4th INTERNATIONAL CONFERENCE
TRANSPORT SYSTEMS TELEMATICS TST'04

ZESZYTY NAUKOWE
POLITECHNIKI ŚLĄSKIEJ :004
TRANSPORT z.55, nr kol. 657

timing advance, signal strengt ratio, Mobile Station Lcation

Vidmantas LIUTKAUSKAS[1]
Rimantas PLESTYS[2]

USING SIGNAL LEVELS OF OVERLAPING GSM NETWORK CELLS TO ENHANCE THE PRECISION OF POSITIONING

This article presents the approaches of determining the MS location, based on the TA alue and signal strength attenuation. The dependency between the MS location uncertainty and the rad inter-arrangement with the BTS has been analyzed. Signal strength method for positioning th mobile terminals using signal level ratio between base stations is presented. This yields precise result in urban environments and good results in suburban and rural environments.

WYKORZYSTANIE POZIOMÓW SYGNAŁÓW NAKŁADAJĄCYCH SĘ KOMÓREK SIECI GSM DO ZWIĘKSZENIA PRECYZJI POZYCJONOWANIA

Niniejszy artykuł przedstawia sposób określania lokalizacji MS, w oparciu o wartość TA i stłumienie „mocy" sygnału. Przeanalizowano zależność pomiędzy niepewnością lokaizacji MS i wewnętrznego układu dróg z sygnałem BTS. Zaprezentowana została metoda „mocy" sygnału do pozycjonowania ruchomych terminali, wykorzystując stosunek poziomu sygnału pomiędzy stacjami bazowymi. Dostarcza to dokładnych wyników w środowiskach miejskich i dobrych wyników również w środowiskach podmiejskich i rolniczych.

1. INTRODUCTION

In order to offer connectivity for a mobile user in network, the location of the user has to be known. The method of determining MS location, based on GSM network parameters such as Cell-ID and Timing Advance is presented in [1].

While solving the fleeting management problems positions of Base Transceiver Station (BTS) and route of transport are known almost in all cases. During the network planning (for location purposes) it is essential to place the BTS's so, that the maximum mobile station (MS)

[1] Department of Computernetworking, Kaunas University of Technology, Studentu str. 50, LT-51368, Kaunas, Lithuania, vidmantas.liutkauskas@ktu.lt
[2] Department of Computernetworking, Kaunas University of Technology, Studentu str. 50, LT-51368, Kaunas, Lithuania, ktk@if.ktu.lt

location accuracy should be ensured. The article analyzes the origins of location errors and presents the methodology to assess them.

In cases the route is unknown, additional parameters from GSM network are used.

Several methods and parameters for database correlation using signal strength have been proposed or realized for positioning purposes in mobile communication networks [6]. The advantages of these techniques include avoiding accuracy degradation in non-line-of-sight propagation conditions. Any changes in buildings or city infrastructure would imply making new measurements to be included in the database. This turns the method into a costly solution.

In the presented method, the database is constructed from calculated values. The calculations are based on the semi-deterministic model developed in COST 231 [4] for urban areas and on the empirical model according to Hata-Okumura for rural areas [5]. Information about the prediction area as building databases for urban areas is considered as well as digital height models from topographic maps. Starting from [4,5] results, the database can be constructed using information of the whole area segments. The number of the segments depends on TA parameter and signal level variation.

2. LOCATION DETERMINATION METHOD USING TIMING ADVANCE PARAMETER

The method is based on the signal delay in the BTS - MS – BTS loop. It is possible to determine the mobile station (MS) distance from the BTS by applying the TA parameter together with the BTS identity number.

MS distance from BTS is:

$$L_{TA} = 0{,}5 \cdot c \cdot TA \cdot \tau_0 + s \tag{1}$$

where: c- radio wave speed in the air ($c=3\cdot10^8$ km/s.); s – the varying uncertainty part in the interval (s= 0÷550 m).

$$TA = \left[\frac{\tau}{\tau_0}\right] = \left[\frac{L_{TA}}{550}\right] \tag{2}$$

where: τ - propagation delay, s.; $\tau_0 = 3{,}70\cdot10^{-6}$, s – GSM network parameter [2]; [x] – integer part of the whole number x. The resolution of $\tau_0 = 3.70\mu s$ corresponds to the measurement error of 550m.

The first step is to analyze the instance when the MS position is localized from one BTS (Fig. 1). $BTS^{(1)}$ is at a distance of $L_{TA(m)} + s$ from the road AB. The road points marked as K_0^1, K_1^1, ..., K_i^1 correspond to the crossing points for the road AB and TA rings. The TA circle radius L_{TA} was calculated by using (1) under the condition that s=0.

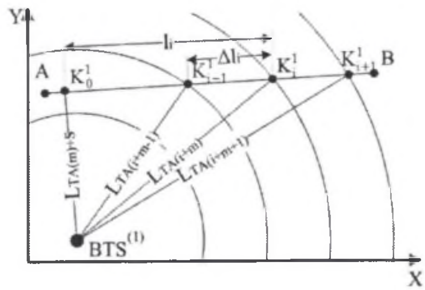

Fig.1. Road crossing with the TA rings

The coordinates for the points K_i^1 (x_{Ki},y_{Ki}), where i=1,2...n, can be calculated foowing the latter methodology [3].

Suppose the A and B coordinates are $A(x_A, y_A)$; $B(x_B, y_B)$, and BTS coolinates are $BTS(x_{BTS}, y_{BTS})$.

Distance between points $K_i^1(x_{Ki}, y_{Ki})$ and $K_{i-1}^1(x_{Ki-1}, y_{Ki-1})$ are:

$$\Delta l_i = l_i - l_{i-1} \tag{3}$$

$$l_i = \sqrt{L_{TA(m+i)}^2 - (L_{TA(m)} + s)^2} \tag{4}$$

$$l_{i-1} = \sqrt{L_{TA(m+i-1)}^2 - (L_{TA(m)} + s)^2} \tag{5}$$

$L_{TA(m)} + s$ - distance from BTS

$$L_{TA(m)} + s = \sqrt{(x_{Ko} - x_{BTS})^2 + (y_{Ko} - y_{BTS})^2} \tag{6}$$

$$m = \left\lceil \frac{L_{TA(m)} + s}{550} \right\rceil \tag{7}$$

$$\begin{cases} x_{Ko} = x_{BTS} + n * k \\ y_{Ko} = y_{BTS} - n \end{cases} \tag{8}$$

$$k = \frac{y_B - y_A}{x_B - x_A} \tag{9}$$

$$n = \frac{y_{BTS} - y_A - kx_{BTS} + kx_A}{1 + k^2} \tag{10}$$

$$L_{TA(m+i)} = 550 * (m + i) \tag{11}$$

$$L_{TA(m+i-1)} = 550 * (m + i - 1) \tag{12}$$

$$\begin{cases} x_{Ki} = x_{Ko} + \dfrac{l_i}{\sqrt{1+k^2}} \\ y_{Ki} = y_{Ko} + k*(x_{Ki} - x_{Ko}) \end{cases} \qquad (13)$$

$$\begin{cases} x_{Ki-1} = x_{Ko} + \dfrac{l_{i-1}}{\sqrt{1+k^2}} \\ y_{Ki-1} = y_{Ko} + k*(x_{Ki-1} - x_{Ko}) \end{cases} \qquad (14)$$

In the case of the GSM network, $i = 1,2...(63 - m)$.

3. CALCULATION RESULTS

Using the presented methodology MS location determination errors with different values are calculated: $L_{(TAm+i)} = 0$, $L_{(TAm+i)} = 100$ ($TA_{(0)}$ + 100m.), $L_{(TAm+i)} = 650$ ($TA_{(1)}$ + 100m), $L_{(TAm+i)} = 5600$ ($TA_{(10)}$ + 100m), $L_{(TAm+i)} = 11100$ ($TA_{(20)}$ + 100m). It should be noted that the smaller is the distance between BTS and the road, the more MS location error decreases. The limit value is Δl_i= 550 m [2] (Fig. 2).

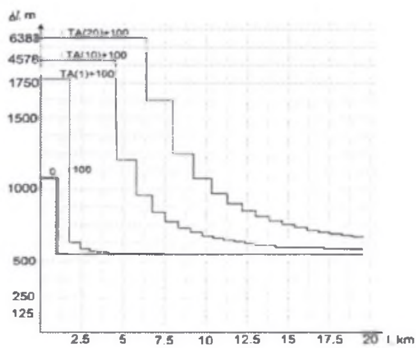

Fig.2. MS location determination error dependency on the road distance to BTS

3. SIGNAL STRENGTH RATIO MODEL

In cases the route is unknown, additional parameters of GSM network are used. This is because of the big error (to 35 km), which occurs when only one TA parameter is used. MS measures the signal level (RxLev) of all the BTSs it can receive, and sends reports via MEAS_REP message to the BTS it is using at that moment. Thus, information about radio signal strength is available in the network. A 5-bit-long, binary coded RxLev value can be converted directly into a receiver-level dBm.

Area is divided into segments. The information about each segment is put into DB. It is taken from the middle point $A_{i,j}$ of each segment.

Fig.3. Dividing area into segments

Each segment is defined by CID_s, which is the identity number of cell-serving BTS, α_1, α_2 - space angles, $RxLev_s$ – the strength of the signal in segment from cell-serving BTS, CID_{n1},..,CID_{nk} – the identity numbers of neighbor base stations, $RxLev_{n1}$,...,$RxLev_{nk}$ – the strength of the signals from neighbor base stations.

$$Z_{i,j} = f(CID_s, RxLev_s, \alpha_{i,j}, \alpha_{i,j+1}, CID_{n1}, RxLev_{n1}, ..., CID_{nk}, RxLev_{nk}) \quad (15)$$

i - means the TA value.

The predictions are based on the semi-deterministic model developed in COST 231 [4] for urban areas and on the empirical model according to Hata-Okumura for rural areas [5].

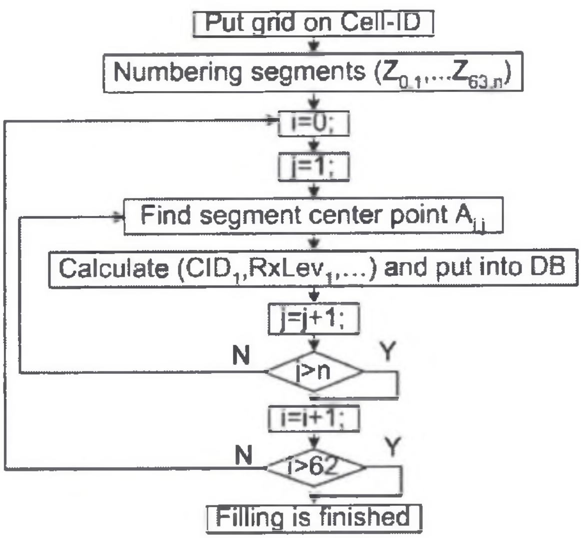

Fig.4. Database filling algorithm

In order to find the centre of the segment $Z_{i,j}$, the direction from base station to this point should be found:

$$\alpha_{i,j} = \frac{\alpha_{i,j} + \alpha_{i,j+1}}{2} \quad (16)$$

ir atstumas iki tasko:

$$l_{i,j} = 550 \cdot i + 275 \quad (17)$$

When DB is constructed, the location of mobile object can be found. During the time period when the mobile phone is active or making the procedures of handover (Call, SMS), we can retrieve the information in the MEAS_REP message. The information contains: CID_{MSs} – serving BTS cell identity number, TA_{MS} – Timing Advance, $RxLev_{MSs}$ – serving BTS the strength of signal at MS place, CID_{MSn1},..., CID_{MSnk} – neighbor BTS cell identity number, $RxLev_{MSn1}$,...,$RxLev_{MSnk}$ - neighbor BTS strength of the signal at MS place.

When the information from the mobile station is received it could be compared with the information in database in order to find MS location segment.

First of all the set of segments where MS could be is found. CID_s should be equal to CID_{MSs}. i is equal TA_{MS}.

So, the set of segments are $Z_{i,1},\dots,Z_{i,n}$.

When the set of possible segments is selected, the data of segments and data received from the MS can be compared. The answer will be the data closest to the received values from the mobile station. But even when the object is in same place, signal level can vary in wide range. In order to reduce the possible error in location, it is advisable to compare the ratio of signal levels instead of comparing the strength of the signals. Inadequacy coefficient is calculated by summing differences of the signal level ratios among corresponding BTS:

$$Coeff = \sum_{p=1}^{k} \left| \frac{RxLev_s}{RxLev_{np}} - \frac{RxLev_{MSs}}{RxLev_{n1}} \right| \quad (18)$$

The coefficient is calculated for all zones $Z_{i,1},\dots,Z_{i,n}$. MS belongs to the zone with the smallest coefficient.

4. THE RESULTS

According to the data received from one of the Lithuania network operators and using HATA formula, the levels of the signals between Vilnius and Kaunas are calculated. The results are obtained in case when $CID_{MSs} = 101$, $TA_{MSs} = 1$ and each sector is of 30 degrees.

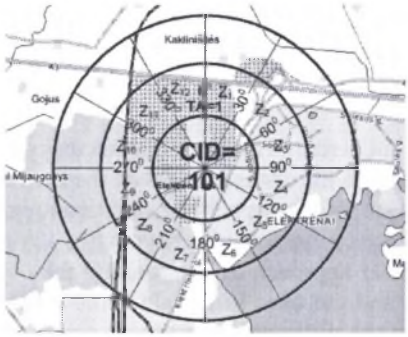

Fig.5. Real zones

The coordinates of serving and neighbor BTS are:
CID_s = 101 (E 24 39 33, N 54 47 16), CID_{n1} = 234 (E 24 40 23, N 54 47 10), CID_{n2} = 287 (E 24 38 50, N 54 46 17), CID_{n3} = 117 (E 24 47 37, N 54 46 29), CID_{n4} = 340 (E 24 41 33, N 54 40 31), CID_{n5} = 214 (E 24 50 43, N 54 54 21).

Table 1

Database fragment of calculated values

CID_s = 101, $RxLev_s$ = 65.4 TA = 1												
CID_{ni}	$Z_{1.1}$	$Z_{1.2}$	$Z_{1.3}$	$Z_{1.4}$	$Z_{1.5}$	$Z_{1.6}$	$Z_{1.7}$	$Z_{1.8}$	$Z_{1.9}$	$Z_{1.10}$	$Z_{1.11}$	$Z_{1.12}$
234	66.89	57.56	52.98	45.93	52.69	63.55	68.04	71.23	72.38	72.38	71.78	69.57
287	75.48	73.48	72.42	72.37	68.26	67.48	63.27	63.27	69.77	71.93	72.57	74.42
117	79.7	79.53	79.35	79.7	80.22	80.55	81.03	81.51	81.96	81.66	81.2	80.55
340	80.61	80.05	79.47	78.99	78.5	77.98	77.98	78.37	78.87	79.47	80.17	80.72
214	84.66	84.74	84.9	85.22	85.45	85.83	85.98	86.06	85.98	85.76	85.37	84.9

All values are in dBm and are negative.

The indications of MS are measured at point E 24 39 49, N 54 47 26.

The results are: CID_{MSs} = 101, TA_{MS} = 1, $RxLev_{MSs}$ = -68dBm, CID_{MSn1} = 234, $RxLev_{MSn1}$ = -59dBm, CID_{MSn2} = 287, $RxLev_{MSn2}$ = -73dBm, CID_{MSn3} = 117, $RxLev_{MSn3}$ = -87dBm, CID_{MSn4} = 340, $RxLev_{MSn4}$ = -90dBm, CID_{MSn5} = 214, $RxLev_{MSn5}$ = -95dBm.

Table 2

Calculated coefficients

	$Z_{1,1}$	$Z_{1,2}$	$Z_{1,3}$	$Z_{1,4}$	$Z_{1,5}$	$Z_{1,6}$	$Z_{1,7}$	$Z_{1,8}$	$Z_{1,9}$	$Z_{1,10}$	$Z_{1,11}$	$Z_{1,12}$
Coeff	0.391	0.216	0.275	0.462	0.276	0.321	0.447	0.480	0.390	0.405	0.406	0.405

After calculating the coefficients, it emerged that the object is in the zone $Z_{1,2}$.

The correct angle is of 43 degrees. So it can be concluded that the location of the object was estimated correctly.

5. CONCLUSIONS

When object is moving in certain trajectory, the accuracy of location estimation using parameter TA varies, depending on the distance between the road and BTS. If the trajectory of object movement is unknown, it is necessary to use additional parameters. The appliance of signal strength parameter can assure more precise results.

Currently the most popular approach of determining the object location is comparison of measured signal strengths and the ones in DB. In some cases this approach causes huge errors which occur because of the different environment conditions and measurement errors. The impact of the environment can be partly eliminated by expressing the ratio of signal levels among the BTS. Often environment conditions impact all strengths of the signals, so the ratio is almost constant. The measurement error is the same for all BTS as well.

BIBLIOGRAPHY

[1] MOVIES IST-2000-30041 Mobile and Vehicles Enhanced Services Location Service Study Report, D2.3.1, 2002

[2] HEINE G., GSM Networks: Protocols, Terminology, and Implementation, Artech House London, 1998.

[3] LIUTKAUSKAS V., LAGZDINYTE I., Approaches of Determining Location of Mobile Station in GSM Network // Elektronics and Electrical Engineering. – Kaunas: Technologija, 2004. – No. 5 (54). – P. 41-46

[4] DAMOSSO E. and CORREIA L. M. (eds.), Digital Mobile Radio towards future generation systems, COST 231 Final Report, COST Secretariat, Brussels, Belgium, 1999

[5] WinProp. Propogation models. Background information. AWE Communications GmbH, 2002

[6] NYPAN T. and HALLINGSTAD O., A cellular positioning system based on database comparison – The hidden Markov model based estimator versus the Kalman filter // Finland. 2002. 1-6 p

Reviewer: Prof. Wojciech Wawrzyński