physical model of the Earth called WGS 84 [2]. The localization applied in GPS uses a precise time synchronization, and the GPS receiver measures the Time of Arrival (TOA) [2]. The satellite signals should be received from at least four satellites to achieve sufficient accuracy. Satellite Based Augmentation Systems (SBAS) could provide additional corrections in a receiver. Its accuracy depends on the constellation and the number of visible satellites. With the SBAS [3] is the XT65's Circular Error Probable (CEP) 2 m and Spherical Error Probable (SEP) 3 m [3].

III. GSM LOCALIZATION

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.

A. *Network Based Localization*

The GSM network was not designed for localization, thus this approach requires additional hardware enhancements in network architecture. The Location Measurement Unit (LMU) needs to be involved to perform time based measurements and computation. With the LMU unit the network is capable of using localization techniques TDOA (Time Difference of Arrival), OTD (Observed Time Difference), E-OTD (Enhanced-OTD). Additional capabilities for localization provide the combination with GPS receiver denoted as A-GPS (Assisted-GPS) and also the measurement of AOA (Angle of Arrival). We focus this work on the processing of the received signal strength information by the MS as the part of service communication.

 ISBN: 978-1-61208-193-9

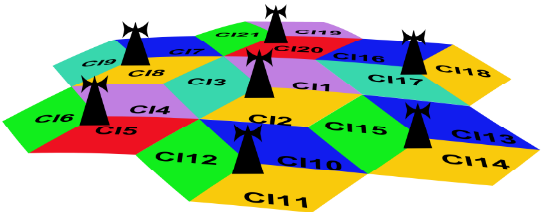

Figure 1. Cell identity of the sectors in a cellular network.

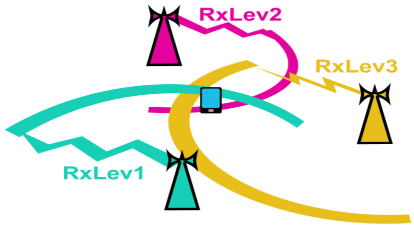

Figure 2. Localization approach based on the measured signal strength

B. *Cell Identity Technique*

The Cell Identity (CI) code uniquely identifies each sector in the network as illustrated in Figure 1. The Broadcast Control Channel (BCCH) [1] carries the CI code expressed in hexadecimal format as part of the common service communication.

With the database of identification and position information of BSs it is possible to track the MS moving in the network according to the actual CI value i.e., trace connected sectors of BSs. Other codes used for the identification of the MS in the network: Location Area Code (LAC), Mobile Network Code (MNC), Mobile Country Code (MCC) [1].

C. *Timing Advance Technique*

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

D. *Received Signal Level Technique*

The Received Signal Level (RxLev) represents the power of the BCCH received by the MS from a network [3]. The RxLev value depends on length and conditions of a propagation channel. The free space path loss formula (1) [10] is

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

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. Character of a propagation environment influences path losses, therefore using the feasible propagation model is mandatory.

IV. MEASUREMENT

We designed the Structured Query Language (SQL) 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, Absolute Radio Frequency Channel Number (ARFCN)) 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 losses depend on a propagation distance and is modeled by propagation models [1][4][5][6]. Figure 3 shows path loss measurement.

Based on the measured parameters of the network, two localization techniques were developed and simulation results were compared.

V. CHANNEL MODELLING

Channel modeling is a complex process influenced by individual propagation conditions. We have modeled path losses by some widely used path loss models (COST 231 [4], ECC 131 [6], WINNER II [5]) and adjusted their parameters to fit our measurement [8]. According to the results [8] we propose the adaptable optimization technique [9]. 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 with a multislope adaptation as described in [9]. We have optimized the break point positions of a multislope model. According to the MSE estimation, we adjusted the path loss model to fit with the measurement (Figure 4). Our adaptable modeling algorithm uses PSO (Particle Swarm Optimization) to adapt the position of break points (blue and red triangles in Figure 4). The first break point bp0 is static and its position is determined as the free space path loss (1) at a distance of 40 m. This distance represents correction of the BS height

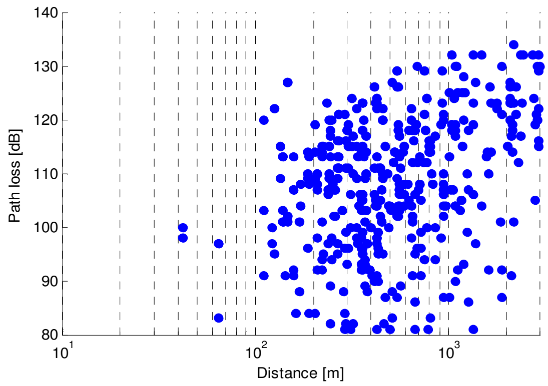

Figure 3. Measured path losses for an outdoor urban scenario in a real GSM network. The distance is determined according to the GPS coordiantes of MS.

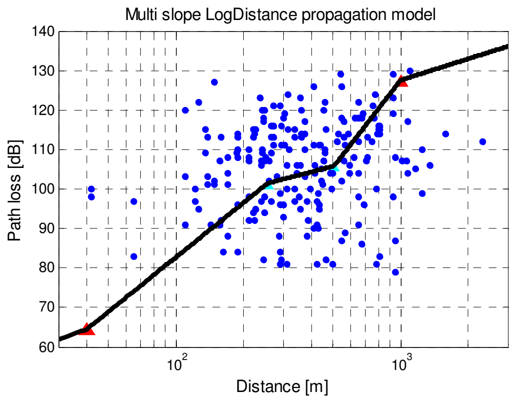

Figure 4. Optimized multislope log-distance model with the deviation error of 12 dB. Break point positions are bp0=[40 m; 64 dB], bp1=[253 m; 100 dB] , bp2=[542 m; 104 dB] , bp3=[1000 m; 127 dB].

for macro cell in an urban area. The PSO algorithm estimates the position of the other three break points (bp1, bp2, bp3) in the range from 40 m to 1000 m The algorithm changes the position (distance and path loss) of the breakpoints and model path losses according to (3) [9].

Path losses of the multislope model are described by (3) for the distances d over the last breakpoint as

$$L_{MS}(d) = PL_{d0} + 10 \cdot n_1 \cdot \log_{10}\left(\frac{h_1}{d_0}\right) + \sum_{i=2}^{n_{BP}} 10 \cdot n_i \cdot \log_{10}\left(\frac{h_i}{h_{i-1}}\right) + 10 \cdot n_{n_{BP}+1} \cdot \log_{10}\left(\frac{d}{h_{n_{BP}}}\right) \quad , \qquad (3)$$

where the first part is similar to (2) and describes propagation losses up to the first breakpoint, h_1 is the distance of the first breakpoint, d_0= 1 m is the reference distance. The summation in the second part of (3) describes the propagation losses between the first (bp1) and the last (bp4) breakpoint (the red triangles in Figure 4), n_{BP} is the total number of break points and h_i is the distance of the *i-th* breakpoint. The last part of (3) describes the path losses in the distances d over the last breakpoint h_{nBP-1}.

To estimate the final path loss value in a particular propagation distance it is necessary to determine the correct value of n_{BP} (representing the number of breakpoints) as the number of the last breakpoint previous to the desired distance.

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 12dB.

VI. LOCALIZATION

Measured signal strength is the initial parameter for the localization. Channel models (COST 231, ECC 131, our optimized multislope log-distance model) were applied to determine the propagation distance. Unfortunately, none of the tested models are precise enough to estimate the exact position applying simple triangulation. Areas like parks, squares, wide streets, and crossroads cause spatial ambiguity and an inaccuracy of the propagation model. Moreover, the relative MS position, reflections and interferences (co-channel, adjacent channel, intersystem) could cause degradation of the measured RxLev value.

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

A. *Geometric Localization Technique*

This technique is possible to apply only in case that the MS have connection 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 the neighboring BS with a line to create the triangle (red lines in Figure 5). Next, divide those lines according to the ratio of the RxLev value. The perpendicular line (green lines) is led through this dividing point of each side of triangle. Intersections of the green lines create a small triangle. The space limited by this triangle defines the possible MS position. Then the final MS position is estimated in the center of the small triangle (the upper red cross on left). The second red cross on the 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 around 300m in an urban environment.

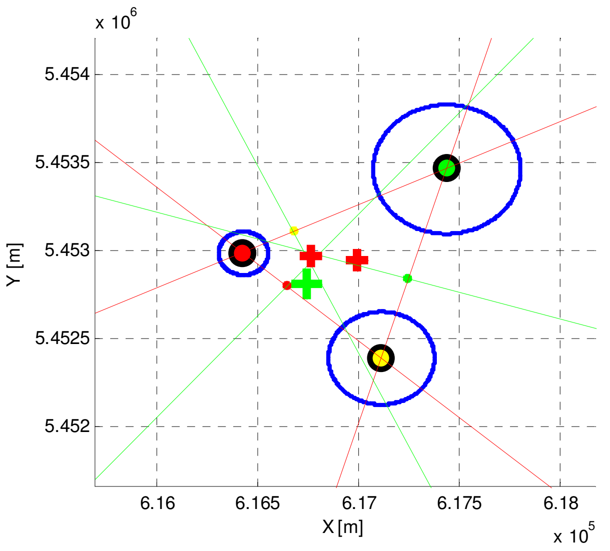

Figure 5. Geometric localization technique (localization error is 165 m). Red lines link BSs and divide them according to the ration of received RxLev. The upper red cross on the left points estimated position, the red cross on the right points the triangle centriod and the green cross points the GPS position.

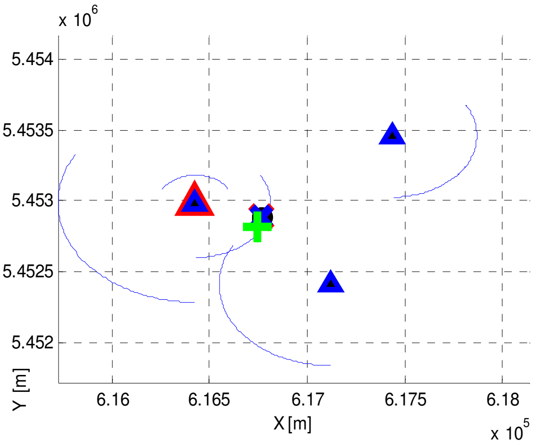

Figure 6. Localization technique with optimization algorithm (localization error is 65 m). The blue arcs describe the modeled propagation distance of received RxLev in connected sectors of BSs. The green cross points real GPS position and the blue cross point the optimized position.

B. Optimization Localization Techniq

This localization technique uses PSO (Particle Swarm Optimization) algorithm to estimate the MS position. In dedicated sectors of the linked BSs (blue triangles in Figure 6) the optimized channel model [9] determines the propagation distance (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 main criteria function computes the criteria value *K* (4) for each of the twelve agents and store one with the minimal value. The stored value is compared with the values received in next loop. A_i represents the distance between the agent position and the modeled propagation distance (the blue circular arcs in Figure 6). A_i is weighted by W_i according to the modeled propagation distance R_i (the higher value of R_i, the higher value of weight W_i). The criteria function *K* for a single agent is described as

$$K = \sum_{i}^{n_{BS}} \left(W_i \cdot A_i \right) = \sum_{i}^{n_{BS}} \left(\left(1 + \frac{1}{(1000 / R_i)} \right) \cdot A_i \right), \qquad (4)$$

where R_i [m] is the modeled propagation distance between the BS and the MS (blue arcs in Figure 6) and A_i [m] is the Euclidean distance between the agent's position and the modeled propagation distance R_i. The n_{BS} is the number of connected BSs. W_i is the weight describing the dependency on the modeled propagation distance R_i.

C. Other Localization Approaches

GSM localization based on measurement of the received signal strength use a fingerprinting approach [11][12]. This approach compares measured or modeled pattern of signal level in the desired area with an actual received value. Instead of determining the MS-BS distance, how it is performed in our approach. Additional improvements of fingerprinting technique are reported in [11] [13]. Achieved localization error was around hundreds of meters. The WLAN (Wireless Local Area Network) localization proposed in [12] has an error of around a few meters.

The localization error (in range of hundreds of meters) of the GSM techniques described in [11][13] is comparable with results obtained by our optimization technique.

VII. CONCLUSION AND FUTURE WORK

We presented the capabilities of localization in cellular wireless networks. We performed measurements of RxLev in the real GSM network in Brno. The post processing of the measured data predicts the propagation distance according to the applied channel model. Propagation models are not capable of involving every individual propagation scenario. Therefore, additional processing is performed to reduce ambiguity. Two localization methods are described and compared.

The first approach is a simple geometric technique. The position is estimated as the ratio of received power from three BSs in the triangle constellation (Figure 5). The positioning error is around 300 m, but it is very strongly dependent on the triangular constellation of BSs. The second technique uses the PSO algorithm (Figure 6). The number

 ISBN: 978-1-61208-193-9

and the relative constellation of connected BSs influence the precision of localization. In some cases, the localization error was in ones of meters. Average error was in tens of meters for scenarios with at least three BSs connected.

We created the database of BSs and stored measured and processed data. We use the CI and the RxLev localization technique. For path loss description, we use the multislope propagation model with optimization adaptation [9]. The mean localization error achieved by the geometric technique was around 300 m, the mean error achieved by the PSO technique was around 80 m. We proved the capabilities of the PSO technique in localization. The results were comparable with approaches presented in [11] [13].

We will focus our further work on a comparison of propagation models for serving and neighboring BSs and improving the optimization algorithm to adapt the size of the searched space. The fingerprinting technique will be considered and involved in the ongoing approach.

ACKNOWLEDGMENT

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. The support of the project CZ.1.07/2.3.00/20.0007 WICOMT, financed from the operational program Education for competitiveness, is gratefully acknowledged.

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