Modular Localization System for Intelligent Transport

Michal Mlynka, Peter Brida, and Juraj Machaj

University of Zilina, Faculty of Electrical Engineering,
Department of Telecommunications and Multimedia, Univerzitna 1, 010 26 Zilina, Slovakia
{michal.mlynka,peter.brida,juraj.machaj}@fel.uniza.sk

Abstract. Positioning is a very important feature due to development of different Location Based Services (LBS). Ubiquitous positioning is the goal that is quite hard to achieve using one localization system. Global Navigation Satellite Systems (GNSS) are widely used in large number of applications. However, they are usable only if there is a line of sight to satellites. This paper deals with Modular Localization System that utilizes existing radio networks infrastructures together with GNSS. The modularity means use of multiple independent technologies that allow determining geographical position in different geographical environments. Modular Localization System which has been designed uses modules based on Global System for Mobile Communications (GSM), Global Positioning System (GPS) and IEEE 802.11b/g standard (Wi-Fi) to estimate the position of mobile device. Smartphones with the Android operating system were chosen as target devices which position will be estimated.

Keywords: Localization, Localization system, Modular localization system, Positioning, Ubiquitous positioning, Intelligent transport system, Android, fingerprinting.

1 Introduction

Localization systems have been used in the many sectors of our life e.g. military, industrial, agricultural and commercial sectors. Application solutions that use these systems are various navigation systems, tracking systems or searching systems (e.g. in warehouses). Wide application possibility of these systems requires their deployment in diverse environments.

There are many localization systems and each has its own advantages and disadvantages. Global Navigation Satellite Systems (GNSS), e.g. Global Positioning System (GPS) offers great coverage area with good accuracy in the outdoor environment. Unfortunately, these systems are not applicable in indoor environment and their accuracy in the urban environment is not as high as in open outdoor environment due to multipath propagation and obstacles in line of sight [1]. On the other hand, localization systems based on the radio fingerprinting method appear to be the most suitable for indoor and urban environment [2]-[5].

There are some systems that allow localization in multiple environments [6]-[8]. These systems require extra infrastructure which is often impractical and financially

A. Bădică et al. (eds.), *Recent Developments in Computational Collective Intelligence*, Studies in Computational Intelligence 513,
DOI: 10.1007/978-3-319-01787-7_11, © Springer International Publishing Switzerland 2014

demanding. For these reasons a modular localization system is propose in this paper. This system is designed for use in a multiple environments by using the existing infrastructure and widespread smartphones. This function is achieved by its individual modules.

The paper is structured as follows. Section 2 deals with the architecture of proposed system. Section 3 contains information about used localization methods. Software solution for a mobile device is described in the Section 4. Test scenario is depicted in the Section 5. The Section 6 concludes the paper and presents some ideas for the future work.

2 Modular Localization System

On the basis of the previous research, the modular localization system was developed [8]. Proposed modular localization system is designed to maximize the coverage of the localization service. This was reached by utilization of the different radio networks which work with the different radio frequency. The example is shown in the Fig. 1.

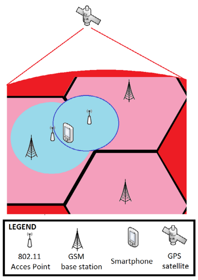

Fig. 1. Example of modular localization system

Logical model of the system is depicted in the Fig. 2. Model of the proposed system consists of the three layers. The lowermost layer consists of the individual localization modules. Openness of the system has been ensured by this layer. Openness means that the system has the ability to add new modular localization blocks e.g. existing GNSS or modules based on radio networks.

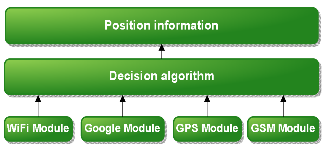

Fig. 2. Logical model of Modular localization system

Smartphone with Android platform has been chosen as a device which position will be estimated. Smartphone with Android is the world's most popular mobile platform. The application of the positioning system has been developed through the Android software development kit (SDK) [10] – [12]. Almost all Android smartphones have integrated GSM, GPS and Wi-Fi chipsets. Based on these facts, four modular localization modules have been implemented. These modules are described in Section 3.

The second layer includes the decision algorithm. The task of this layer is to determine which position estimate will be provided to the user. This decision is based on predetermined criteria. Flowchart of the used decision algorithm is shown in the Fig. 3.

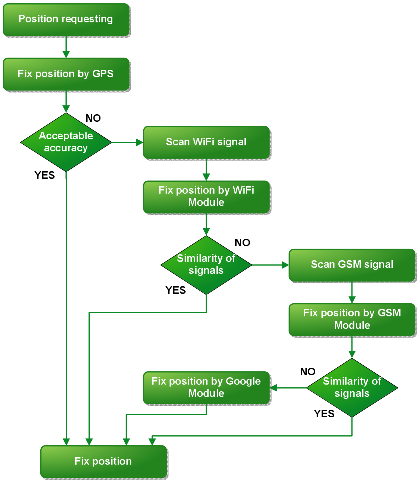

Fig. 3. Diagram of decision algorithm

The decision algorithm has been designed to work with multiple position information. Role of the algorithm is to determine which position information is the most reliable. If the position determined by GPS has acceptable accuracy, it is rated as the most reliable. The acceptable accuracy of GPS module can be set by user. In general, today's smartphones offer GPS accuracy of 4 m in open area. In the dense urban area the positioning error can rise up to 20 m or even more. When accuracy is not acceptable or there is no GPS signal, the algorithm prefers the position information obtained by Wi-Fi localization module. If it is not possible to estimate position of the mobile device using the Wi-Fi module, position information obtained by the GSM localization module is used. There may be situations when both Wi-Fi and GSM localization modules cannot determine the position estimate (e.g. there is no similarity between the actual measured signals and signals stored in the database). In this case, the Google module can be used.

The top layer is Position information. This layer ensures view of the estimated position of user on the map. Also, it can give all radio signals and position information which has been obtained by Decision algorithm layer, to the user. These can be used for environment analysis during the deployment of the localization system.

3 Localization Modules

The system consists of the several localization modules as shown in the Fig. 2. These modules are designed to ensure ubiquity. The particular localization modules are described in the following paragraphs.

3.1 GPS Module

GPS module is based on the GPS space satellite navigation system that provides location and time information. This service, was made available to civilians in 1996 for navigation purposes, it is free of charge. GPS can support an unlimited number of users, and may provide position estimates anywhere in the world. To obtain a location, there is necessary an unobstructed line of sight between the receiver to the satellite. The accuracy of the position estimate depends on the number of used satellites and satellite geometry. The achieved accuracy by the smartphone GPS chipset can be in the range of 4 m in the open outdoor environment. In the urban environment the accuracy can significantly decrease [1], [12].

3.2 Wi-Fi and GSM Modules

Wi-Fi and GSM modules are based on radio fingerprinting localization method. Fingerprinting algorithms consists from two phases. First phase is the offline phase (also called calibration phase). In this phase the radio map is created and stored in the database on the localization server. The second phase is called online phase, in this phase position of mobile device is estimated.

Offline Phase

Area where localization services will be offered is divided into small cells. Each cell is represented by one reference point. Reference points are represented by geographic coordinates. Information about Received Signal Strength (RSS) values from all APs (Access Points) in range are measured at each reference point. Element of radio map has the form:

$$P_j = (N_j, \alpha_{ji}, \beta_{ji}, \theta_j), j = 1,2..., m; i = 1,2..., n, \quad (1)$$

where N_j is number of j-th reference point, m is the number of all reference points, i is number of AP, n is the number of all APs, α_{ji} is the vector of RSS values, β_{ji} stands for the identifier of APs and parameter θ_j obtains additional information which can be used during the localization phase.

Values β_{ji} are tagged by Media Access Control (MAC) address and Cell identity (CID) for Wi-Fi and GSM networks, respectively [2], [3], [13]-[15].

Online Phase

During the online phase the server uses a deterministic nearest neighbor algorithm to estimate the location of mobile devices. Actual measured RSS values received by smartphone are compared with the values P_j stored in the database using the Euclidean distance. Euclidean distance represents the shortest distance between two vectors in Cartesian coordinate system and is defined by:

$$d_{Eij} = \sqrt{(\sum_{k=1}^{n} a_{ik} - b_{jk})^2} \qquad (2)$$

where n is number of elements in vector, a_{ik} represents k-th element of vector A and b_{jk} represents k-th element of vector B. Position of the reference point with the smallest Euclidean distance is considered as the estimated position [2], [3], [13]-[15].

3.3 Google Module

Android SDK includes localization library which offers localization of a mobile device by network provider function. This function determines the location of mobile device based on availability of cell tower and Wi-Fi AP. Results are retrieved by mean values of a network lookup. This module does not provide high accuracy. On the other hand, this module provides localization in unknown urban environment [8], [12].

4 Developed Software Solutions

For our experiment an application to Android smartphone has been developed. With this application, the user can create radio maps of Wi-Fi and GSM signals. Later, based on this map, the position of a user may be estimated using Wi-Fi or GSM localization modules. Real position on the map, which is needed for offline phase, can be specified by touch of user finger or given in the World Geodetic System 1984 (WGS 84) coordinates as well. The application enables to calculate distance between points. Currently measured data can be stored to the text file for later analysis [10], [12], [16], [17].

The application can offer multiple position estimates. This feature allows investigating the accuracy of the individual modules in different environment. The red color shows the position estimate obtained by GPS, blue by Google network provider, green by Wi-Fi, cyan by GSM. Information about obtained positions is shown in top left corner as is showed in the Fig. 4. It is also possible to monitor information about the current GSM and Wi-Fi radio signal.

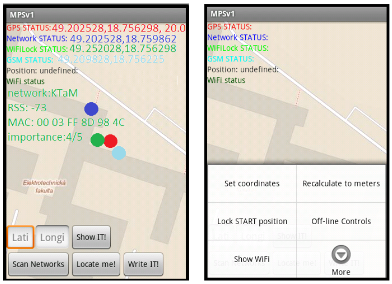

Fig. 4. The screen of developed application

As outdoor maps, OpenStreetMap (OSM) by MapQuest Android API has been used. These maps are open and freely available [16].

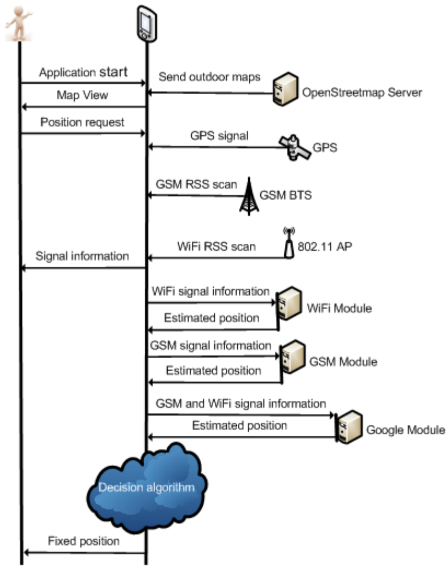

Fig. 5. Sequence diagram – fixed position by smartphone

In the Fig. 5 sequence diagram is shown. This diagram describes how the position of mobile device is estimated by the proposed modular localization system in the time domain.

5 Experimental Scenario

Experimental scenario was performed at the University of Zilina campus. As shown in the Fig. 6, area near the buildings was chosen. In this area poor GPS coverage was expected.

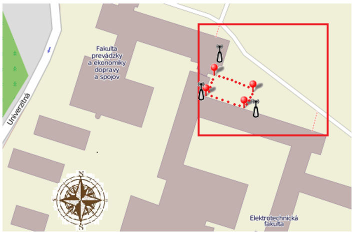

Fig. 6. Experiment area – University of Zilina

Examination area has size of 22x16 meters. Measurements during the offline phase were performed in a grid, with points spaced 2 m apart. Existing radio infrastructure with three added AP was used. 18 APs and 11 BTSs were totally used. Measurements were performed using smartphone HTC Legend. The Fig. 7 depicted how radio map was created. The first, geo-points in chosen area were selected. These geo-points were targeted by Trimble VX [18]. The chosen method does guarantee targeting points with accuracy of 4 cm. In each of the targeted points with poor GPS signal, Wi-Fi and GSM radio signals from nearest APs and BTSs were measured. These measurements were sent to the localization server and stored in the radio map database.

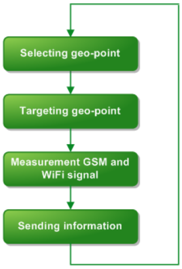

Fig. 7. Process of radio maps creating

After creating the radio maps, accuracy of the localization modules were tested. To evaluate the accuracy of individual localization modules 100 position estimates were performed. Accuracy of a given localization module was obtained as the distance between the real (positions obtained by Trimble VX) and the estimated positions. This distance has been obtained by Vincenty formula. Vincenty formula is commonly used in the geodesy to calculate the distance between two geo-points in WGS 84 system. Mean values of localization error for the individual modules are shown in Tab. 1.

Table 1. Average localization error of the different modules

Module	GPS	Wi-Fi	GSM	Google
Accuracy [m]	26.31	4.82	5.32	69.89

The cumulative distribution functions (CDF) of the accuracy of individual modules are shown in Fig. 8-11.

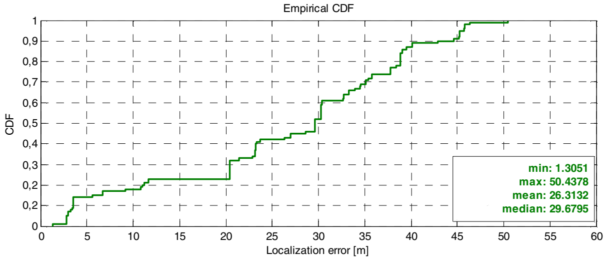

Fig. 8. CDF accuracy of GPS module

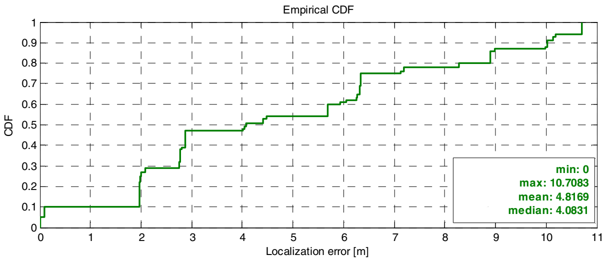

Fig. 9. CDF accuracy of Wi-Fi module

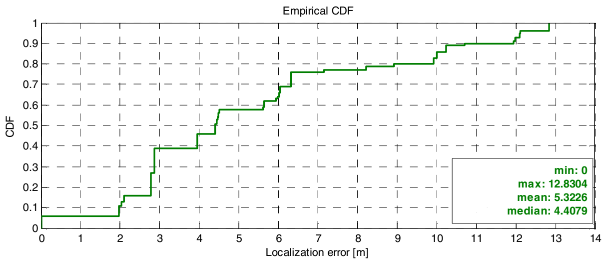

Fig. 10. CDF accuracy of GSM module

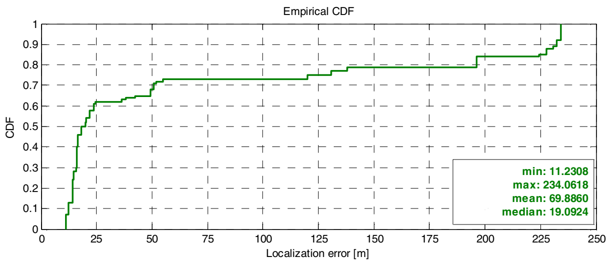

Fig. 11. CDF accuracy of Google module

As shown in Fig. 8-11, GPS accuracy in chosen area wasn't acceptable. GSM and Wi-Fi modules offer better accuracy and they seem to be more suitable. This phenomenon was due to good radio infrastructure. Google module doesn't offer good accuracy but it is usable without needs of offline phase.

6 Conclusion and Future Works

From results shown in this paper it is clear that localization by GNSS (e.g. GPS) is not always the best solution. On the basis of achieved results it can be assumed that Wi-Fi and GSM modules offer better accuracy near the buildings and are important part of modular localization system. Of course, this accuracy depends on the network infrastructure in examined environment, used algorithms, propagation conditions, etc. Google module does not offer good accuracy but this module allows localization in situation when there are no GPS signals and radio maps for other modules are not created. Proposed modular localization system offers higher accuracy and the ability to estimate position in a diverse environment. Whereas that system uses the existing infrastructure, introduction of this system is not financial expensive.

Proposed system increase the accuracy of the position estimates, but the most important is the fact that the system allows localization in areas where GNSS fails. Openness and modularity enable localization in the both outdoor and indoor environment simultaneously.

For future work there is idea to implement new localization modules. New localization module can be represented by existing satellite navigation systems (e.g. Galileo, GLONASS) or by localization based on the utilization of radio networks e.g. DVB-T, FM radio, etc. The introduction of new modules may not require hardware modifications.

Another part which offers improvement the accuracy of the estimated position is decision algorithm. There can be added logic which will work with prediction information (e.g. Kalman Filter).

Acknowledgements. This work has been partially supported by the Slovak VEGA grant agency, Project No. 1/0394/13 and by

„Broker centre of air transport for transfer of technology and knowledge into transport and transport infrastructure ITMS 26220220156"

We support research activities in Slovakia/Project is co-financed by EU

The authors would also like to thank Ing. Juraj Mužík, PhD. and Ing. Andrej Villim, University of Žilina, Faculty of Civil Engineering, Department of Geodesy, Žilina, Slovakia, for their help to target geo-points with Trimble VX.

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