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RESEARCH ARTICLE

# Cellular Handover Zones as Location Estimators

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***Abstract***

*Mobile communication systems produce gigabytes of mobility information day-to-day on country level, which could be exploited in various Intelligent Transportation System (ITS) applications. This paper presents the basic concept for tracking users based on handover (HO) zone detections provided by the telecommunication network. This concept is able to provide essential information for transportation investigations, moreover it can be used for localization. Since this application requires to understand the potential error sources, the contribution of this paper is to determine these errors and assess their impact on the derived position. For this investigation, we created a data acquisition system, and defined different measurement scenarios, namely, terminal vs. network side data acquisition, idle vs. active measurements, and with using various tracking software, and phone types. These results are compared. To describe the geometric and accuracy properties of the HO zones, point error and error ellipse are used. These metrics have been evaluated on our test data.*

***Keywords***

*handover zone · positioning · mobility · GSM · ITS · LBS*

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## 1 Introduction

Monitoring real-time traffic status is an essential part of the Intelligent Transportation Systems (ITS) to control or intervene [1]. The monitored parameters can be derived from measuring location-based or location-related information (e.g. traffic flow) manually or with various technologies, such as vehicle tracking with video or inductive loops [2]. The reliability of the manually recorded survey data is not satisfactory since the sampling is not representative [3], on the other hand, the installation and maintenance of traffic monitoring sensors are expensive and they may not be available in 24 / 7 (e.g. in case of bad weather conditions). The telecommunication network-based tracking or positioning can provide auxiliary or alternative solutions [4], [5].

This study deals with GSM networks due to its high penetration. Several methods exist for determining positions of terminals in the GSM network, such as Cell-ID with Timing Advance (TA), Enhanced Observed Time Difference (E-OTD), Uplink-Time Difference of Arrival (U-TDoA), and others [6–8]. These methods ensure different accuracy of positioning, and have different costs of deployment and maintenance.

In this paper we will describe a novel method, namely HO zone based location estimation, which has several benefits over current methods: neither requires additional hardware to be installed nor has extra signalling cost to reach the terminals, like in case of E-OTD or U-TDoA [6, 9]; yet it provides more accurate localization compared to Cell-ID with TA based methods. Furthermore, the main advantage of this method is to enable to track road users without their cooperation or consent, thus important traffic parameters can be derived from the thousands of patterns of available mobility data stored by the network.

## 2 Concept

Regarding the GSM concept the terminals – also called mobile stations (MS) – act as measuring devices. Among others they determine the strongest radio signal level of the nearest base transceiver stations (BTS). In connected mode these values are sent to the serving BTS. Based on these measurements the network can decide to change the communication channel of the MS. This process is the so called handover (HO) event and it is specified by the handover protocol [10]. Several HO types exist: some of them reports communication channel frequency changes; others – that is useful for our purpose – reports the changes of the serving cells. The location information can be derived by knowing the typical locations where the MSs change from the old to the new serving cell (i.e. the cell borders). Those points where the cell borders and the roads are intersected each other provide the typical useful HO locations. Since the HO events do not occur at the same position after repeating the same cell transition, we define the HO zone – as a set of HO events – as a geometric area on a road, where active MSs perform HO process from the old cell to the new cell. These objects are characterized with the *geometry, old cell id, new cell id* attributes, where the geometry maps the zone to a particular road, and the cell id uniquely identifies the cell in the telecommunication network. Note that HO zones with same *old cell id, new cell id* can exist with different *geometry*, i.e. different roads intersecting the same cell border (Fig. 1).

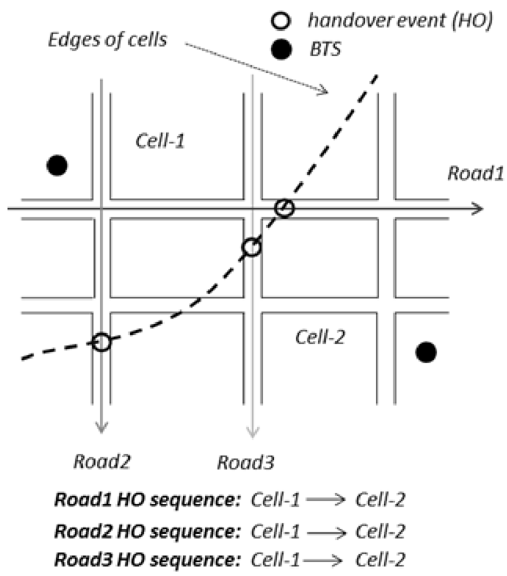


**Fig. 1.** Same HO sequence on different roads

The HO zone method requires to build and maintain a HO zone database storing the attributes described above. The database is created in *off-line phase*, with either by measuring the HO zones, or by calculating them from cell coverage models (cost effective, but less reliable method). In this paper we focus on the first method, namely using cell-phone measurements to build the database. Mobile phone(s) and GNSS receiver(s) are used as measuring tools.

In the *on-line phase*, independent MSs moving in connected mode on a road will generate HO events that can be observed and logged by the network or terminal-side. The location of HO events can be looked up from the database and its anonym location can be provided.

Ideally a handover between two cells on a road should take place deterministically at a certain geographic location, where the signal strength of the new cell is higher than the signal strength of the old cell with a hysteresis value. In a real system, however, the handover, as executed by different MSs on the same road, will take place at different locations, or it can even happen that the handover will not take place at all. Fig 2 shows the measurements of three different MSs, while moving on the same road. The terminal #1 and #3 observe same HO sequences, in contrast with the terminal #2 that logs another cell changes not observed by the two other terminals. The objectives of this study is not to discuss the physical and system engineering causes of this process, yet we accept it when building our model, by defining a HO zone *(directed road, old cell, new cell)* as the convex hull of $n - k$ geographical points of measured HOs, where $n$ is the number of measurements, and $k$ is a number between $[0; n - 1]$ meaning that $k$ measurements did not include the particular zone. In ideal case $k = 0$, and the convex hull is a geographic point.

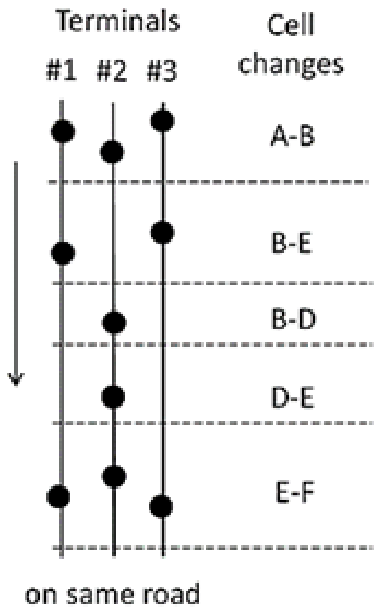


**Fig. 2.** Terminals observe different HO sequences on same road

### 3 Use Cases

HO zones together with live HO stream allow to estimate vehicular travel time on roads. A connected anonym MS, when moving on a road, generates handovers (Fig. 3). One can calculate the speed of an anonym MS: timestamp of HO can be extracted from the signalling events on network side, and the HO location can be looked up from the HO zone database. This approach can be used for traffic flow estimation [14].

Origin to destination (OD) matrix models the flow of moving vehicles and commuters from certain origins to certain destinations during a time period $T$. Having a HO zone database and the HO signaling stream of a certain area (e.g. a city or country), OD matrixes can be built to model the movement of anonym MSs from origin to destination, for example the movement of the commuters in a city during a day, or the incoming anonym visitors from certain districts to a concert stadium [11, 13].

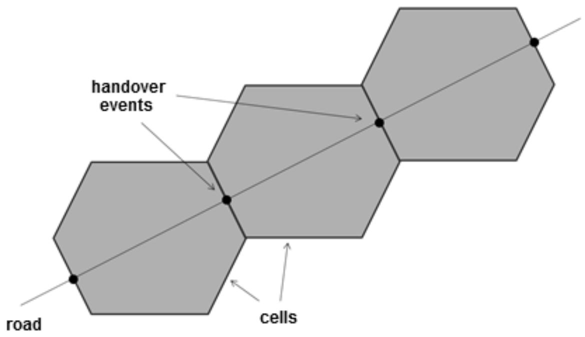


**Fig. 3.** Concept of travel time estimator

### 4 Handover statistics

Handovers are only available from moving terminals in connected mode (i.e. circuit switched call). Appropriate number of HO events is required for certain use cases. For this reason we examined the distribution of HOs in a city. The data set contains all HOs in 24-hour interval that arrived from several MSCs in a large city. From these events 11,195,210 HOs were in GSM and 565,481 HOs were in UMTS network. In GSM network the HO distribution is as follows: 4,367,135 intra-cell, 441,552 inter-cell and 582,187 inter MSC HOs. The rest was unusable for our purpose.

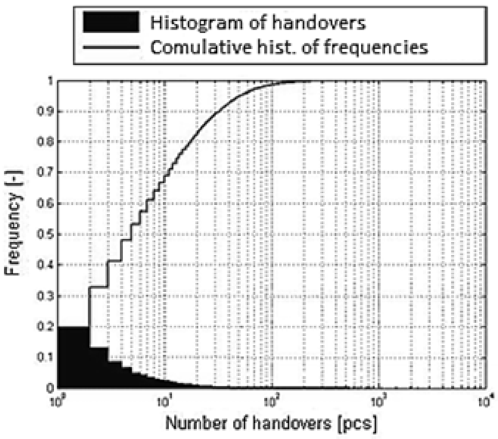


**Fig. 4.** Histogram and empirical CDF of HOs

The histogram and empirical cumulative density function (cdf) of HOs can be seen in Fig. 4. The horizontal axis shows the daily sum of HOs executed by anonym terminals, the vertical axis shows the frequency of certain number of daily HOs. Thus the figure shows the likelihood of HOs' frequencies generated by terminals. Note that most terminals execute less than 110 handovers per day. About 70% of terminals send less than 10 handovers which are unusable for estimating travel time, however, can be useful for OD matrices.

### 5 Measurement system

In this section we describe the measurement system created for assessing handover zones and building handover zone database. It consists of terminals executing GSM calls and GNSS receiver(s). All measuring units have to be synchronized e.g. with Network Time Protocol (NTP). The HO events are tagged with *timestamp, old cell, new cell* triplets, while the GNSS logs *timestamp, latitude, longitude*. Since all devices are time-synchronized, the locations and the HO events can be matched by correlating HO and GPS timestamps. Three different tracking software was used:

- Mobile Quality Analyzer (MQA) is a commercial application developed by Nokia Siemens Networks (NSN). Although the primary aim of this software is to collect data for analyzing the quality parameters of networks, it also allows to observe HO events. The application runs on Symbian, Android, and on iOS. The acquired data is automatically uploaded to a dedicated database.
- CellTrack is a free software running on Symbian OS. The program can log cell changes to the phone's local file system.
- CellIDLogger is a free software running on Android OS. It is available from Google Play. The program is also able to log cell changes to the local file system.

Regarding the locations of the HOs, external GNSS receiver is used for determining the geographic coordinates. Although, many smart phones have built-in GNSS, these devices are less accurate than an external receiver. During positioning in urban areas the urban canyon effect (i.e. tall buildings hide the required view of the sky, thus the geometry of satellites is poor for determining position) can decrease the accuracy. While designing measurements, this effect has to be taken into account. The data acquisition was executed in Budapest, Hungary with various phone brands and OS systems using an external GNSS receiver. The measurements are taken place at one of the highway of Budapest in a populated urban area, but where the chance of detecting urban canyon effect is very small.

### 6 Experimental results

As we introduced earlier, HOs do not happen deterministically at the same geographic location, when repeating measurements. In the following sub-sections we discuss the various factors that can have impact on HO measurements, and thus on successfully building a HO zone database.

#### 6.0.1 Comparison of Tracking Software

Here, HO events on same MS are investigated using two different software: MQA and CellTrack on Symbian; MQA and CellIdLogger on Android. The aim was to validate the reliability of the tracking software. When comparing the results we expected to get the same HO sequence with the same timestamps. However, different terminal software logs HO events with certain delay to each other, and also slight variations in the observed HO pattern may happen. Fig. 5 presents 10 minute measurement executed with a connected Nokia E72 phone, using MQA and CellTrack as tracking software.

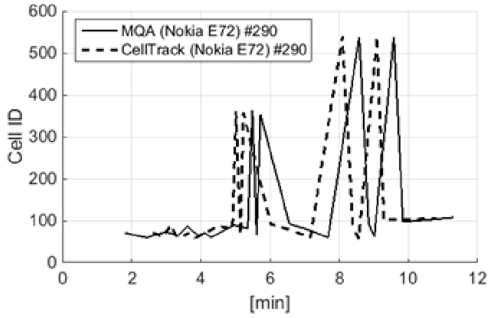


**Fig. 5.** Differences of MQA and CellTrack tracking software on same phones

In the figure the vertical axis shows the time, and the horizontal axis shows the current Cell-ID. The values of Cell-ID were re-quantized for appropriate display which means that the number of horizontal axis is not the same as of the real Cell-IDs, but different numbers represent different Cell-IDs. The transitions on the figure shows the changes of Cell-ID, i.e. HOs. The cell changes of logging software are matched, where the lines overlap each other.

Note the logged cell changes are almost the same but significant time difference can be observed in the figure. These differences are between 2 - 30 seconds, and can result relatively large positioning errors. The differences may due to the phone CPU, memory overload or a software bug, and it shows the drawback of terminal side data acquisition approach.

#### 6.0.2 Comparison of Two Connected Phones on the Same Road

In this experiment, two connected terminals of the same type are used for collecting 15 minutes of data from phones carrying on foot. We compared the HO sequences of the two terminals using MQA logs.

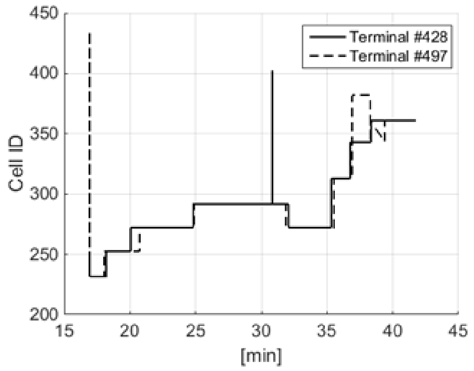


**Fig. 6.** Cell changes of two connected terminals (same type) during the same test

The results can be seen in Fig. 6. It shows that the terminals observed different cell changes. It proves the sequences of HO could be very different even if the same terminal type is used on the same road. Terminal #428 observed 8 Cell-IDs, while terminal #497 observed 10 Cell-IDs. HOs of matching terminals were accepted when timestamps of HO was within 2 minutes. The total number of the same Cell-IDs observed by two terminals was 7. 1 Cell-ID was observed only by terminal #428 and 3 Cell-IDs were observed only by terminal #497. We note larger sample set shows significantly higher differences.

The time differences of the same HO events as observed by the two terminals are also examined. The correlation between terminals is shown by Fig. 7. The linear line represents the ideal case, when the observed cell changes occur at same time (correlation is 1). Discrepancies have been noticed; the average of the time difference is 14 seconds and the standard deviation is 20 seconds, meaning that same handover events occur at different times.

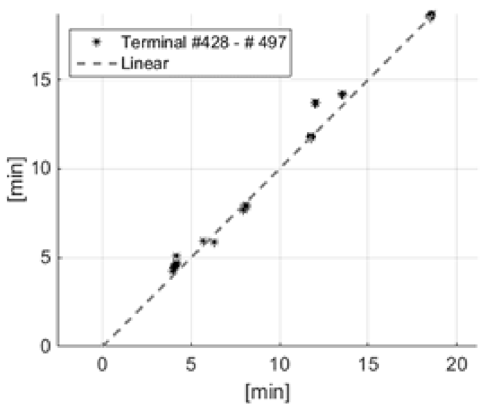


**Fig. 7.** Correlation between same cell changes of same type of terminals on same road during the same test

#### 6.0.3 Comparison of Phone Types

It is important to examine the handover behaviour of different phones due to large variety of phone types. In our experiment two vendors and three phone types were compared, namely Nokia E71, Nokia E51 with Symbian OS and HTC Wildfire with Android OS. The Nokia phones run CellTrack, while the Android phones used CellIdLogger for logging HO events. The measurement took 30 minutes. Results are shown in Fig. 8.

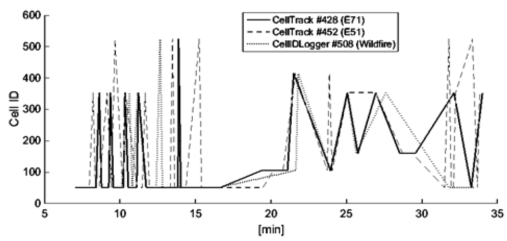


**Fig. 8.** Cell changes of three different types of phones

The figure shows significant differences between terminals. The shapes of the data in the figure show correlation between the terminals, but in several cases at different time the cell IDs are different. The figure also shows time differences for the same HOs as observed by different terminals.

It is interesting to see that the terminal #508 observed the half of HOs detected by the other two terminals. From other measurements it was also found that the tracking software logs significantly less HOs in case of certain phone types. We suspect that the phone hardware (e.g. antenna type) or phone software bug could create such differences. To prove this hypothesis, the comparison of network side and terminal side logs are required.

#### 6.0.4 Network vs. Terminal-side Measurements

In order to use terminal measurements for determining location of HOs in *off-line phase*, it is important to investigate the logs provided by both the terminal and the network simultaneously. If a particular solution correlates network side HO events with HO zones, it proves to use network side logs to build HO zones. For this purpose network and terminal-side logs were acquired in the NSN Test Network. We used six terminals and examined one HO transition eight times between two cells. On the terminal side we recorded HO events using CellTrack and MQA logs, while on network side we recorded MSC logs. We synchronized all terminals and the MSC via NTP. All eight HOs were detected both on terminal and network side. In case of CellTrack time differences were between 0 - 3 seconds (average is 1 second), in case of MQA they were between 2 - 4 seconds (average is 3 seconds). Taking into account the results above this small time difference is promising. On the other hand in real networks other factors may have an influence, such as fluctuating traffic, the effect of multiple cells (our NTN setup contained only two GSM cells), and also the network elements in our test network were NTP synchronized, which may or may not be the case in another operating telecommunication network. These factors may vary the results of terminal and network side comparison.

#### 6.0.5 Comparison of idle and connected phones

The aim of this experiment is to detect whether there are significant differences between idle and connected phone measurements. Idle mode measurements are preferred on terminal side, since it does not have any costs, such as calling bills. But also note that cell changes observed by an idle phone cannot be detected on network side based on the MS cell (re)selection protocol. It means terminals observe all related cell changes, but only HO, as a special cell change, is reported to the network, and it is only triggered when the device is connected.

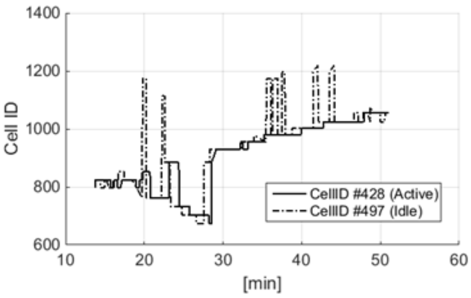


**Fig. 9.** Cell changes of idle and connected phone

Two terminals were used in this investigation, one in connected, and the other in idle mode. The connected terminal logged the HO events while the idle phone logged the cell changes. The measurement took 40 minutes. Results can be seen in Fig. 9. Note that both time and cell change differences are significant. Both terminals observed 14 different cells but the mean of the time difference of same cell changes is 72 seconds, the standard deviation is 31 seconds. This result indicates that the measurements are preferred to be performed in connected mode.

#### 6.0.6 Conclusion of Comparisons

Repeated measurements on a particular road will not produce the same HO locations. Since the number of measurements is limited due to economic considerations, the best available option is to model the HO location as a collection of HO measurement points. Different approaches can be used for measurements (e.g. idle vs. connected, terminal vs. network log, etc.); however, we found that the best results can be achieved by using connected terminals from different vendors, and logging the HO events on the network side.

### 7 Geometric properties of zones

To handle the different HO locations derived from the same cell changes, the HO zone concept has to be introduced. The zones can be created as convex hull of the measured HOs (Fig. 10), thus zones define an area where HO occurs in *off-line phase*. In this section we present two geometry metrics to describe and characterize the accuracy of the HO zones, which metrics are well-known in positioning engineering [12]. Two dimensional hull results when the GNSS error (2 dimensional on a road) is added to the HO measurement error (1 dimensional on a road).

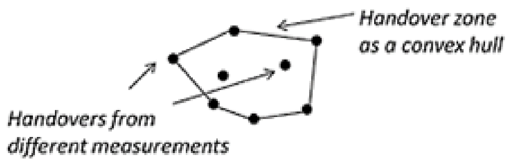


**Fig. 10.** Creation of HO Zone

#### 7.0.7 Error ellipses

2D normal probability density function (pdf) can be determined from HOs which gives the likelihood of locations. In case of our problem it gives the probability of a HO event in a given position. The error ellipse is a horizontal cross-section of this 2D pdf. The probability of a HO event occurred inside the ellipse is 39.4% [12].

Firstly, the covariance matrix has to be determined:

$$\begin{bmatrix} \sigma_x^2 & c_{xy} \\ c_{yx} & \sigma_y^2 \end{bmatrix} \tag{1}$$

where $\sigma_x^2$, $\sigma_y^2$ are variances and $c_{xy}$, $c_{yx}$ are the covariances of HO coordinates. The eigenvectors of covariance matrix give the direction of largest and smallest variance. With these values the implicit equation of error ellipse is as follows:

$$\frac{g^2}{\mu_{max}^2} + \frac{h^2}{\mu_{min}^2} = 1, \quad (2)$$

where $\mu_{max}^2$ ,$\mu_{min}^2$ are the largest and smallest variances and $g, h$ are independent variables. The axis sizes of the error ellipse gives the largest and smallest errors. The error ellipse also provides the errors in any directions.

The test for analysing the error ellipse of the HO zones was conducted on a highway of Budapest using eight measurement rounds with 3 terminals, thus a single HO zone has to contain 24 points in ideal case, when all HO is observed in each round. The database stored 3310 and 420 HO points and zones, respectively. The geographic coordinates of the HO events were measured with an external GNSS receiver. A selected part of the calculated ellipses can be seen in Fig. 11, which is translated to the centre of mass of all HO points. Most cases, the direction of the ellipse correlates with the motion heading. It means that the error of the HO location is significantly larger than that of the GNSS error. This explains the nearly linear shapes of the ellipses. In the direction of the road both the error of HO and GNSS present, whilst perpendicular to the road only GNSS error has impact.

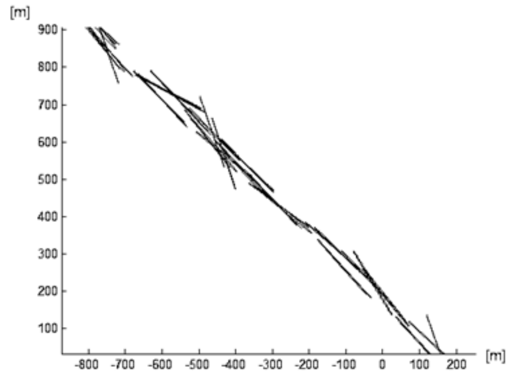


**Fig. 11.** Error ellipses of HOs

Besides the error ellipse, the point error is calculated for defining the accuracy with one single value. This error metric could be calculated from largest and smallest variances with the following expression:

$$P = \sqrt{\mu_{max}^2 + \mu_{min}^2} \quad (3)$$

This value has been determined in case of all zones which has at least 3 HO points. The average of these values is 97.2 meter and the standard deviation is 76.3 meter. The histogram of the point error can be seen in Fig. 12. Note that the point error for most of the zones is typically less than 300 meters. This result also shows that the distribution of point errors is not symmetric Gaussian.

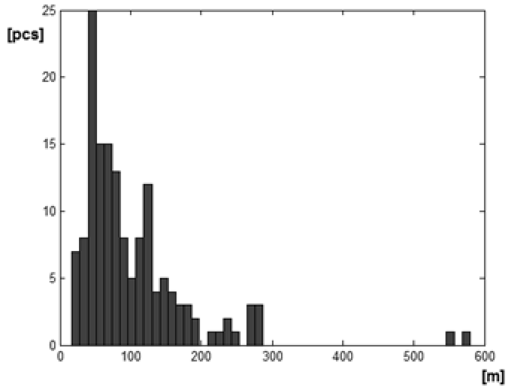


**Fig. 12.** Histogram of the STDs of the HO Zones

## 8 Conclusions

This study presented several examinations regarding the assessment of the accuracy and reliability of the HO zone based localization concept. We found that the HO events do not have deterministic behaviour and depend on various parameters. Even when we used the same phone with the same tracking software on the same road, the generated HO sequences was different on repeated measurement rounds. Thus, it is important to investigate what factors or conditions can have impact on the HO event.For this reason, various types of tracking software are also compared to determine the differences between them. Time and cell differences were detected in all cases, thus using network side data acquisition is required. We also compared various phone types, and found they generate different HO sequences, thus using different types of phones in the *off-line phase* is recommended. If network side measurements are not available, connected, terminal-based measurements have to be applied. Another option can be to use idle phone to log the cell changes via cell reselection mechanism. To detect dissimilarities between these two data acquisition, we compared the phones in idle and connected mode, and the results indicated that even if cell reselection sequences show similarities to HO sequences, differences are also noticeable, thus using connected phones for the measurements are also recommended.

The paper also presented two error metrics to determine the accuracy properties of the zones: the error ellipses of HO zones are calculated for the geometric representation of the positioning error, while the point errors are determined for describing this error with a simple value. Consequently, the HO zone based solution provided approximately 250 - 300 meter accuracy in urban environment for most of the HO zones.

Since the telecommunication system depends on the particular telecommunication network implementation, the results also can vary depending on the implementation. Thus, our tests and examinations are limited. Nevertheless, this study helps estimate the limitations of the HO zone concept in the sense of accuracy and reliability. Our work also presented the most important steps and potential risks in respect of measuring HO zones.

Most of our examinations used terminal side measurements, yet network side measurements in a real network would give interesting insights to the behaviour of the terminals, as seen by the network, and would lead to more comprehensive conclusions. Ultimately, as a future step the UMTS networks could be a potential area to create similar measurements in respect to the handover and cell reselection mechanisms.

## References


1 **Nuzzolo A, Comi A**, *City Logistics Planning: Demand Modelling Requirements for Direct Effect Forecasting*, Procedia - Social and Behavioral Sciences, **125**, (2014), 239–250, DOI 10.1016/j.sbspro.2014.01.1470.

2 **Golarits P**, *Results of a Traffic Flow Survey at New Rural Roundabouts in Hungary, Comparison with Four Leg Priority Junctions*, Perodica Polytechnica Civil Engineering, **40**(2), (1996), 95–102, http://www.pp.bme.hu/ci/article/view/3759/2864.

3 **Toth Z**, *Problems of reliability and exactitude of traffic surveys data*, Perodica Polytechnica Civil Engineering, **46**(1), (2002), 71–82, http://www.pp.bme.hu/ci/article/view/621/376.

4 **Drane C, Macnaughtan M, Scott C**, *Positioning GSM telephones*, Communications Magazine, IEEE, **36**(4), (1998), 46–54, 59, DOI 10.1109/35.667413.

5 **Koppanyi Z, Lovas T, Demeter H, Beeharee A, Berenyi A**, *Tracking Vehicle in GSM Network to Support Intelligent Transportation Systems*, XXII ISPRS Congress, In: **Shortis M** (ed.), XXII ISPRS Congress 2012: Technical Commission II, International Society for Photogrammetry and Remote Sensing ( ISPRS ); Melbourne, Australia, 2012, pp. 139–144, http://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XXXIX-B2/139/2012/isprsarchives-XXXIX-B2-139-2012.pdf.

6 **Kupper A**, *Location-Based Services: Fundamentals and Operations.*, John Wiley & Sons, 2005, ISBN 978-0-470-09231-6.

7 *Digital cellular telecommunications system (Phase 2+); Location Services (LCS); Functional description; Stage 2 (3GPP TS 03.71 version 8.9.0 Release 1999)*, http://www.etsi.org/deliver/etsi_ts/101700_101799/101724/08.04.00_60/ts_101724v080400p.pdf. Technical description.

8 **Deblauwe N, Van Biesen L**, *An Angle Of Arrival Location Estimation Technique for Existing GSM Networks*, Signal Processing and Communications, 2007, In: Signal Processing and Communications, 2007. ICSPC 2007. IEEE International Conference on, Institute of Electrical and Electronics Engineers (IEEE); Dubai, United Arab Emirates, 2007, pp. 1527–1530, DOI 10.1109/ICSPC.2007.4728622.

9 **Green MP, Wang SS**, *Signal propagation model used to predict location accuracy of GSM mobile phones for emergency applications*, 2002 IEEE Radio and Wireless Conference, RAWCON 2002, In: Radio and Wireless Conference, 2002. RAWCON 2002. IEEE, Institute of Electrical and Electronics Engineers (IEEE); Boston, Massachusetts, USA, 2002, pp. 119–122, DOI 10.1109/RAWCON.2002.1030132.

10 *Digital cellular telecommunications system (Phase 2+); Radio subsystem link control (GSM 05.08)*, 1996, http://www.etsi.org/deliver/etsi_gts/05/0508/05.01.00_60/gsmts_0508v050100p.pdf. Technical specification.

11 **Calabrese F, Colonna M, Lovisolo P, Parata D, Ratti C**, *Real-Time Urban Monitoring Using Cell Phones: A Case Study in Rome*, Intelligent Transportation Systems, IEEE Transactions on, **12**(1), (2011), 141–151, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5594641.

12 **Detrekoi A**, *Kiegyenlítő számítások*, Tankönyvkiadó Ltd., 1991.

13 **Tettamanti T, Demeter H, Varga I**, *Route Choice Estimation based on Cellular Signalling Data*, Acta Polytechnica Hungarica, **9**(4), (2012), 207–220, http://www.uni-obuda.hu/journal/Tettamanti_Demeter_Varga_36.pdf.

14 **Wunnava S, Yen K, Babij T, Zavaleta R, Romero R, Archilla C**, *Travel Time Estimation Using Cell Phones (TTECP) for Highways and Roadways*, Deparment of Electrical and Computer Engineering, Florida International University, 2007, http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_TE/FDOT_BD015_12_rpt.pdf.