Localization in Real GSM Network with Fingerprinting Utilization

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Abstract. This paper attempts to present current state in the area of user localization in cellular networks and shows custom solution for positioning using pocket computer and fingerprint method also known as fingerprinting. It operates in Global System for Mobile communications (GSM) network, although fingerprinting is also applicable in other wireless networks, such as Universal Mobile Telecommunications System (UMTS), Bluetooth or 802.11. Implementation is explained and it is compared to existing solutions. The performance of the system is evaluated for various scenarios by statistical characteristics and Circular Error Probability (CEP). The scenarios are proposed from observation of various parameters that influence the localization accuracy.

Keywords: Localization, Positioning, GSM, Fingerprinting method, Circular error probability.

1 Introduction

Location based services (LBS) attract more subscribers every year and number of them is expected to significantly grow over next years [1]. Therefore technologies that provide means to localize devices in unknown environments are interesting for research in order to provide faster, more accurate and generally better results for users.

The only currently operational global navigation system is Global Positioning System (GPS), which provides very good results. The problem with GPS is that users are required to buy new device (GPS receiver) or they have to buy high-end cell phone which offers embedded GPS receiver. Other problem is that GPS basically communicates in one way from satellite to user and other infrastructure is necessary when user needs to transmit some data. To overcome these issues, localization by means of GSM networks is taken into consideration, because GSM is the most used mobile technology with about 80% market share [2] (see Fig. 1) and provides communication between user and network operator as well as communication between users themselves.

Presently used localization methods are based on observation of miscellaneous signal parameters. Methods used in cellular networks are Cell Identification (Cell ID), Received Signal Strength (RSS), Angle of Arrival (AoA), Time of Arrival (ToA) and Time Difference of Arrival (TDoA) [3], [4] and [5]. The research of many specialists has been focused on RSS method [6], [7], [8], [9], [10], [11] which can be then processed using Trilateration technique [12], [13] or Fingerprinting technique [8], [9] and

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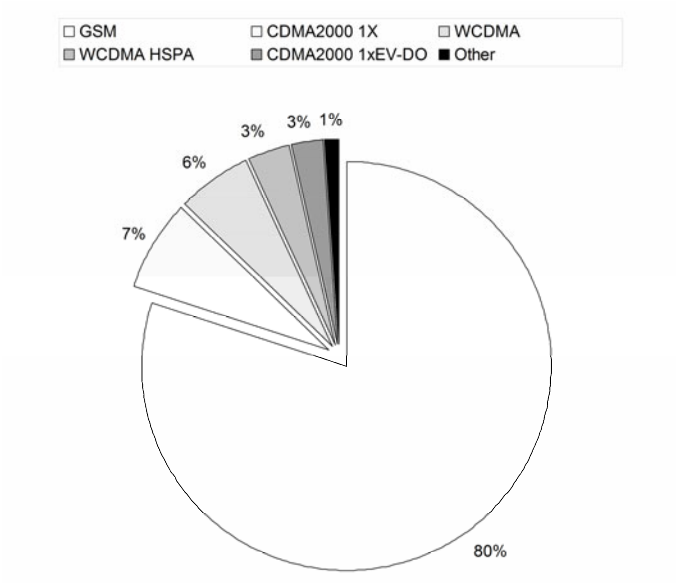

Fig. 1. Present market share of individual mobile technologies

[14]. Fingerprinting seems to be most accurate and affordable technique as it is suitable for Non Line-of-Sight (NLoS) environments as well as it is more immune to multipath than trilateration.

Our fingerprinting solution is based on received signal strength information. Generally, the RSS collection can be performed by either measurement in a real environment or prediction as described in [15]. In first case, it is very time consuming operation, but it is more precise, because real RSS information is used. In the latter case, prediction of RSS is more comfortable, but the data highly depend on a quality of map model of given environment. There is a compromise between the demanding effort and accuracy in [8].

This paper examines the accuracy of positioning system based on the proposed fingerprinting positioning system within a GSM network. Here we focus on an impact of different environments on positioning accuracy. The positioning accuracy is evaluated by median and circular error probability.

The system utilizes GPS coordinates as a reference position during radio map creation. Hence, advantage of the system consists in the fact that results of mobile positioning are presented in WGS-84 (World Geodetic System) and are compatible with GPS and maps based on WGS-84. The radio map is created automatically. The process of map creation is initialized and finalized by a device which performs measurements themselves. GSM and GPS data are measured during this process. When all desired data are measured, they are sent to the server. Some similar systems exist, but they are not based on GPS system [9]. In that case, reference points are marked manually in the map. The other way lies in association of reference points with fixed points, e.g. building, crossing, street, etc. Finally, the most important advantage is that the location system is independent on a network operator. The system only utilizes signals from a network operator.

The rest of the paper is structured as follows. Section 2 introduces fingerprinting phases, which are offline and online phase as well as explains basic GSM infrastructure and integration of fingerprinting into GSM environment. In Section 3, architecture of implemented positioning system is presented. Section 4 introduces experimental scenarios and experiments carried out in this study. In Section 5, the experimental results are presented and discussed. Section 6 concludes the paper and suggests some future studies.

2 Fingerprinting

The fingerprinting method relies on a uniqueness of radio fingerprints in a similar way than forensic science does with human fingerprints. The radio fingerprints are vectors of miscellaneous radio signal parameters such as received signal strength, timing advance or angles. These vectors are coupled with position coordinates and altogether form a database of well known spots, where these parameters are known. Fingerprinting has two phases, so-called offline and online phase, which are described in following sections.

2.1 Offline Phase

The offline phase is a process of radio fingerprint collection at some area and their load into database. For purpose of this work, Cell Identity (CID), Base Station Identification Code (BSIC), Broadcast Control Channel (BCCH) were measured in order to

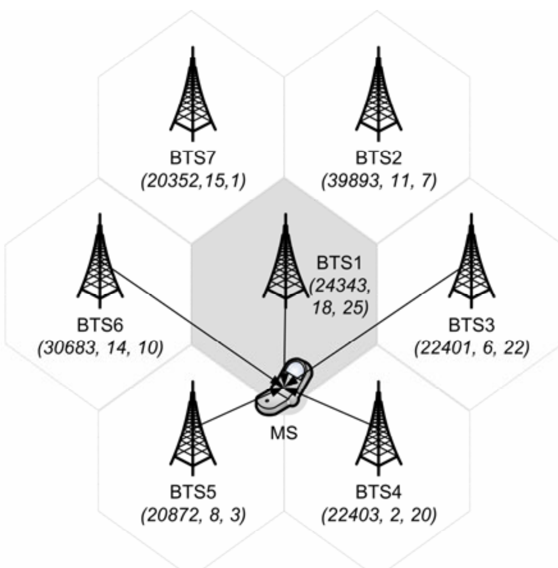

Fig. 2. Sample GSM environment with seven base transceiver stations (*BTS1-BTS7*) and one mobile station (*MS*). Base station identifiers (*the triple in parenthesis under BTS name*) are written in the following order (CID, BSIC and BCCH).

identify Base Transceiver Station, as shown in Fig. 2. At every spot, Received Signal Level (RxLev) of serving and neighbor cells was measured together with geographical coordinates such as latitude, longitude and altitude.

Fig. 2 displays Mobile Station (MS) surrounded by seven Base Transceiver Stations (BTS). The BTS1 is called serving BTS and the other ones (BTS2-BTS7) are called neighbor BTS. MS detects and measures signals from BTS1 and BTS3-BTS6. RxLev from these BTSs then form fingerprint vector. Each BTS is uniquely identified by aforementioned parameters CID, BSIC and BCCH.

2.2 Online Phase

The online phase is process of position estimation using radio fingerprint measured at unknown spot. The fingerprint is then compared to records in the database and by means of correlation the closest matching vector is found. For purpose of this work, Euclidean distance between individual vectors was measured. The closest matching vector is then treated as position estimation. This approach is called Nearest Neighbor (NN) and is the easiest and most common algorithm. Other techniques like K-Nearest Neighbor averaging (KNN), Smallest M-vertex Polygon (SMP), neural networks or Bayesian modeling could have been used as well [16].

3 Architecture of Localization System

Entire system uses fingerprint database as well as central computation server, as shown in Fig. 3. It is designed in service-oriented architecture, which is usable by service providers, such as GSM operators. The system structure allows easy implementation of changes, central maintenance and further optimization of accuracy and performance. It is usable by multiple users, which is one of the basic requirements for a network service.

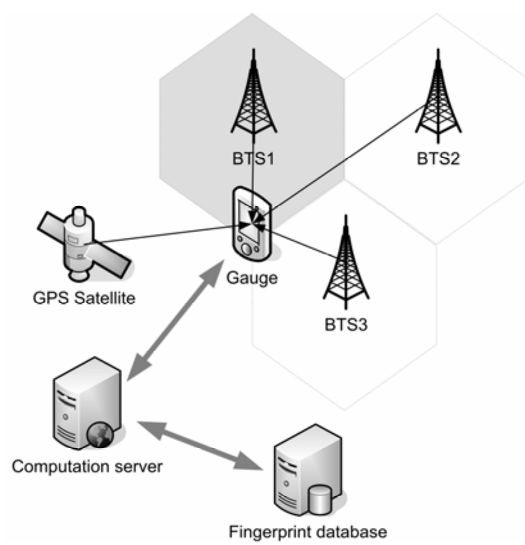

Fig. 3. Architecture of localization system

Gauge is a device that is able to measure necessary data from GSM network. In order to load database over offline phase, it has to be able to measure "precise" position, what is handled by integrated GPS receiver. For purpose of this work, pocket computer HP iPAQ hw6515d with Microsoft® Windows CE® 4.21 and Microsoft® .NET Compact Framework 2.0 were used.

Computation server contains web services that calculate estimated position using fingerprint vector from gauge, fingerprint database and NN algorithm. Furthermore, it also allows visualizing data stored in database utilizing Google Maps™ API.

Fingerprint database stores fingerprint vectors in a way that allows quick data retrieval. Oracle® Express database is utilized for this purpose.

3.1 Localization Algorithm

At first, *measurement* of GSM signals is done. Signal levels of adjacent BTSs and identifiers of these stations are detected. Then the radio map *database lookup* is made and set of interesting spots from database is returned. At third phase, Euclidean *metric calculation* is performed for every interesting spot and the nearest one is chosen as a position match. This is the simplest version of algorithm called NN. KNN, SMP or other techniques could have been used as stated above.

Lookup phase introduces optimization to localization process. After measurement is done, database is queried only for interesting spots, where at least one BS identifier matches current measurement. This reduces cardinality of returned set and speeds up metric calculation and position match processes. Increased performance allows doing more position estimations per time unit.

3.2 Localization Error

The localization error is calculated as a distance between estimated position **E** and reference position **R** measured by GPS. These two points are located on the surface of WGS-84 ellipsoid and difference in the altitudes can be neglected, because all measurements were performed at plain surface. Let γ be an angle between vectors that originate from centre of ellipsoid and head towards **E** and **R**. Let $R(\delta)$ be a function that calculates radius of Earth ellipsoid at geodetic latitude δ. Let lat_E and lat_R be the geodetic latitudes at point **E** or **R** respectively. Then the distance Δ between **E** and **R**, which represents localization error, is calculated as

$$\Delta = 0.5\gamma(R(lat_E) + R(lat_R)). \tag{1}$$

The equation basically calculates length of an arc located on the surface of sphere with radius of mean value between $R(lat_E)$ and $R(lat_R)$. The length is accurate enough for further calculations.

4 Experimental Setup

There were extensive experiments done in outdoor environment. All data were measured in the GSM network. The measurements were performed in three different scenarios by means of above described positioning service. The scenarios differ in environments where experiments were performed:

- scenario 1 - open area, at the edge of the Zilina city, with few movable reflectors (pedestrians, cars) and few buildings,
- scenario 2 - open area, rural part of the Zilina city with not many movable reflectors (pedestrians, cars) and many small houses,
- scenario 3 - urban area, Zilina city centre, with many movable reflectors (pedestrians, cars) as well as many building with various heights.

Database (*offline phase*) was created from received signal levels of the serving cell and up to six neighbor cells. Number of neighbor cells varied and six cells were not always available due to weak received signal. The measurements were performed with above mentioned pocket computer. The device moved at the speed of a pedestrian and it varied from 2 to 3 km/h. Samples were measured once per second. Measurements have been performed at about 2000 spots and carried out almost 14000 measurements per single scenario.

In the phase of localization (*online phase*), ten measurements were taken at 10 different spots for each scenario giving altogether 300 measurements and localization error was calculated for all of them. Then the average of the 10 localization errors was calculated for each spot and resulted in approximate localization error for certain spot. All ten approximate localization errors (for all ten spots) were then used to calculate statistical characteristics, such as median or Circular Error Probability (CEP), for all individual scenarios.

The three environments were purposely chosen because of their different properties. The areas have significantly different signal propagation conditions due to a various numbers of reflectors. Especially movable reflectors have unpredictable impact. For example, reflectors (cars and pedestrians) could have been at the point during process of map creation but not in the phase of localization. This phenomenon has the main impact on the positioning accuracy. The static reflectors should not have significant impact. Therefore it can be said that performance of localization service was validated in the representative samples of environment. The density of spots in database was same for all scenarios, i.e. distance between adjacent spots was approximately 2 meters. The number of used BTSs was no more than seven in all scenarios, but particular BTSs were different. The experiment was implemented in real GSM network which operates in the 900 MHz band.

The reference coordinates of MS position were obtained by means of GPS receiver in these experiments. Thus the final position estimation done by fingerprinting was expressed in WGS84 coordinate system in order to be compared with results from GPS receiver.

The performance of localization service was evaluated by different criteria. These criteria are used because of more general validation of the results. The obtained results are compared by statistical characteristics – median, histogram and CEP. The CEP is defined as the radius of circle that has its centre at the final estimated location and contains the location estimated with probability P_{CEP}.

The applicable positioning accuracy results from particular location based applications. Our results are compared to FCC emergency standard [17]. The standard defines location accuracy and reliability for E-911 calls. Our system is focused on standard for handset-based solution, which requires

- 67 % of all fixes must be less than 50 m from ground truth,
- 95 % of all fixes must be less than 150 m from ground truth.

Therefore, we focused on CEP under probabilities of 67 % and 95 % (marked CEP67 and CEP95).

5 Experimental Results

In the following part we discuss results obtained in three different scenarios by means of localization service described above. The obtained positioning results for all scenarios are shown in Table 1.

Table 1. Localization error vs. scenario

Scenario	*1*	*2*	*3*	*Overall*
Median [m]	16	24	40	27
CEP67 [m]	23	37	49	36
CEP95 [m]	53	68	72	64

According to results shown in Table 1, it can be concluded, that the environment plays very important role in positioning process. The most accurate results were obtained in scenario 1. The median value is 16 meters. The localization error increases with growing number of reflectors. In case of the second scenario the median of error is 24 m. The most inaccurate results were reached in scenario 3, where a lot of movable and static reflectors could be found. The CEP67 and CEP95 values are important for implementation for emergency use. On the basis of the results, it can be claimed that the solution fulfils FCC recommendation for positioning accuracy. Overall results for all scenarios are 36 m for CEP67 and 64 meters for CEP95. These results are obviously under the thresholds (50 and 150 meters).

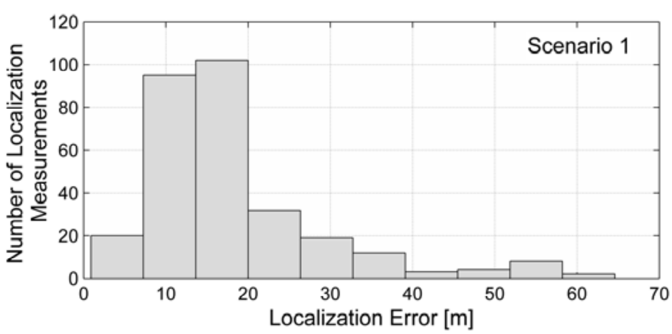

Fig. 4. Histogram of localization error for Scenario 1

Fig. 4 depicts the histogram of localization error for the first scenario. Environment in this scenario is characterized by open area with a very small number of reflectors. Line-of-Sight (LoS) signal propagation is dominant in this scenario. As can be seen in the figure, the majority of localization errors lies between 10 and 20 meters. These are very precise positioning results for GSM cellular networks. On the other hand, we have to note that these are almost ideal conditions. The localization error histogram for the second scenario is shown in Fig. 5.

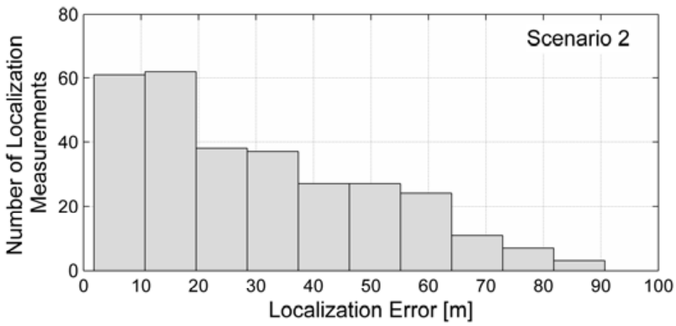

Fig. 5. Histogram of localization error for Scenario 2

According to Fig. 5, there is greater localization error in scenario 2 than in scenario 1. The reason is the different environment, which is characterized as open area with many movable reflectors. The positions of these reflectors are different between offline phase and online phase. We suppose that this fact causes accuracy decrease and increase of number of higher localization errors.

Fig. 6 shows the histogram of localization error for the third scenario. The environment can be described as urban area with many buildings and movable reflectors. NLoS and multipath signal propagation is dominant in this scenario. As shown in Fig. 6 the localization error is more distributed compared to previous scenarios and it is the highest. This is caused by hostile environment. There is significant difference between data from database (radio map) and data measured during positioning.

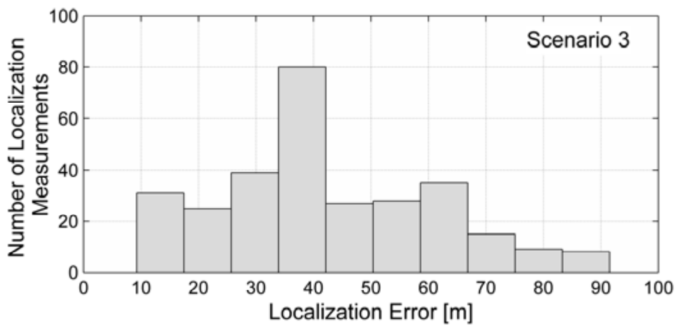

Fig. 6. Histogram of localization error for Scenario 3

Table 2 compares implemented fingerprinting solution with other localization methods in GSM network. It is obvious that fingerprinting provides generally better results than other methods except AGPS used in GSM network. An implementation costs for this method are small, because it is not necessary to modify mobile terminals and radio map could be created by means of sophisticated simulation tool. The positioning results could be also sufficient under precise environment map condition.

Table 2. Comparison of localization methods [18]

Name	*Localization Error*
Cell Identity	100 m – 39 km
Cell Identity + Timing Advance	555 m
Received Signal Strength	100 m – 3 km
RSS + AGA [7]	100 m – 700 m
Enhanced Observed Time Difference	50 – 200 m
Time Difference of Arrival	100 – 200 m
Angle of Arrival	150 m
Fingerprinting	53 – 72 m
Assisted GPS (AGPS)	5 – 30 m

6 Conclusion and Future Works

We proposed and verified positioning solution based on fingerprinting method and GSM. The solution utilizes received signal level information. The proposal is implemented as mobile-assisted positioning. The MS collects the necessary data from surrounding base stations. The measured data are sent from mobile terminal to the localization server for position estimation. The server estimates position and the information about position is sent back to the terminal. Position information is displayed in the map on terminal screen. There is no significant performance at mobile station required to localize itself, because this is handled by servers, which are components of the network.

The experiments were realized in three significantly different scenarios from propagation condition point of view. We can observe hostile shadowing, multipath propagation and almost ideal radio channel on the other hand. Therefore, we can conclude that the performance of the location based service was validated in the representative samples of environment. The obtained results fulfil FCC recommendation for positioning accuracy in emergency calls, i.e. CEP67 is 36 m and CEP95 is 64 meters.

Fingerprinting accuracy can not compete with GPS technology but it can help if GPS signals are too weak. There are various ways for further research and improvements. At first, localization could be improved by using more advanced algorithms such as KNN, SMP, neural networks or Bayesian modeling. Also execution of multiple measurements at one spot and Kalman filtering of input data could have positive impact on positioning accuracy. Secondly, the process of radio map creation could be either replaced by radio coverage model or at least some data could be extrapolated.

At last, system could be extended for indoor localization, however with some necessary modifications in the process of radio map creation.

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References

1. Location Based Services Forecast from ABI Research, http://www.twine.com/item/11djpjdj2-172/location-based-services-forecast-from-abi-reserach
2. GSM Association, Market Data Summary (Q2 2009) Connections by Bearer Technology (2009), http://www.gsmworld.com/newsroom/market-data/market_data_summary.htm
3. Wang, X., Wang, Z., O'Dea, B.: A TOA-based location algorithm reducing the errors due to non-line-of-sight (NLOS) propagation. IEEE Transactions on Vehicular Technology 52(1), 112–116 (2003)
4. Deligiannis, N., Kotsopoulos, S.: Mobile Positioning Based on Existing Signalling Messaging in GSM Networks. In: Proceedings of 3rd International Mobile Multimedia Communications Conference (MSAN), Nafpaktos (2007)
5. Brida, P., Cepel, P., Duha, J.: Mobile Positioning in Next Generation Networks (Chapter XI). In: Kotsopoulos, S., Ioannou, K. (eds.) Handbook of Research on Heterogeneous Next Generation Networking: Innovations and Platforms, pp. 223–252. IGI Global, New York (2008), ISBN 978-1-60566-108-7
6. Krejcar, O.: User Localization for Intelligent Crisis Management. In: 3rd IFIP Conference on Artificial Intelligence Applications and Innovation (AIAI 2006), Athens, Greece, June 07-09, vol. 204, pp. 221–227 (2006), ISSN: 1571-5736
7. Brida, P., Cepel, P., Duha, J.: A Novel Adaptive Algorithm for RSS Positioning in GSM Networks. In: CSNDSP 2006 Proceedings, Patras, pp. 748–751 (2006), ISBN 960-89282-0-6
8. Anne, K.R., Kyamakya, K., Erbas, F., Takenga, C., Chedjou, J.C.: GSM RSSI-based Positioning Using Extended Kalman Filter for Training ANN. In: IEEE Vehicular Technology Conference, Los Angeles, vol. 7(60), pp. 4141–4145 (2004), ISBN: 0-7803-8521-7
9. Laitinen, H., Nordstrom, T., Lahteenmaki, J.: Location of GSM Terminals Using a Database of Signal Strength Measurements. In: URSI XXV, National Convention on Radio Science, Helsinki (2000)
10. Takenga, C., Kyamakya, K., Quan, W.: On the Accuracy Improvement Issues in GSM Location Fingerprinting. In: Vehicular Technology Conference, VTC-2006 Fall, Hannover, pp. 1–5 (2006), ISBN 1-4244-0062-7

11. Nerguizian, C., Despins, C., Affes, S.: Indoor Geolocation with Received Signal Strength Fingerprinting Technique and Neural Networks. In: de Souza, J.N., Dini, P., Lorenz, P. (eds.) ICT 2004. LNCS, vol. 3124, pp. 866–875. Springer, Heidelberg (2004)
12. Hata, M., Nagatsu, T.: Mobile Location Using Signal Strength Measurements in a Cellular System. IEEE Trans. on Vehicular Technology VT-29, 245–252 (1980)
13. Wong, C.L.C., Lee, M.C., Chan, R.K.W.: GSM-based mobile positioning using WAP. In: Wireless Communications and Networking Conference (WCNC), vol. 2, pp. 874–878 (2000)
14. Otsason, V.: Accurate Indoor Localization Using Wide GSM Fingerprinting, Master's thesis, Tartu (2005)
15. Kurner, T., Meier, A.: Prediction of outdoor and outdoor-to-indoor coverage in urban areas at 1.8 GHz. IEEE on Selected Areas in Communications 20 (2002)
16. Kolodziej, K.W., Hjelm, J.: Local Positioning Systems, LBS Applications and Services, pp. 156–157. CRC Press, Boca Raton (2006), ISBN 978-0-8493-3349-1
17. WTB/Policy: FCC Wireless 911 Requirements (2001)
18. Brida, P.: Location Technologies for GSM. In: Proceedings of 5th European Conference of Young Research and Science Workers in Transport and Telecommunication TRANSCOM, Zilina, pp. 119–122 (2003), ISBN 80-8070-081-8