LAPPEENRANTA UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF INFORMATION TECHNOLOGY

DETERMINING THE LOCATION FOR A MOBILE DEVICE BY UTILIZATION OF LOCAL RESOURCES OF THE ENVIRONMENT

The topic of the Master's thesis has been approved by the Department Council of the Department of Information Technology on 15.01.2009

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Lappeenranta, March 10, 2010

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ABSTRACT

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Determining the location for a mobile device by utilization of local resources of the environment.

Master's thesis.

2010

84 pages, 26 figures and 5 table.

Examiners: Professor Jari Porras
M.Sc.(Tech) Bishal Raj Karki

Keywords: Positioning system, coordinate based locations, Maemo, context awareness, user location.

The subject being analyzed of this Master's Thesis is a development of a service that is used to define a current location of a mobile device. The service utilized data that is obtained from own GPS receiver in some possible cases and as well data from mobile devices which can be afforded for the current environment for acquisition of more precise position of the device. The computation environment is based on context of a mobile device.

The service is implemented as an application for communicator series Nokia N8XX. The Master's Thesis presents theoretical concept of the method and its practical implementation, architecture of the application, requirements and describes a process of its functionality. Also users' work with application is presented and recommendations for possible future improvements are made.

TIIVISTELMÄ

Lappeenranta Teknillinen Yliopisto
Tietotekniikan osasto

Andrey Naralchuk

Diplomityö: Kannettavan laitteen paikantaminen paikallisessa verkkoympäristössä

2010

84 sivua, 26 kuvaa ja 5 taulukkoa.

Tarkastajat: Professori Jari Porras,
Bishal Raj Karki

Avainsanat: Paikannusjärjestelmät, käyttäjän paikantaminen, Maemo, kontekstitietoisuus.

Tämän diplomityön aiheena on kannettavan laitteen paikantaminen paikallista verkkoympäristöä hyödyntämällä. Paikantaminen toteutetaan GPS-vastaanottimen ja muiden verkkoympäristössä olevien laitteiden lähettämän paikkatiedon perusteella.

Tässä työssä esitetään paikantamiseen käytettävä menetelmä, käytännön toteutus ja sen arkkitehtuuri, paikantamiseen liittyvät vaatimukset ja rajoitteet sekä tulevat kehitysmahdollisuudet. Paikantamiseen käytettävä ohjelma toteutettiin Nokia Communicator-matkapuhelimelle Maemo-käyttöjärjestelmälle.

FOREWORD

Sincerely, I want to thank for my supervisor Professor Jari Porras and the second supervisor M.Sc. (Tech) Bishal Raj Karki for their exhaustive guidance on this Master's thesis.

An individual thanks for people who organized IMPIT program and especially for International Officer Riitta Salminen.

I am also very appreciating for my friends: Tanya Petrova, Matylda Jablonska, Rustam Jemurzinov, Otso Lonka, Ivan Martynov, Alexey Denissov and many other people for advices, critics and help for the experimentation part.

I also wish to thank my parents. They were helping me to study of moral support and pick me up.

In Lappeenranta, Finland, 10th of March 2010

Andrey Naralchuk

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ABBREVIATIONS

2G	Second Generation of mobile cellular networks
3G	Third Generation of Mobile cellular networks
Advanced TDMA	Advanced Time Division Multiple Access
AS	Anti-Spoofing
ACL	Asynchronous Connectionless Link
CDMA	Code-Division Multiple Access
Digital AMPS	Digital Advanced Mobile Phone System
DGPS	Differential Global Positioning System
ICMP	Internet Control Management Protocol
IEEE	Institute of Electrical and Electronics Engineers
IUCAF	Scientific Committee on Frequency Allocations
FDMA	Frequency Division Multiple Access
GLONASS	GLOBal’naya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GSM	Global System for Mobile
GPS	NAVSTAR Global Position System
GUI	Graphical User Interface
HLR	Home Location Register
MB	Mobile Device
MS	Mobile Subscriber
MSC	Mobile Switching Center
OFDM	Orthogonal Frequency-Division Multiplexing
OTDA	Time Difference of Arrival Method
PDC	Personal Digital Cellular
SA	Selective Availability
SAI	Serving Area Identification
SGSN	Serving GPRS Support Node
TCP	Transmission Control Protocol
UDP	User Datagram Protocol

UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
UWC-136	Universal Wireless Communications 136
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiplexing Access
WBFH	Wide-band Frequency Hopping
WLAN	Wireless Local Area Network

1. INTRODUCTION

Application functionality and decently formed interface are key drivers for being able to build competition on a market. The task of providing these for mobile devices having limited computational ability, small screen and keyboard is more difficult than implementing on desktop personal computer. In efforts to improve functionality, mobile devices are becoming more intelligent and can adapt to changing situations.

There exists a big amount of applications designated to provide some service on the basis of current location of mobile device. The location can be determined in a few ways: user points the location by himself selecting a point on the map; existence of an internal receiver of NAVSTAR Global Positioning System (GPS); usage possibilities of other devices from environment of the reference mobile device.

In that way the given Master's thesis relies on an idea that location of mobile device can be determined on the basis of surrounding environment. The environment must have mobile or static devices; whose locations are known within a global frame and are capable to communicate. It can be: mobile phone base station, a mobile device with internal receiver of global positioning or receiver of global positioning that has communication abilities. These facts allow creating facilitative environment for determination of a location of any device having communication abilities.

The feature of this Master's thesis is utilization of the paradigm of context awareness because there exists necessity of interaction between different types of devices and those devices must be able to adapt themselves by setting up on the assumption of current mobile and computing environment.

1.2 Context

There are a lot of context definitions which have shortcomings. The most widely accepted and generalized definition of a context was made by Dey. He defined term of context as 'Any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves.’ [1]. Context awareness is given as following ‘A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task.’ [1]. Also context-awareness and context was explained as ’Context aware-computing is not something that will be driven by preexisting information about users and places: context isn't just, or primarily, derived by looking up a bunch of formal attributes in a database. Rather, context should be seen as a function of interaction between users/objects and environment, and a consequence of focus or attention.’ [2].

Context information can be generalized by several groups based on relevance to the object. Objects are: user, device, application or environment. Utilization of the context information is divided by ePerSpace [3] to the following groups:

- Environmental context (properties of surrounded physical environment such as temperature);
- Personal context (describes user’s characteristics such as blood pressure);
- Task context (features of an application such as event);
- Social context (as example the relevance to social networks can be presented in context);
- Spatio-temporal context (describes features such as time, location and so on);
- Device context (presents description of the state of device such as battery level);
- Service context (describes specifics of the service representation);
- Access context (permission ability to a network can be convolved to context).

1.3 Context service

An example is demonstrated for understanding context service. Let us assume that the user of an application for a mobile music player aims on listening to music. But in same case, the type of the music can be varied and changed according to the time of day of the user and his current employment status. In the morning the user prefers listening to pop music, during the dinner he turns on the jazz and at evening he chooses rather classical music. Therefore, the player must select a different song list on the assumption of time. As additional parameter for type of music, a variety of current activity of the user may be served. Illustrating some of statuses, following examples are given: during substantial physical work, on leisure time, on the walking way with a dog and so on. This example unequivocally demonstrates the usage of environmental and spatio-temporal contexts. In this Master's thesis the environment, device and access contexts will be utilized in such a way that abilities of the device, abilities of the current environment and networks can be involved successfully.

1.4 Research question and structure of the Master's thesis

The task for this Master's thesis is to develop practical implementation that is capable of showing information about current location of a mobile device in a global frame. The information may be characterized as a service for users of the reference implementation. The scientific question that has to be answered by this Master's thesis is: "How to define location of mobile device based on environment in which the device is?". To answer this question, the thesis establishes aims in front of itself: development of technique and application which is providing definition of location. As a result, a user of the application that implements this technique can see a location on the map with discussed value of accuracy.

The structure of this Master's thesis is formed in terms of necessity for providing clear answer to the formulated scientific question. Thus the thesis is divided into theoretical and practical parts. The theoretical part begins from section 2. It tells about types of mobile devices, investigates information about location presentation in details, existing mobile networks, their properties and how they can be utilized for presenting necessary services.

Section 3 presents existing techniques for location definition and describes features of their applications. Section 4 discusses on problems met in location definition techniques and possible ways to solving or reimbursing them. Section 5 introduces an analysis of data resulting from realization of experiments with mobile devices to prove theoretical ideas and builds a conclusion about theoretical part.

Section 6 introduces practical part of the thesis. It presents description of the technique, a selection of facilities for its accomplishment, functional and user's requirements for the system, architecture of the application and a principle of operation. Section 7 presents the implementation process by describing specific aspects and testing process. Section 8 makes a conclusion about the whole work and presents possible ways for future improvements.

2 SOURCES OF INFORMATION

Sources of context information in borders of environmental, spatio-temporal, device and access contexts are directed in subject area of this chapter.

For successfully implemented main function - provision by location information, developing software must be informed about equipment where the application is being run; networks that can provide access; characteristics of this access as well as information about nearby devices and their abilities. Context of mobile device will be utilized to choose the most optimal strategy of behavior to propagate presumptive location.

In conjunction with afore mentioned information, available sources will look as follows:

- GSM/CDMA networks – cell based location definition;
- Wireless – environmental based location definition;
- Bluetooth - environmental based location definition;
- GPS – satellite based location definition;
- External devices – different types of sources.

External devices (for example mobile device with some connection of external GPS receiver) are not considered in this Master's thesis.

2.1 GSM/CDMA networks

A starting point might be Second Generation of mobile cellular networks (2G) that helps understanding the main idea in building of location service systems [4]. 2G is presented into four standards: Global System for Mobile (GSM) communications and its derivatives, Digital Advanced Mobile Phone System (Digital AMPS), Code-Division Multiple Access (CDMA) and Personal Digital Cellular (PDC). These standards have been developed for Pan-European standard and spread over the world. This generation was built on low range voice and data transfer and had been improved by inserting additional enhancements. These enhancements were named as 2.5 Generation and sometime they can guarantee facilities of Third Generation of Mobile cellular networks (3G) systems. Basic GSM provides 9.6 Kbps capacity but some additional improvements let achieve up to 14.4 Kbps that have not been used commonly [5].

The next solution of General Packet Radio Service (GPRS) allows achieving 115 Kbps of capacity [4, 5]. GPRS is considered as the big step for increment of bandwidth and utilization of resources. The most important breakthrough is that it is a packet transmission. Universal Terrestrial Radio Access (UTRA) interface and enhanced GSM core networks are the basement for this generation [4].

Nowadays the 3G has been used commonly already in developed countries. The sellers of mobile services have almost completed the upgrading of mobile network stations to correspond to the 3G standard. 3G networks have several directions for improvement of the systems that have been deployed. The base technology of deployment defines criteria for their definition: Wideband CDMA, Advanced Time Division Multiple Access (Advanced TDMA), Hybrid CDMA/TDMA, and Orthogonal Frequency Division Multiplexing (OFDM).

The capacity of Wideband CDMA has been defined with 5MHz frequency and more, which is able to provide 144 and 384 Kbps bandwidth of the connection [4]. The bandwidth can be distributed to multiple channels. This property improves reaction time and accordingly is better than the solution restricted by single channel.

Advanced TDMA has been selected for researches as more preferable technology than CDMA and Universal Wireless Communications 136 (UWC-136) was the only one that stayed for the 3G proposal [4, 5]. The system utilized three different carrier frequencies: 30 kHz, 200 kHz and 1.6 MHz. The limited frequency 30 kHz has variable modulation. 200 kHz is used as in GSM for data transmission at the velocity up to 384 Kbps. This frequency is being used on the open ground and in objects in motion, while 1.6 MHz frequency is being utilized only indoor and can achieve 2 Mbps data transmission.

Hybrid CDMA/TDMA technology supposes that the radio spectrum is divided into 15 temporal channels and these ones use CDMA multiplexing [4]. Orthogonal Frequency-Division Multiplexing (OFDM) technology has been built on assumption that the data stream can be divided into different streams. These streams have lower dimension than initial one. OFDM uses multicarrier modulation for data passing of these streams.

Investigating the above mentioned technologies emphasizes that for development of adaptable software, it is necessary to take care of the features of current environment. For instance, for defining mobile phone location in a network of Advanced TDMA class, a detailed testing is needed to choose the most optimal propagation model because of the different behavior of this technology (outdoor/indoor) and properties accordingly. These tests have to be directed to decide optimal frequency for definition of length to device and other characteristics.

Positioning in GSM/CDMA networks is widely used with expression of Location Service. This type of services uses predefined locations of mobile phones' stations. Mobile device is informed about its location by location service. This service is available for mobile device users, mobile network operators and other service providers. In most of the cases the information presents the location of requested object and error or accuracy the calculation has been made with. Location services begin their spreading in USA as a service for accident appearance that presents the place of calling user [6].

In Finland for instance, TeliaSonera Finland Oyj provides this kind of service for subscribers by sending SMS. The precision of the data about location is defined based on the location of mobile network base stations and that depends on the area in which the mobile device user is. The accuracy for the cities is far higher than in more sparsely populated regions. It depends on the amount of mobile network base stations which can identify the device. Based on the information from TeliaSonera Finland Oyj [7] the accuracy can vary from several hundred meters to several kilometers.

In order to understand how to achieve information about location of a device of mobile network, it is needed to look at the core of the network [4, 5]. The core should have the required set of the elements needed for robust functionality of the network. The Mobile Switching Center (MSC) takes an important place in circuit – switched core network. It is necessary to point that the same Mobile Switching Center can be utilized for GSM network as well as for Universal Terrestrial Radio Access Network (UTRAN). The Mobile Switching Center is performed on the Visitor Location Register (VLR).

Physically the register is implemented with connection of MSC so that the division of these two blocks is conventional.

The Visitor Location Register contains essential information about mobile phone base stations which were included in the current area of MSC. This fact makes roaming functionality possible to implement in that region. These responsibilities VLR includes a data about all active subscribers in predefined region. VLR has almost the same category of parameters as Home Location Register (HLR) but the main difference is that HLR has permanent information about subscribers. If the user has made subscription it means that HLR would be updated. If the user has made a new registration with another network then this data would be copied from VLR to VLR of new network and it would be removed from the old VLR [4, 5].

VLR is presented itself with following information [8]:

- International Mobile Subscriber Identity;
- Mobile station international ISDN number;
- Mobile station temporal number;
- Temporary mobile station identity;
- Local mobile station identity;
- Location area where the mobile station has been registered;
- Identity of the Serving GPRS Support Node (SGSN) where the mobile subscriber (MS) has been registered;
- Last known location and the initial location of the MS;
- An indication of whether the location measurement unit was successfully registered in an associated serving mobile location center;
- The serving mobile location center address.

The last two parameters essentially define location of mobile device and can be utilized in context-dependent software.

2.2 GNSS

Another method involves special class satellites for location calculation. It is called Global Navigation Satellite System (GNSS). This method supposes availability of sufficient number of positioning satellites. The method defines position of a device based on delay differences between data transmission from different satellites of this class.

Nowadays, there are 4 GNSS that are presented on different phases of the development:

- NAVSTAR Global Position System (GPS) (United States) had been completed and has been working since 1995 in full functionality [9];
- GLOBal'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) (Russia) had been completed by the end of 2008 and is in operation phase [10];
- Galileo (European Union) is in the initial phase of the development. The acceptance of the orbit is planned to be accomplished in 2010 and the number of involved satellites will be increased to satisfy necessity of full operation by the 2015 [10];
- COMPASS (China) the system is in the development phase [11].

GPS has been established as a project from creation a team for development navigation system and location definition of an object. The project involves representatives of the military forces of United States and Defense Map Agency. The developed system have been named NAVSTAR GPS (or GPS in daily usage) and is been used by US Department of Defense for military applications. Utilization of the system for general citizens is available with restriction of operational abilities. GPS widely available global satellite system that allows instantaneously defines position with help if immediate sequence of data from at least four satellites. The current status of the system provides with covering of demanded amount of satellites almost all places of the Earth. 24 satellites are located in 6 orbits that circular formed and located in distance of 20200 km from Earth's shape. The degree level of the orbit plane in relation to the Equator is 55 degrees. The period of full rotation is 11 hours and 58 minutes. Therefore, each day the satellite appears in 4 minutes earlier [12, 9]. Such parameters of the orbit afford to achieve an optimal resonance state in treatment to rotation period of the Earth.

The main characteristic of the satellite is frequency. All signals that are sent by the satellite are solved with base frequency of the satellite (fundamental frequency). Two carrying frequencies f1 and f2 have 10 and 24 centimeters length of wave accordingly [9]. They transmit modulated signal and the message. The message contains information about satellite time and orbit characteristics. The f1 frequency includes code modulation of the different accesses C/A-code (Coarse-Acquisition, Clear-Access or Civil-Access). Frequencies fl and f2 also include P-code (precise or Protection). The restrictions of Civil-Access were named as Selective Availability (SA) and Anti-Spoofing which sensibly decline the quality and the accuracy of defining position [12]. SA determines the deviation from precise value and it is established for manipulation with navigation data message about orbit (epsilon) and the frequency of satellite clock (dither).

With this dither, the process of GPS satellite clock is artificially declined with adding noisy signal with unpredictable frequency and amplitude. These actions are performed to provide an access for common citizens. Two additional signals: frequency and amplitude change randomly with the time. The value of amplitude is up to 0.3 second that approximately corresponds to 100 meters and the frequency changes with a few minutes [12]. In such a manner the system implements the restriction SA to be accorded to 25 meters of the accuracy. The users of military forces use special key to remove SA deviation in real time that allows utilizing the system in full capacity. The system uses Anti-Spoofing (AS) to defense utilization from fabrication by encrypting Y-code to P-code.

This provides excluding swindle opportunity while receiving the signal on the Earth. Encryption of P-code into Y-code demands existence decode algorithm. As the result of utilization deployed AS is that the common citizens have only access to C/A-code that is transmitted through one frequency. Based on aforementioned, the software that does not have differential and optimization algorithms has limited accuracy about 100 meters. This level of accuracy is mainly governed by SA influence which is essentially bigger than distortion of ionosphere and other considerations. The noisy influence can be decreased almost completely by using software with differential and optimization algorithms. The accuracy of such software defines by distortion of implemented algorithms and ionosphere influences. From May 2000 the accuracy for common citizens becomes the same as for military forces. It was possible by removing SA [9].

In contrast to United States' project, the Soviet Union had established their own project GLONASS [9] in 1976. The project was planned to cover the Earth by 1991. The purpose of the GLONASS development is to provide real-time location definition and velocity computation. The service was intended for usage by Soviet military with navigating and accomplishment of ballistic missiles. When the Soviet Union collapsed, the project became effete because the satellites were designed for a short life-time work, however there was still possibility for renewing the project. In 2001, the project was committed for repairing and had been developed successfully by help of Indian Government. By 2008, 18 satellites, involved into operation, were taken off the ground. By the end of 2009, the amount of satellites is planned to be 24 (3 are reserved) and by 2011 the performance of the system will be equal to GPS.

The GLONASS contains 24 satellites, 21 of which are in operation to transmit the signals. The satellites are located on three orbital planes. Each orbital plane is separated from another plane by 120 degrees and consists of 8 satellites each. The satellite orbit is circular with one satellite at every 64.8 degree inclination and it lies at distance of 19100 km from the earth's orbit. The complete rotation period equals roughly 11 hours and 15 minutes. The orbit plane has latitude displacement that is 15°. The satellites arrangement is in the condition when it allows having an access as a minimum of 5 satellites from any place in the Earth [12]. The satellite identification is carried out from satellite belonging to some orbital plane, so that the satellites of the first plane have an identification number from 1 to 8, the second plane - 9-16 and the third one - 17-24. The designed and calculated system defines the rotation when the satellite appears exactly in the same place after 8 days. Therefore, each orbital plane has 8 satellites.

The satellites movement is different in comparison with GPS satellites movement. The satellite in GPS system appears once under the same place of the Earth during one day. The resonance factor has small influence for GPS satellites and so that they are cheaper. The useful signal will be considered hereafter. Each GLONASS satellite transmits the signal on its own frequency and the code for signals is the same. The signals in GPS system are transmitted on the same frequency but the code is different. As addition the GLONASS system utilizes Frequency Division Multiple Access (FDMA). The transmitted signal from the satellite is built based on the fundamental frequency of the satellite f0 as well as in the case with GPS system. The frequency for transmission is located from 1602,5625 to 1615,5 MHz that is L1 band. So that each satellite has specific frequency spectrum of FDMA which can be presented as formula 1602,5625 + 0,5625 * n MHz, where the n is ID number of the satellite which can vary from 0 to 24. And the L2 frequency is located from 1240 to 1260 MHz and can be calculated with following formula: 1246 + 0,4375 * n MHz [12, 10].

When GLONASS project was on the decline the band 1610,6-1613,8 MHz was deteriorated and the special research was established by Radio Astronomy Service with collaboration of GLONASS administration to check influence of this impediment. And the agreement between GLONASS administration and the Scientific Committee on Frequency Allocations (IUCAF) was signed to clear such frequency for GLONASS. The Galileo and COMPASS [11] systems are not considered in this Master's Thesis because these systems are not in operating state

2.3 Wi-Fi

The most common Wireless Local Area Network (WLAN) includes the following standards [13]:

- HomeRF and HomeRF 2.0 (Wide-Band Frequency Hopping (WBFH));
- Institute of Electrical and Electronics Engineers (IEEE) IEEE 802.11 FH/DS;
- Wi-Fi (IEEE 802.11b);
- IEEE 802.11gOFDM & 802.11gPBCC (Wi-Fi speed extension proposal);
- MMAC (HiSWANa);
- HiperLAN/2;
- IEEE 802.11a;
- Bluetooth.

Only three of these standards Wi-Fi (IEEE802.11b), Bluetooth and Home RF, have been widely spread. Wi-Fi and Bluetooth technology is considered in the scope of this Master's thesis.

The standard IEEE802.11b specifically defines that Wi-Fi is established by using only 2.4GHz radio frequency, but the next extension of Wi-Fi name includes all standards of Wireless Network that follows 802.11 standards. Commonly used 802.11b standard, named as 802.11 High Rate, have been developed as extension to 802.11 provides 11Mbps data transmission and applies to build WLANs. The standard 802.11g is used to transmit the data through small distance with bandwidth up to 54Mbps and additional transmitter and receiver antennas allows to increase bandwidth up to 4-5 times faster than standard 802.11g. The real speed for 802.11n standard is 100Mbps [13].

At this rate Wi-Fi provides a location-independent network access through the radio waves. In usual case such network is deployed as final link that connects the wire networks with mobile devices. Wi-Fi networks can be opened as public WLAN or closed. A password is needed to establish the connection into closed network. The network includes devices with Wi-Fi network cards and wireless routers. And the access point is available for connection within about 60 meters. To achieve high transfer rates, distance between device and router should be less than 30 meters. To extend the range of wireless, market exposes wireless signal boosters. New Wi-Fi technologies extend the available distance from 91 meters to 183 meters and more.

2.4 Bluetooth

Bluetooth technology appeared as the result after scientific researches about development of a communication tool that is intended to be according with requirements of the industry: low cost, replacement of cord connection by wireless connection with low power. Such connection provides the base communication abilities for mobile devices in ad-hoc form. The gain was achieved and the developed technology has been integrated into row of different devices.

In 2002, the standard 802.15.1 had been developed and proved. The developed standard completely corresponded to Bluetooth wireless technology. The standard has lower bandwidth of the channel and smaller distance between devices to be compared with 802.11 but these standards are working on the same frequency – 2.4 GHz. Therefore, Bluetooth technology is intended to work into noisy environment. Sequence of 48 bytes presents an address that unambiguously defines a device into the network. The protocol presented as combination of circuit and packet switching. Bluetooth maintains asynchronous data channel, the channel with supporting asynchronous data and synchronous voice channels and not more than 3 simultaneous synchronous voice channels.

The specification of the technology defines two different levels of power: low power provides the coverage area inside the room and high power can cover the middle distance such as one house. Power saving mode is defined by so called HOLD MODE. This variant can be established for connection and HOLD time can be defined. During this piece of the time Asynchronous Connectionless Link (ACL) packets are not transferred from master device. This mode is usually used when there is no necessity to send a data during relatively long period of time. To save the power the dispatcher can be turned off. Also the mode is successfully utilized to discover other devices or in the mode of waiting incoming connection.

The dynamic correction of transmission power considers that the power of dispatcher antenna of two other devices can be asked for increasing or decreasing. Connection is in mode of master-slave. The master side is independent from slaves. The request by slave can influence only to master dispatcher. Power adjustment is done in steps. Therefore, the device into the waiting mode with maximum safety of the power wastes equals 0.3 mA and into maximum load mode 30 mA. During interleaved mode the wastes varies accordingly [14].

3 LOCATION DETERMINATION TECHNIQUES

This chapter presents methods that are used in positioning a device. The main topics covered in this chapter are: GNSS principles in positioning, methods for positioning in GSM/CDMA networks, positioning in hybrid networks and optimization approaches for positioning.

3.1 GNSS principles in positioning

For successful positioning process it is essential to have at least 4 satellites at the same time. This visibility allows to measure distances between device and satellites having used features of signal transmission. These four or more measurements of distances are utilized in calculating device location in some system of reference and clock error for receiver. Two such systems are widely used: XYZ-coordinate system and Latitude, Longitude, Height. For example the Google Map is working with Latitude, Longitude, Height system of reference but there is a big number of applications with the XYZ-coordinate system [15].

The GNSS receiver really measures the time for traveling signal information from a satellite to the receiver. Therefore to define this time, the receiver should be aware of the time the signal has been sent as well as receiving time. The sending message by satellites contains different parameters and one of them is the time when the message left the satellite. To know receiving time the GNSS receiver has own quartz clock which is not sufficiently accurate. In that sense the receiver has to calculate error of its own clock.

The calculation of actual distance between satellites and the device brings the position definition to the next step. The signal speed is about 300 km/s but it is decreased because of the Earth's atmosphere. Having inaccuracy in time +-10 microseconds we can calculate the distance with incorrectness of few meters. This implies that GNSS satellites have to use atomic clock to provide acceptable accuracy in results. Afterwards, the receiver computes the error.

Further the receiver computes the error of its own clock based on obtained information received from the satellite. This error is directly connected with the accuracy of the calculation. To obtain further calculation the receiver has to know satellites' locations. All information is needed about clock errors and the position that the satellite was located while sending this signal. Essential list of parameters is included to satellite broadcast message. This information is integrated in the actual measurement streams. [12]

The estimated location of the device based on four measurements of lengths and satellite locations has been restricted by accuracy. On this step the improvement of the result should be involved. Such methods will be discussed latter in subsection 3.3. These methods are mainly regarding influence of environmental factors such as ionosphere and troposphere. Gain to solve ionosphere effect binds over utilization of different length of wave, thus the satellite transmission uses two or more frequencies. For GPS system the second frequency is closed for common users, while in GLONASS system it is available. The model for correcting ionosphere effect is currently applied to broadcast message. Using information of this message, calculated result will be more precise on tens of meters. This model was named Klobuchar model and enables defining of meter precision [16]. The troposphere effect varies from 2 to 10 meters, when the satellite position is straight up and in the most inclined position. More advanced models take into account different characteristics such as water vapour in the air. Such models allow achieving submeters level accuracy.

3.2 GSM/CDMA principles in positioning

However, the core operation process of cellular mobile network has been described in previous section (section 2.1), this section provides explanation of location service (LS) functioning principles.

3.2.1 Cell-Coverage-Based Method

Cell –Coverage – Based Method is a simple method, which does not need any calculations or measurements. It does not require any improvements of the working mobile network as well. For evaluating mobile device location, predefined and known base cell station location is used. The location is taken from the last base station in which the mobile device has been registered. One base station is enough when using this method. The information can be sent through usual means. The location may be expressed as cell identity or as information about exact position of base station. Calculating error for this method, the covered cell area has been taken into account. In general case, the covered area is from few hundred meters to a few kilometers (see Figure 1). The real location of the mobile device in Figure 1 is covered by Cell C. The location of mobile device is considered with location of cell center. The cell radius will be considered as accuracy of determined location. Actually, error level is enough for some amount of applications. A payment for such kind of service can be evaluated using cell properties or for subscribed area the customer can spend less amount of money. As examples of utilizing this method, the service about traffic intensity can be presented. Achieved level of accuracy allows successful usage.

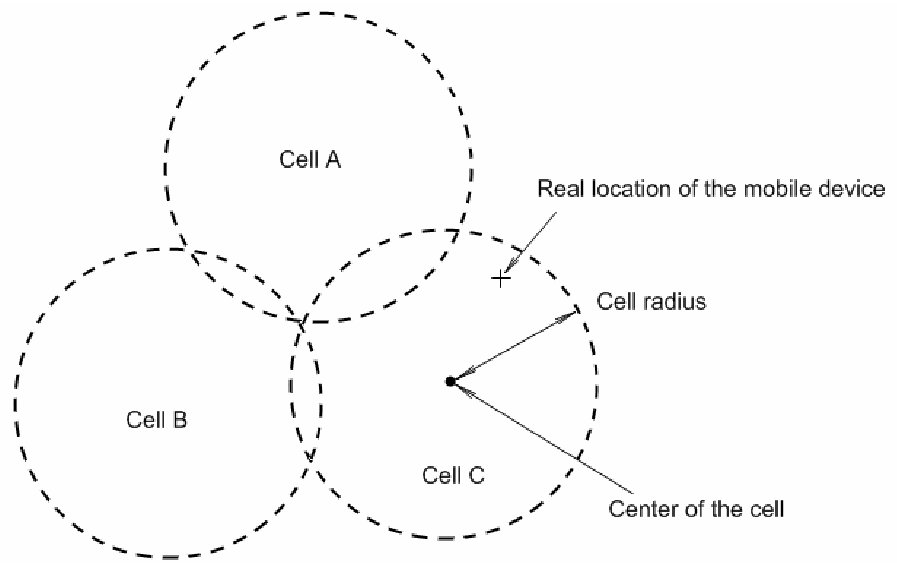

Figure 1 Cell-coverage-based method [4]

3.2.2 Observed Time Difference of Arrival

The main idea of the observed Time Difference of Arrival Method (OTDA) is to calculate distances between available base station and a mobile device. These distances are measured by mobile device based on the special signal that base stations sent. This special signal is transmitted through common pilot channel. The signal is coded specifically for a cell code to be uniquely recognized by the mobile device. That process allows making measurements in compliance with suitable channels with different base stations (see Figure 2).

The responsibility of the Mobile Device (MB) is to evaluate distances and based on the known locations of base station to make the calculation of its location. Computations can be accomplished either by the mobile device or base stations with informing the device about result. This method is required for calculation of exactly known base stations' locations and relative transmission time differences. In an effort decreasing the error during distance measurements, the signal is transmitted as many times as possible because the average measurement is much more correct than single measurement.

The relative time difference between Nodes, B1 and B2, can be expressed as following:

$$R_{12} = x_2 - x_1 \qquad (1)$$

Where x_1 is the measured delay for signal transmission between Node B1 and mobile device MD, x_2, x_3 respectively for Nodes B2 and B3.

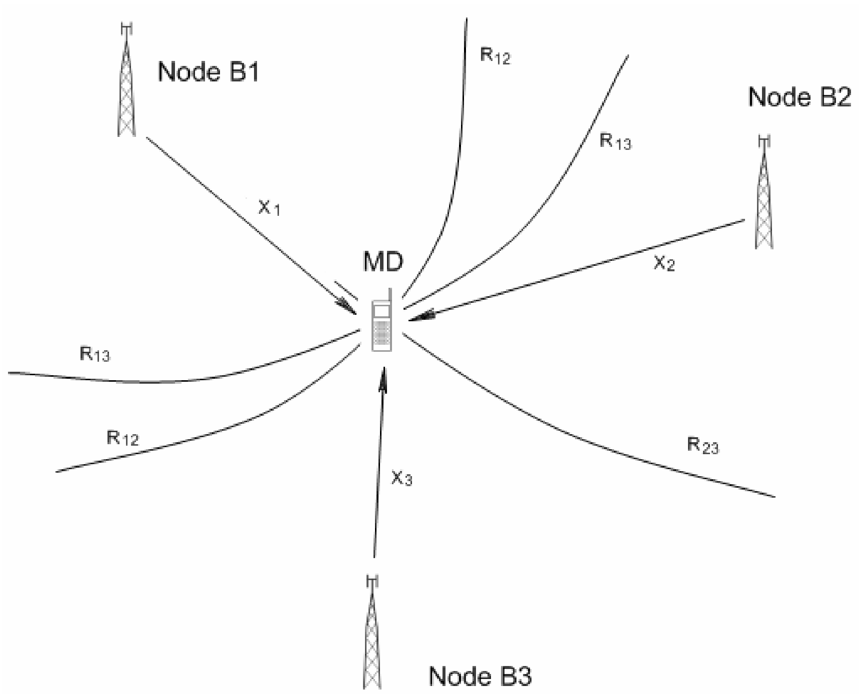

Figure 2 Observed Time Difference of Arrival [4]

The curve R_{12} is shown in figure 2 as hyperbola. If the delay measurements are calculated only for two base stations then the location will be considered with high accuracy. Thus the minimal amount of available base stations should be three, however theoretically at least two distance measurements should be implemented. Practically there are some deteriorate influences so more than two base stations give better result.

The location of the mobile device is placed on the cross of hyperbolical curves R_{12}, R_{13}, R_{23} . This method has some features of implementation in respect to calculation as it has been already pointed.

- MD-assigned OTDA supposes that the measurements will be performed by mobile device and this data is sent to base station that makes location calculation.
- MD-based OTDA supposes that the measurements are performed by mobile device as in MD-assigned case but this information is used to calculate location in the same equipment without sending to base stations. In this mode the base stations provide mobile device with needed information. This fact influences the price of mobile device.

Improving result by using OTDA methods, some enhancements have been developed and successfully utilized. In the case when the mobile device is located nearby base station, the transmitted base station signal may block those of the mobile device. Such problem is known as hearability problem [4]. The use of idle period downlink method helps solving this problem. In compliance with this method the base stations has to stop transmission and during that time mobile devices perform measurements of their location. Main drawbacks of this method are data transmission possible only in unsynchronized mode and unavailability of base station during idle time. While idle period, only one base station makes transmission and other stations transmit only pilot signals. This solution makes recognition of base stations faster for mobile devices.

OTDA method does not allow achieving high level of accuracy. Reasons are: different types of barriers, encountered on the signal way and signal reflections. Sometimes it can happen when the real distance between mobile device and base station is less than measured with delay. The reason for this, is the path of signal which has not been achieved in the shortest way. Another problem of the increased accuracy is the time synchronization. There is no precise time, like in satellite atomic clock which should be used to make pilot signal for measurements. The time synchronization between base stations is not carried out often to achieve high accuracy. This problem is somehow solved by measuring and storing time differences and this information is used for location calculations. Another method to solve such problem is by using predefined measurements. These measurements of time delays are implemented for preliminary known locations. This approach will be discussed latter in chapter 3.4.

The result of position calculation also depends on the mode of base station. Asynchronous mode of the base station makes relative time difference not as a constant value so that the calculation has to be provided with the latest available result. In time-division duplex mode of base station is usually synchronized by time and allows making calculation more precisely. The 1 nanosecond error of time difference between base stations is about 0.3 meters of position error and it is usually tens of nanoseconds in real time.

3.3 Network-Assigned Global Positioning System

The main GPS principles were considered in chapter 3.1 and in conclusion of the before mentioned it is necessary to mention that achieved accuracy for general citizens is about 100 meters. This accuracy can be improved in precision or calculation time. These improvements are established in cooperation with mobile cellular networks.

3.3.1 Differential GPS

The Differential GPS (DGPS) method intends to decrease accuracy error that is made with selective availability (see section 2.2 for more information). As additional purpose the method helps solving of other influences such as atmospheric features. The idea of functionality process is straightforward. Usually improvements of this method are applied to maritime navigation and aviation [17, 18]. The method supposes the arrangement for GPS receivers with known real position. Such receivers make necessary calculation of the location as well as additional parameters based on achieved GPS information. The location error of this region at the current moment of time is defined with help of receiver's property having known positions. The information about error is available for GPS receivers in the region and they can improve estimated result.

The DGPS method is widely deployed already. DGPS usage allows achieving 1 meter accuracy but specific evidence has to be marked. Considering the changes of frequency of selective availability, DGPS corrections have to be updated within 20 seconds. Otherwise the correction data will be irrelevant.

3.3.2 Assisted-GPS

Assisted-GPS method is directly applied to cellular mobile networks and has two possibilities for calculation of location. These possibilities are called Assisted-GPS in common way. One of the approaches suggests that the mobile device has fully-featured GPS receiver, however another one requires only GPS receiver with reduced completion in the device. The first approach was named mobile device-based method and another one mobile device-assisted method.

The mobile device-based method is considered to be more expensive because it requires definite hardware. Assisted-GPS technique provides the mobile device with needed timing and data assistance information. The base station receives the GPS signals, makes some calculation of time arrival and provides this information to mobile device as time assistance. This improvement definitely decreases the reception and recovery time and data assistance guides with appointed GPS parameters. The mobile device can receive decryption of visible satellites and additional information about calculation corrections which is specific in current region. The use of assisted-GPS allows significant increase of the mobile device speed positioning system. Reason for that is the big part of computation that is performed by base station but not by the device itself.

3.4 Other approaches for positioning

There are some additional technologies and approaches which are used in positioning, however mainly they do not appear as a basis. Some of them are utilized to meliorate applied techniques. One of these approaches is angle of arrival method [4]. This method is able to define the direction from which the mobile device sends the signal. Such method suggests that the base station utilized sectorized cells or adaptive antennas. Sectorized cells have beginning and ending values of angles according to visibility from the base station. The adaptive antenna is capable to identify the angle with help of beam position. This information is collected from different base stations and then based on it, location of the device is calculated. The method is advantage in the mobile networks which have adaptive antennas.

Second approach, called the observed time of arrival method [4], considers time arrival of the signal in position evaluation, which is possible for implementation in the case when both sides of communication have some common time prototype. The time arrival is defined from the received and the sent time of the signal. This approach allows using time evaluation of time arrival by base station as well as mobile device. Unfortunately, such common time prototype is not described in specifications.

Next method appears as improvement of observed time difference of arrival method [4, 19]. Such method is intended to solve the problems which can happen in some area which have evaluation difficulty for other positioning methods. The network cells of this problematic region are equipped by special devices and they are involved for positioning process. The network allowed about exact location of these devices. The special devices are utilized in network purpose by mobile devices. The mobile devices are provided with an access to mobile network through the reference of such special device. This method is not standardized and the companies use different techniques in implementing it.

The last method that is briefly described in this subsection is another improvement of observed time difference of arrival method called as OTDA positioning elements [4]. The idea of such approach is that additional positioning elements are located in already known locations connected to network. The positioning elements make broadcast data transfer with information about synchronization code which is different than the synchronization code of the base station. The mobile device receives signals and makes estimation of time differences. Collected data is transferred to the network which calculates the mobile device location. This method can be very suitable for regions that have only one available base station or for uncovered regions between base stations. Some modification of this method is useful for indoor positioning systems as well.

3.5 WLAN positioning approaches

Positioning with use of WLAN is actual since the technology is been increased in popularity. There are some methods and approaches for location definition in this type of networks. They can be divided in two categories: trilateration [20] and fingerprinting [21]. Trilateration method will be discarded since the idea is very similar as described in chapter 3.2.2 of this thesis. The article [21] describes radio-frequency based system for location and tracking mobile device. Especially, the system intends to be utilized in building environments. This approach uses signal strength characteristics as the basement for location definition. The method supposes utilization before located base stations with known positions. This approach and experiments will be now discussed in detail.

To construct and apply suitable model for signal spreading, authors collected information about radio signal which was described as a function of mobile device location. Additionally, used software in experimental part allowed collecting other information about signal strength and a signal to noise ratio. To be more accurate the spreading model includes algorithm for calculating the number of walls that have been met in the signal way. The location of the mobile device was determined using triangulation approach which can be applied in the case when three or more base stations are visible. Thus the measured signal strengths are involved into calculation process when the guessed location is determined. Obtained location is reputed being unknown location of the mobile device.

The study analyses collected data from 70 different positions in 4 orientations. Each position contains measurements of signal strength between device and 3 base stations. To evaluate accuracy, one of the locations and orientations is excluded from calculations by some method. Then the nearest neighbor in signal space is searched in remaining 69 points and 4 orientations. This simulates the process of real position definition. Three methods for searching excluded point were compared: empirical, random selection and strongest base station selection. With random selection the excluded point was selected randomly. The strongest base station selection method supposes that the mobile device location is the same as the nearest base station that has strongest strength signal. The empirical method appeared to be the best one. For example in 50th meter the resolution is about 3 meters that is almost 3 times better then the strongest method and almost 6 times better when the point is selected with random method. Conducted analysis of influence multiple nearest neighbors in work [21] defines that the better result will be calculated when the amount of neighbors is between 3 and 5. If it is more than 5, the accuracy decreases accordingly.

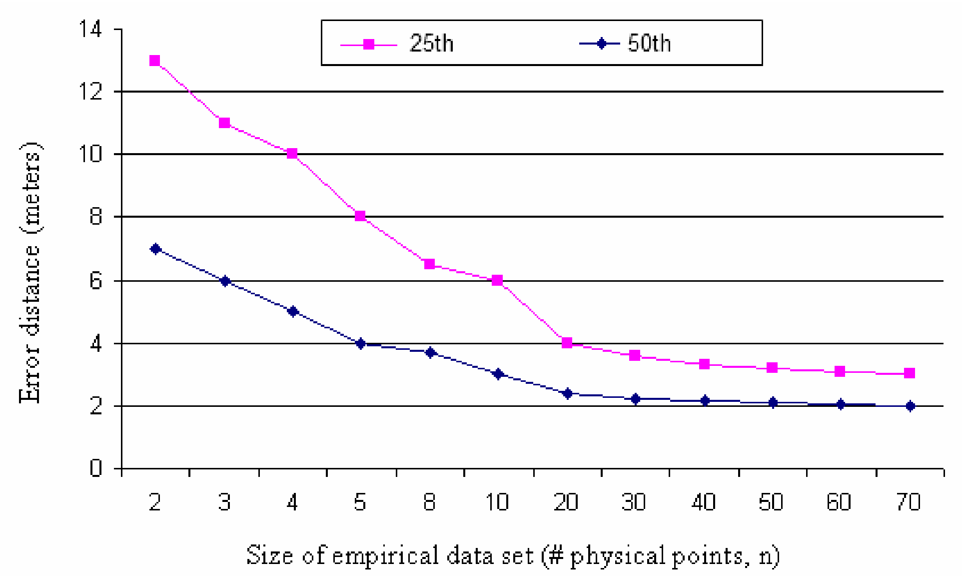

Figure 3 The error distance versus the size of the empirical data set [21]

To estimate how the number of physical locations influences accuracy of location definition, the computation error was calculated for cases when the empirical data set is being changed from 2 to 70 [21]. It is shown in the Figure 3. The 25th and 50th are percentile values of the error distance. To get error distance value, n points were selected randomly from empirical data. The region for experiments is placed in rectangle with border size of 22.5 and 43.5 meters (one floor of the building). In that sense in order to achieve exhaustive accuracy the size of empirical data set should be more than 40.

The model for data spreading which was selected in [21] is Floor Attenuation Factor model based on characteristics of simplicity and high accuracy. Shown adaptive model for wall barriers looks like

$$P(d)[dBm] = P(d_0)[dBm] - 10n\log\left(\frac{d}{d_0}\right) - \begin{cases} nW * WAF & nW < C \\ C * WAF & nW \ge C \end{cases} \quad (2)\ [21]$$

where n is the rate at which the path loss increases with distance, $P(d_0)$ is the signal power in reference distance d_0, d is the distance between transmitter and receiver, C is the number of walls.

In conclusion of the formula the signal strengths have to be normalized with influence of critical number of walls C that makes involvement of the wall attenuation factor WAF .

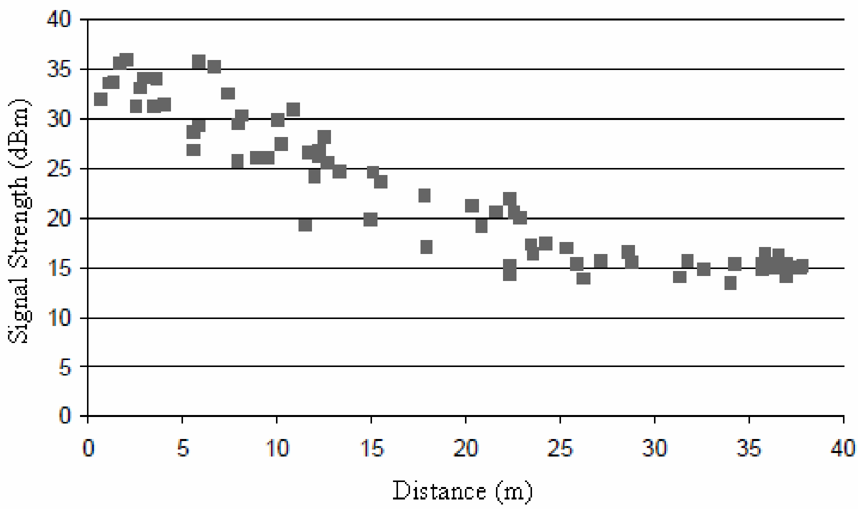

Figure 4 Corrected data with applied adaptive model [21]

From Figure 4 it can be clearly seen that the signal strength depends on the distance. So the linear models can approximate such data easily to formulate this dependency.

Such approach is oriented to deploy real time location system inside a building.

Hoping to increase the accuracy of method [21] the probabilistic method has been developed in work [22]. This approach is more complicated in attitude toward computations and requires increasing memory size in comparison with nearest neighbor approach [21]. Thus it is not considered in the current thesis. The article [23] studies positioning with fingerprinting technique. The main directions are to define location with increased accuracy and as advantage of the method the user orientation can be evaluated. Authors demonstrate experiments for indoor and outdoor environments.

The experimental part was performed in area of 36 by 17.5 meters which has different rooms. 5 WLAN access points were arranged equally. The communication phase does not need a connection establishment. The mobile device sends the request to all access points during measurement time and receives the replies with identification number of the access point. The points for data collection are lodged in the most interesting 20 test places. Figure 5 shows the collected result of signal strengths in different orientations of a mobile device.

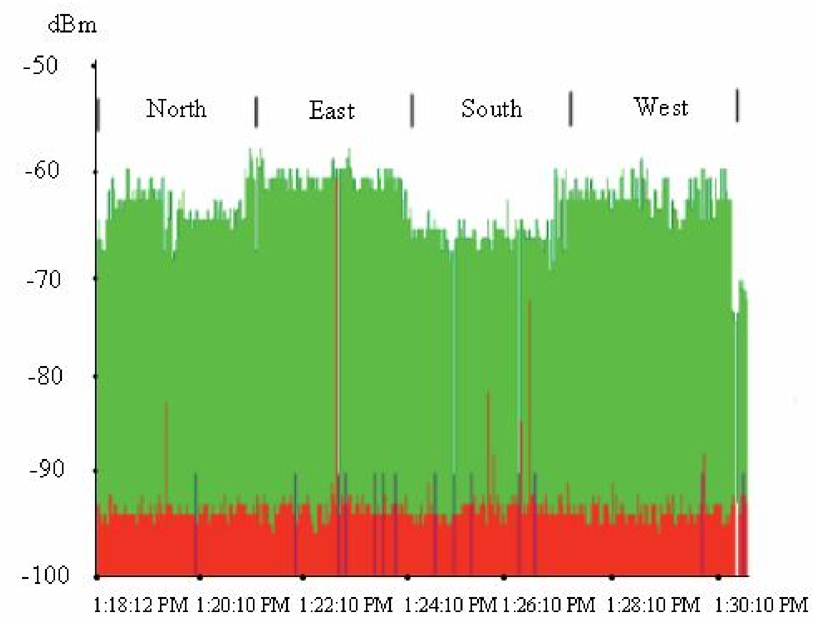

Figure 5 Correlation between the received signal strength and the mobile device orientation (data collected on a weekday) [23]

For location definition the traditional approach uses an average value of the signal strength [21] but approach presented in [23], so called direction-based fingerprint approach, divides the collected database into 4 databases and uses them as knowledge database. Obviously this division cannot describe all mobile device orientations but according to big influence of device orientation and taking into account this influence the distance can be defined more accurate than allowed with traditional approach. One of the disadvantages used approach is increasing size of knowledge database by four times. For indoor utilization the result formed with direction-based method was compared with traditional method. The percentage of rightly calculated positions is much bigger than the traditional method shows, 95% and 55% accordingly for direction-based and traditional approach. This result appears because the traditional approach does not consider errors as a signal strength difference between device orientations which is really significant.

The outdoor experiment was performed in area 500 by 800 meters in urban part of the Sidney [23]. This area includes more than 1300 WLAN access points with different implementations. For test 172 equally allocated access points were involved and 23 test points were measured. The received result after experimental analysis showed that the average error of position estimation equals 35.8 meters and the direction-based approach shows 23.5 meters. So the outdoor test shows that the signal strength is much stronger but position predicate is difficult by virtue of the fact that there are many obstacles in the signal way.

3.6 Bluetooth positioning approaches

The implementation of a positioning system with Bluetooth technology can be performed with help of cell identity approach in the simplest way. The accuracy of position definition in that case depends on the coverage area (for more information check subsections 2.4 and 3.2.1). Other methods also match for Bluetooth positioning: Angle of Arrival (Chapter 3.4), Time of Arrival (Chapter 3.4), Time Difference of Arrival (Chapter 3.2.2, [24]). Bluetooth Local Positioning Application design and implementation are discussed in [25]. RX power level based positioning approach was utilized in this study. Also authors substantiate the necessity of choice selected computational instruments. Thus, the simple log-distance model was selected as a distribution model for calculating a distance with help of RX power level.

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} + 20\log(\lambda\lambda - 20\log(4\pi) - 10n\log(d) - X_{\alpha} \qquad (3)\ [25]$$

where P_{RX} (dBm) and P_{TX} (dBm) are power levels of receiver and transmitter; G_{TX} (iBm) and G_{RX} (iBm) - antenna gains of transmitter and receiver; λ (m) is wavelength and d (m) distance between transmitter and receiver; n indicates other obstacles such as walls; X_{α} is a normal random variable with deviation α.

The large number of measurements and utilization of Extended Kalman filter were processed in hoping to minimize the estimation error. Since Kalman filter is inapplicable for non-linear models the Extended Kalman filter was chosen. It is assumed that the estimated current position is described by linearised equation of reference locus. The measurements and propagation model are presented in Figure 6.

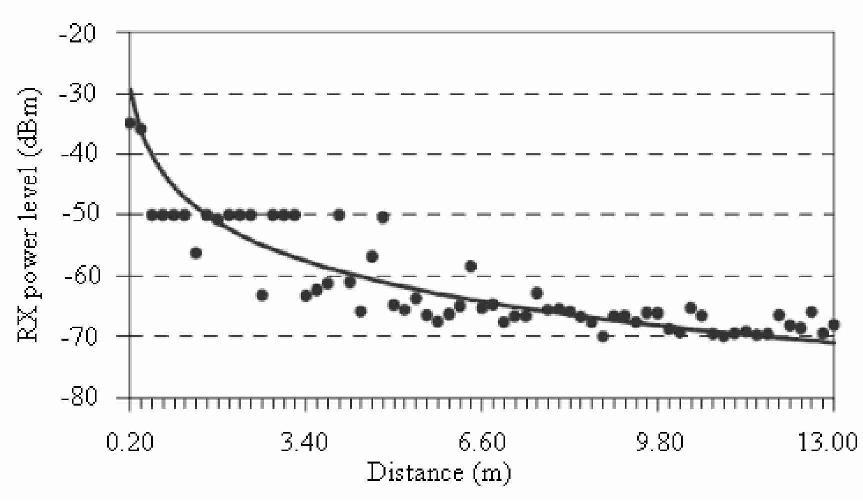

Figure 6 Measurements and propagation model [25]

The evaluated position of the device is presented in XYZ-coordinate system. The use of Bluetooth local positioning application approach with applied Kalman filter shows 15.5 meters of error after first iteration. During first four iterations the error decreases promptly but after sixth iteration the error is almost on the same value - 3.7 meters.

3.7 Method comparison

This subsection concludes comparison of different positioning methods and approaches. Many characteristics should be taken into consideration; some of them such as cost appear to be most important. Methods have their own utilization, specific conditions and working requirements as well. A special attention to OTDA from the GSM/CDMA positioning list of methods should be paid as the method is comparatively fast and able to achieve 10 meters of accuracy (such accuracy can be achieved with help of additional approaches which were described in subsection 3.4 but the usual accuracy equals about few tens of meters). The method involves hardware improvements for mobile network and mobile device that are set up inexpensive.

Network-assisted GPS method is able to achieve the same level of accuracy as OTDA, moreover it is fast also in usage but has some significant disadvantages. The accuracy is quite poor in the case when the mobile device does not have clear GPS satellite visibility. Another disadvantage is that the approach requires GPS receiver inside mobile device and because of that the cost increases relevantly.

Quickness is advantage of methods angle of arrival and observed time of arrival. The mobile device does not require any additional improvements but the network has to be equipped with relatively expensive hardware. These methods have some disadvantages that make them less popular. The most significant ones are low accuracy and unavailability due to some reasons [4].

The cell-identity-based method is determined as the most inaccurate method. The calculation result of this method can equal about one hundred meters (in picocell) or several kilometers (macro cells). The cost is an advantage of using of this method. Deployment location service based on this approach does not require any hardware improvements because of that it is widely spread already.

The method of pure standalone GPS [4] works well but it has some problem. Such problem is connected with availability of this method. It works only in coverage area with mobile network. It appears to be unhelpful for some amount of application. Mobile devices, which are equipped with GPS receiver, do not require coverage area of mobile network. The standalone GPS-equipped method provides good accuracy and the result is more precise outside urban regions because they have reflection surfaces which troubles for receiving signals. This approach increases the cost of mobile device respectively, however the mobile network does not need any changes. The Figure 7 intends to generalize fields of application and different types of positioning technologies. Thus, GNSS is porposed for outdoor usage and does not work inside buildings. Bluetooth and WLAN positioning intends to work for indoor positioning. Cell Positioning works inside coverage area but accuracy is poor. Advanced Network Positioning is more accurate in respect of Cell Positioning and suggests the same availability.

Problems in positioning and optimization algorithms are discussed latter in Section 4 of the current thesis.

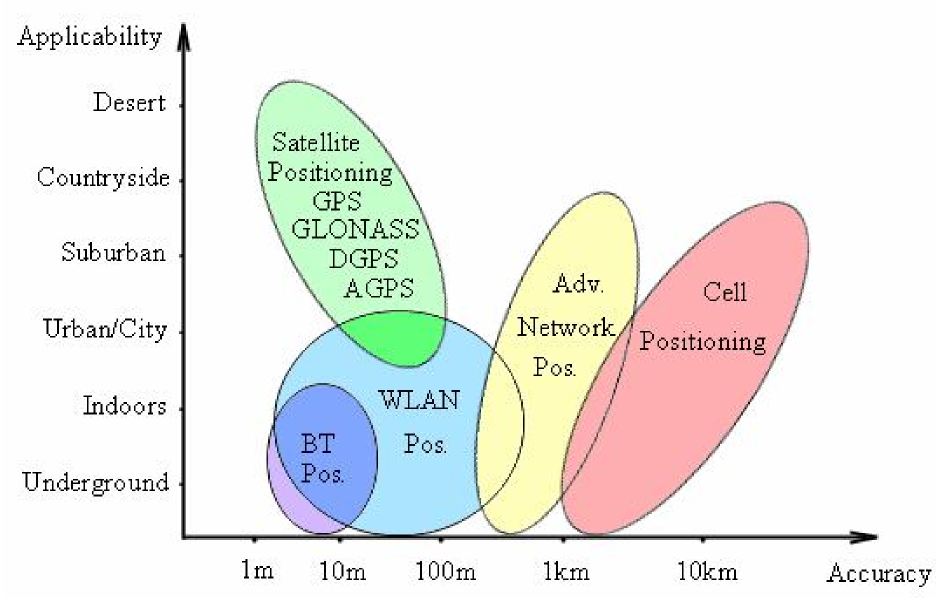

Figure 7 Accuracy and field of application for different types of positioning [4] [26]

4 CHALLENGES IN POSITIONING

This section focuses on problems that have to be taken into consideration for any positioning system: power consumption and battery, movement detection, optimization algorithms for improving accuracy of the result.

4.1 Power consumption and battery

A positioning device such as a mobile unit has restrictions of utilization of the battery. For this reason the consensus have to be established between limited power and service provision. The obtained result during location calculation has to be updated and the frequency of these updates should be selected to satisfy displaying actual data. Later on this aspect will be discussed for internal GPS receiver of Nokia N810 communicator on which the final application intends to work.

The first phase of receiving process searches available satellites and achieves the information from them (so-called first time fix delay). This phase requires full power consumption during whole period until the result will be figured out. It takes 40 seconds (15 seconds in very good condition) when the device is unaware of satellites (ephemeris is unknown) and 3 seconds when the device is aware of satellites (ephemeris is known). The second phase is the positioning itself. The receiver in this phase knows ephemeris and calculates the location based on it. Estimation of updated location takes about 1 second of full power consumption and to be more efficient in the question of limited energy the frequency of estimation can vary. For example the calculation executes every ten seconds that meaningfully increases battery lifetime.

Assuming that the power consumption of the receiver equals 300mW estimated average consumption for 1 second updating frequency would equal 300mW, in case the frequency is 10 seconds it would approximately equal 30mW (300mW/10=30mW) as the device is in the idle mode between measurements. The power consumption for idle time should be included into more advanced model, however considerably small and therefore unaccounted. Delay value should be chosen in such a way that it satisfies a user. In that sense the user is aware of missed measurements.

Evaluating how long the selected device can work with different settings of the GPS receiver, the modest experiment was performed. The necessary measurements can be done for Nokia N810, as this is the selected testing device. It has BP-4L battery which provides 1500mAh with 3.7 volts [27]. The power consumption of GPS receiver takes about 10% of full power consumption of the device. If the receiver utilizes full power, the battery would be depleted after 18.5 hours (3.7V * 1500mAh / 300mW). It happens when the measurement has been computed each second. In the case when there are some delays between measurements the lifetime of the battery grows up accordingly.

The last software patch package for internal GPS receiver of N810 [28] improves fix times having up to 3 minutes. If the delay is adjusted to perform location definition in value of 3 seconds the battery will be low after 18.5 hours * 3 = 55 hours. It is assumed that idle power consumption is ignored and the device has the required amount of satellites available all the time. Figure 8 shows how the delay influences to battery power consumption.

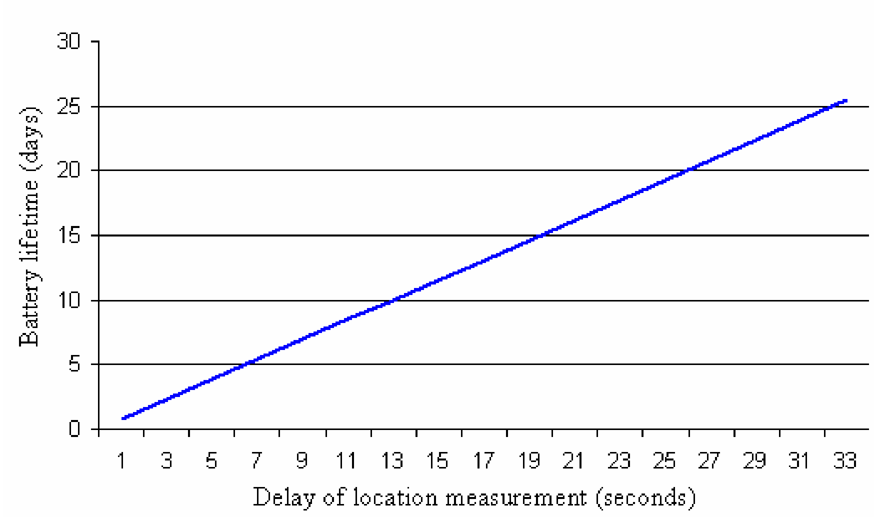

Figure 8 Influence measurements delay to battery lifetime

With increasing delay the lifetime increases. For 7 seconds delay the battery lifetime is about 5 days, with 1 second delay it is only 18,5 hours. It proposes that ephemeris is known during all operational time. Otherwise, the device tries to achieve such information that increases power consumption.

4.2 Movement detection

The possibility, being informed about whether mobile device has been moved or not, gives additional advantage of location definition techniques. If the device is in movement, the positioning system will have to increase frequency location updates. When the device is stationary the location could be evaluated once. The situation about device in movement is discussed in section of optimization algorithms (subsection 4.3) but this section tells about methods of movement detection.

Author of the paper [29] with collaboration of Nokia Research Center has performed experiments and has showed different approaches to estimate movement state of the device.

4.2.1 Cell Identity based movement detection

The work [29] points out the possibility of utilizing Cell Coverage Based method approach (subsection 3.2.1 of this Master's Thesis) for movement definition. It can work in GSM networks but for Wideband Code Division Multiplexing Access (WCDMA) it depends on the release of the network. The information available for experiments in 3G networks is:

- RAN 1.52 [29]: Serving Area Identification (SAI) available for terminals. SAI is able to include one or more cells;
- RAN 04 (2.0) [29]: Cell-ID and round-trip-time available for terminals from one or more cells (in 3G a phone can be connected to more than one cell simultaneously)

The idea of the approach is quite simple. If the mobile device is stationary it will have connection to same cell as some time before. If the device is in movement the frequency of cell changes is quite high. In general case it behaves in that way. When the device is stationary there are many cases with handovers between two or more cells. Therefore some improvements in order to avoid handovers are put into usage:

- The mobile device creates list of cell identities and when the cell changes the previous cell, identity with time are saved into this list. Only one record that has specific cell identity is in the list and the last updated time is saved for it.

- This list is used to define a movement event. When new change of the cell happens the list is utilized for searching last updated time for new cell identity. The device is implied to be in movement when the time difference between new changes and the last one is more than predefined limit.

The accuracy of such approach is poor and related to cell size.

4.2.2 Signal strength based movement detection

The idea of this approach supposes that device movement can be defined by virtue of analysis of signal strength history. Signal strength histogram of the stationary device differs from that of device in movement. When the device is moving further or closer towards the base station the change is significant. As example, Figure 9 shows the signal strength measurements of the mobile device in the train from Lappeenranta to Helsinki. In the case when the device moves in such way that the distance to base station is staying constant, the signal strength can be estimated with imperceptible variance.

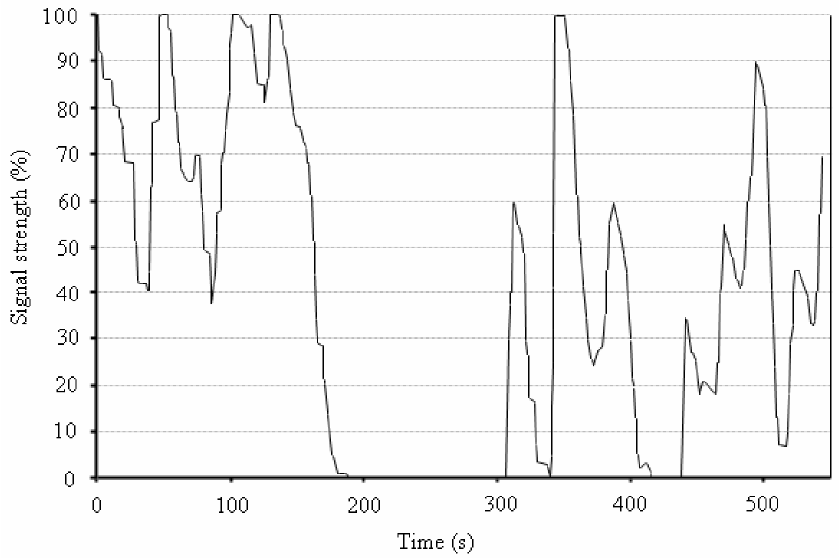

Figure 9 Signal strength of the device in moving train [29]

Different types of measurements were performed in work [29] and the conclusion is perceived:

- Signal strength can change significantly in the case when the device is stationary;
- Signal strength can stay constantly while the device is moving with high speed (>100km/h);

- Signal strength changes provide sufficient information to detect movement but the algorithm would not be simple (to be more reliable signal strength and cell identity based algorithm put together).

4.2.3 Timing advance based movement detection

Additional method with which is possible to recognize the state of device can be built on timing advance measurements [29]. The distance between mobile device and base station can be calculated with timing advance method, and the movement can be noticed with changes of timing advance measurements. Measurement of this approach is spaced within a border of 0 and 63, where one step means one bit of timing advance. Practical accuracy of the approach equals more than 550 meters that is not promising.

4.2.4 Movement detection based on accelerometer

This method [29] defines movement of the device with utilization internal additional unit called accelerometer. Theoretically it is possible to estimate the speed however practically accumulated error does not allow achieving reliable accuracy. Therefore the accelerometer cannot be utilized into speed determination.

The fact that the device is in movement is detected from accelerometer changes. These changes are initiated by the physical environment such as vibration, gravitational changes, etc. If assumptions are made about hypothetical speed and the time of changes the distance can be calculated approximately. For example the device can be in the moving car or user takes it from table for a few seconds and puts it back. Having known character of changes helps to choose optimal delay time between location requests.

Accelerometer is able to detect additional characteristics of the state by comparison of existing templates of the changes in some observed parameters. Thus it is possible to recognize whether the user with device is walking or running. Further analysis of the changes can output conclusion about speed based on event frequency.

Concluding the study about movement aspect, it is inevitable to mark that the property of the connection behaves differently. For example wireless does not work when the device is moving with speed of 10 kilometers per hour. The Figure 10 shows how connection bandwidth changes with different speed values.

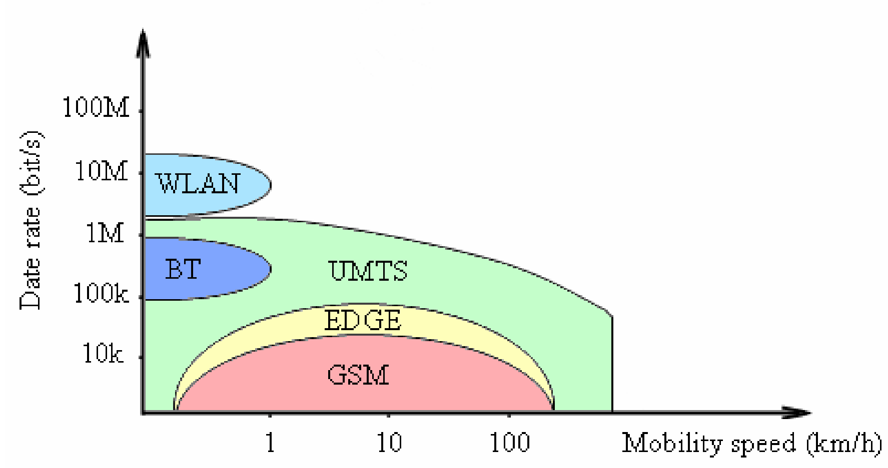

Figure 10 Adaptable abilities of different technologies to movement

4.3 Optimization techniques

All optimization techniques which can be applied to positioning can be divided into two different directions. The first direction is intended to optimize a work with hardware. This type of optimization technique is able to predict the next location without making additional request for measurements. For example the movement of the device is proved (subsection 4.2) and calculation was done during which the speed and history of the last measurements were saved. Having this information it is possible to predict next location of the device. These techniques concern as extensive treatment to positioning because it does not increase accuracy of result. This subsection mainly is focused on the second direction of algorithms. The second direction of algorithms applied to remove environmental influence to measurements such as ionosphere distortion, signal reflection and others. This type of algorithms improves the quality of result hoping to separate noisy signal from favorable information.

Based on selected method and approach for positioning suitable optimization technique is adopted. Empirical method that was discussed in subsection 3.5 used reasonable data collection. For example, collected data include four different orientation of the device, adequate number of samples, etc. Utilized parameters and variables of the method are selected in the most optimal variant after performed analysis. As alternative to empirical method, radio propagation model is used. To be more optimal into this model the additional dependencies were included. For example wall attenuation factor that indicates how the signal will be decreased through number of walls that it is going through. It crucially increases the final result [21]. In addition to wireless positioning, optimization methodology is presented in work [30]. Multi-stage estimator and constrained optimization method are considered to estimate and compensate the propagation delay error and improve location accuracy.

Article [31] holds discussions about possibilities of the most representative methods in wireless positioning to be more sufficient regarding location estimation. This article appoints that there are two methods used for improving estimation. Correlation method supposes collecting data during preparation stage - reference measurements are accumulated into database with corresponding reference locations. And during location estimation stage the measurements are compared with collected data error estimation. Calibration method supposes that errors are directly extracted as subtraction of ideal reference measurement and actually measured reference measurement. During preparation stage the extracted error vector is added to calibration database which has associations between error vector and reference location. During working stage when the device requests location definition the location measurements are treated by collected information from calibration database to the improvement of estimation result.

In real-time positioning and tracking systems Kalman filters are utilized in optimization purpose. A big amount of scientific articles are dedicated to this topic. Kalman filter [32] intends to do recursive reevaluation of condition vector in dynamic system so that the filter is implemented with time representation but not with frequency. Kalman filter is useful for nondeterministic system therefore it was modified to be able to work with deterministic system. This modification of Kalman filter was named Extended Kalman filter [32, 33]. Recursiveness of Kalman filter supposes that while calculating current state of the system it is necessary to know the current measurement as well as state of filter itself. For example, utilization of Kalman filter in cellular tracking system is shown in Figure 11.

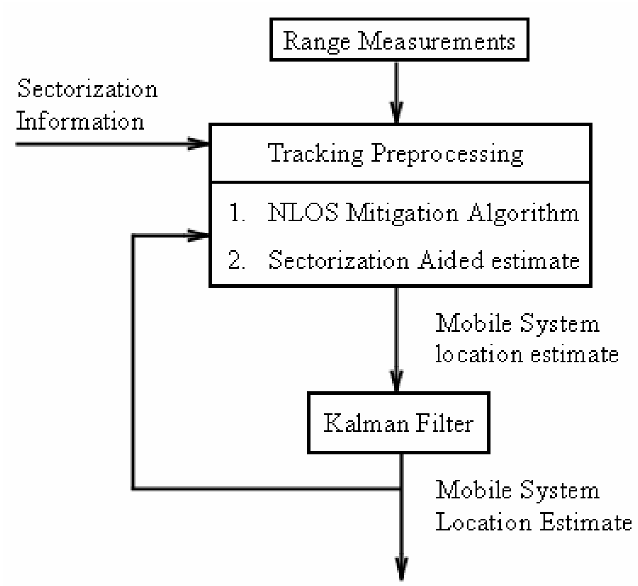

Figure 11 Cellular Based MS Location Tracking System [34]

On Figure 11, range measurements - computed location. Tracking processing module combines sectorization information with previously estimated locations. Then instantaneously computed location is mitigated by Kalman filter. Different modifications of Kalman filter are successfully applied to GNSS [33], wireless positioning [34] and others.

There are other optimization techniques, such as Non-Line-of-Sight mitigation algorithm [35], that are not considered in the current thesis due to limitations. Optimization methods are not considered in the practical part of this thesis as not being essential however possibilities of improving the system are discussed in section 8.

5 EXPERIMENT AND ANALYSIS OF COMMUNICATION CHANNEL

This section begins with description of testbed in subsection 5.1.1. Then data collection process is discussed including instruments in subsection 5.1.2 that were developed for this purpose and concludes in subsection 5.2 with mathematical analysis and built propagation model.

5.1 Data collection

5.1.1 Testbed

Experimental testbed is located on the country road with no traffic while measuring process. The place is selected far away from buildings to avoid noise signals. That part of the road is straight around 200 meters and does not have any barriers. Equipment for collecting data includes 2 Nokia N810 Internet Tablets with running Maemo 4.1 Diablo and equipped with wireless adapter (WLAN standard: IEEE 802.11 b/g). One device is selected to be in the same place during all data collection process while the other one is being tracked.

This experimental stage provides environment to measure communication characteristics of internal wireless network adapter in case when connection is established between two devices N810. Interested parameters of the wireless channel are: bandwidth and latency; and how they change with different distances between devices. Settings for the wireless adapter are made on default.

5.1.2 Data collection

The data collection includes gathering of different connection related characteristics such as position and orientation of the selected mobile device. Collected data will be utilized in building propagation model after analysis phase (subsection 5.2). Two applications are developed to provide the entire data collection process using two protocols Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). Each application is able to work in two modes: server side and client side (it is managed by input parameter at the start). TCP test includes 1 test for latency estimation - MSC TCPTest1 diagram is shown in Figure 12.

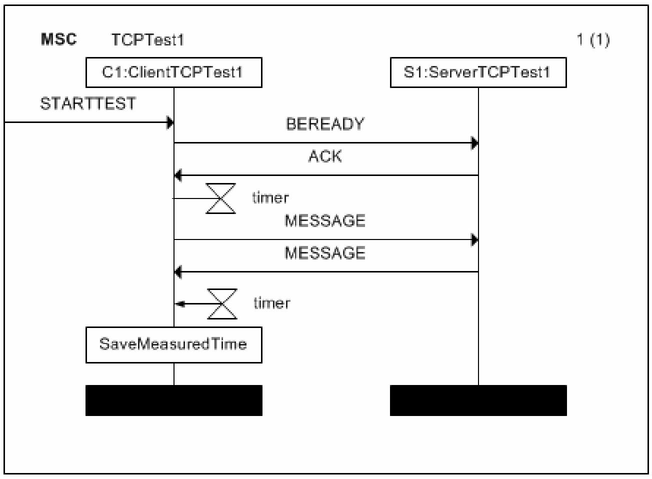

Figure 12 MSC diagram of TCP test

UDP test includes 3 tests: latency test, bandwidth test and time for transmission of fixed amount of data. MSC diagrams of UDP test can be seen in Figure 13.

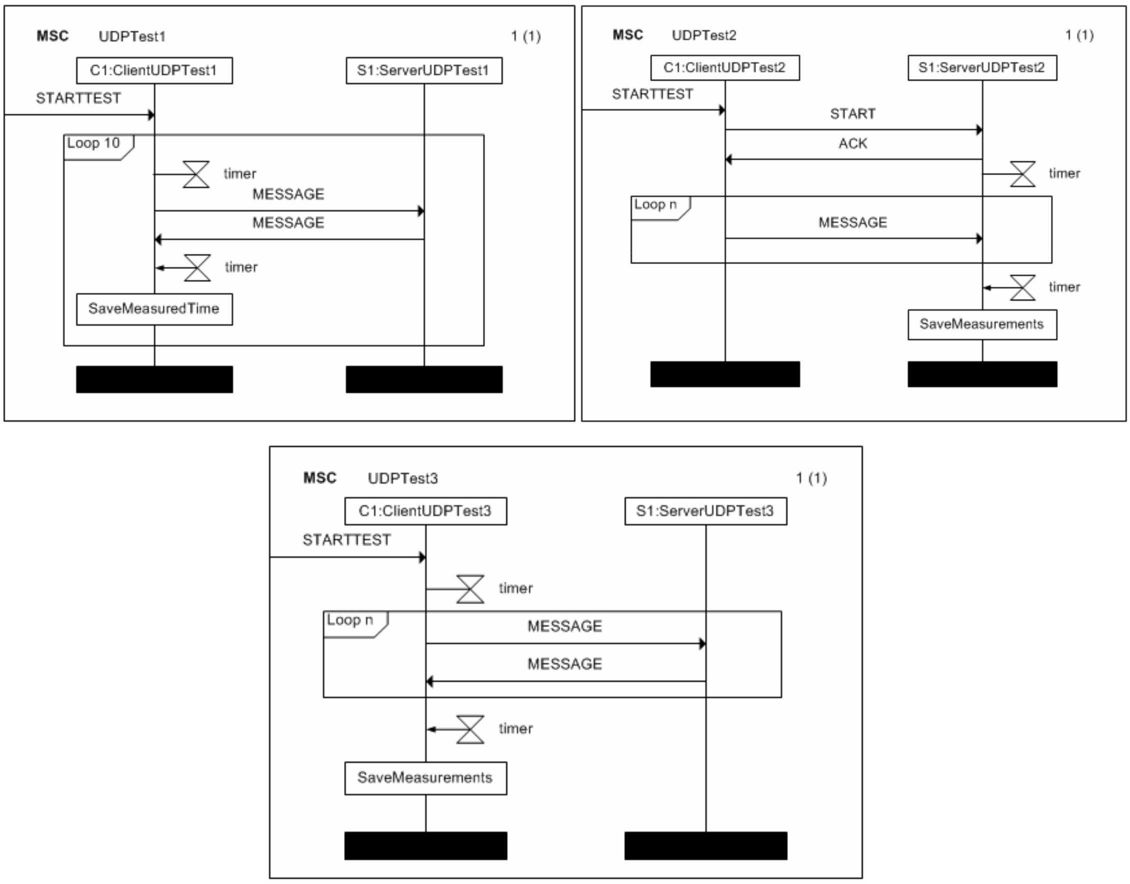

Figure 13 MSC diagrams of UDP test (top-left: UDPTest1 – latency test, top-right: UDPTest2 – bandwidth test, down: UDPTest3 – time for package transmission)

The test process is done as follows. First device was established on a fixed position with the running test application in server mode. Second device was placed on the predefined distance from the first one. The measurements are done on distances 0, 20, 40, 60, 80, 90 meters.

In the TCPTest1 (Figure 12) the server side is working as echo server. Transmission is performed through a TCP connection. After receiving acknowledgment message from the server part, the client application saves first time stamp and sends a message of 100 bytes in size. The fact of a successfully received message fixes second time stamp which is saved as a subtraction from first time stamp. Collected data is presented in form of (d, t) where d -distance between devices in meters, t -transmission time in microseconds.

In the UDPTest1 (Figure 13) the server side works as an asynchronous echo server on UDP protocol. Time difference between begin time stamp and end time stamp is considered as the result including the distance between devices in form of (d, t) where d -distance in meters, t -time in microseconds.

The UDPTest2 (Figure 13) depicts bandwidth of data transmission on UDP protocol. The test requires input parameters: amount of sent packages (np) and package size in bytes (sp) in bytes. The resulting data are presented with distance in meters (d) and time in microseconds (t) in form (np, sp, d, t).

The UDPTest3 (Figure 13) shows calculated time difference between the message exchanges that take place in the loop. The number of iterations in the loop is taken as input parameter of test application.

The last performed test includes collected data about time for echo test of link over Internet Control Management Protocol (ICMP). ICMPTest1 data collection includes 30 measurements for each distance of interest (0, 20, 40, 60 and 80 meters).

5.2 Data analysis

The experiments show that the TCPTest1 appears to be insensitive to increasing distance between devices. This can be explained by the protocol realization [36] that uses retransmission of lost packages. Thus the number of sent and received packages vary which makes the measurement a little more difficult. Latency tests UDPTest1 and UDPTest3 show non-reliable data transmission. The echo time of sending-receiving does not appear to be predictable regardless the distance between devices. A probable reason is that this protocol is placed on one of the high levels in stack of protocols. The average time, minimal, maximal time of all measurements for the same distance between devices is shown in Figure 14.

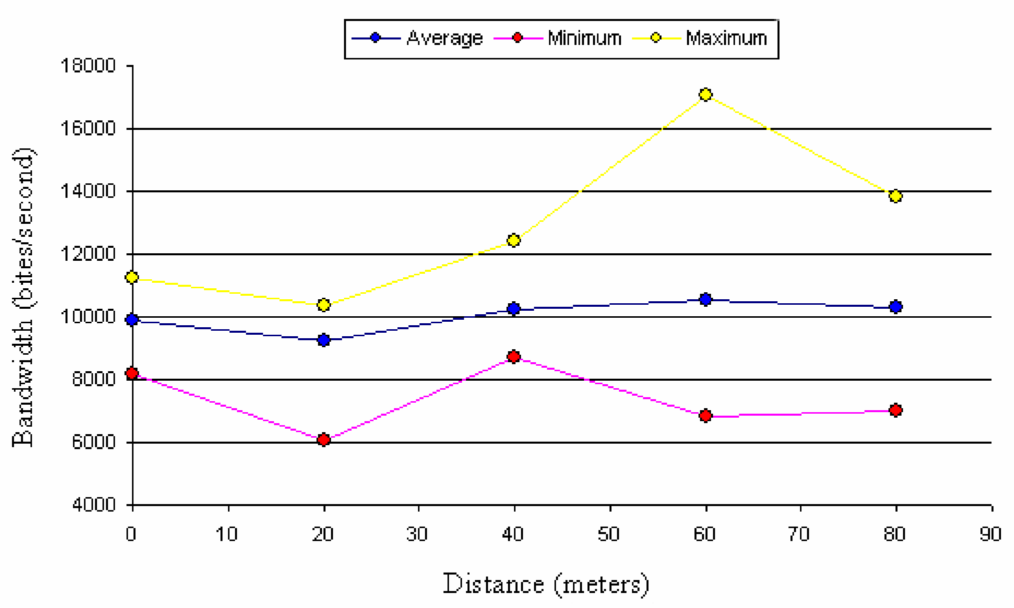

Figure 14 Average result of UDPTest1

In Figure 14 the yellow dots show maximal echo transmission time, red dots represent minimal time and the average time is given in blue dots. The UDPTest2 includes transmission of fixed package size equal to 10000 bytes. The transmission starts when an acknowledgment is received as it is shown in Figure 13. Upon sending acknowledgment the server side saves time stamp and waits for a package n times. In this experiment, value of n is equal to 10 which means only 10 packages are received. Collected data are shown in Figure 15 where red dot is the minimum value of all samples in the same distance, yellow dot – maximum and blue dot – an average value of time. It can be clearly seen that the bandwidth does not vary when the distance is less than 1 meter. However, increasing the distance reduces the bandwidth.

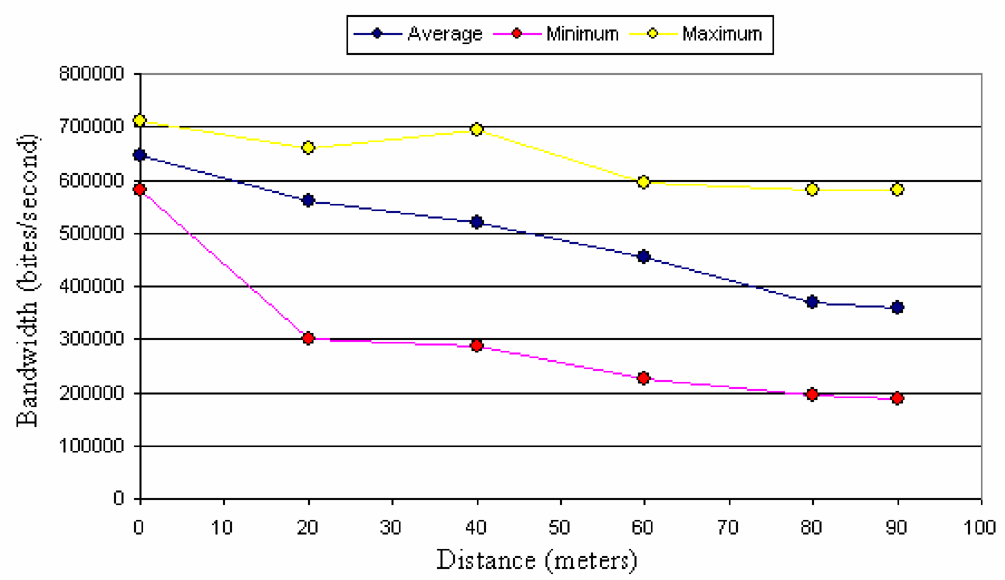

Figure 15 Average result of UDPTest2

The speed variety (difference between maximal and minimal value of speed for the distance) grows with growing distance between devices. The analysis of UDPTest2 data concludes that the measurements have to be performed at least 3 times to achieve accuracy within 10 meters. However, 3 measurements are considered as unreliable because it takes at most 2 seconds to perform them.

In the last test data packages are sent over ICMP protocol in WLAN connection where the echo time is measured. The ICMP protocol was chosen as it is placed in one level lower in the TCP/IP stack than TCP or UDP protocols with assumption that it could be more sensitive to the distance. ICMPTest1 provides fundamental data to be analyzed and uses in propagation model. Collected data are shown in Figure 16.

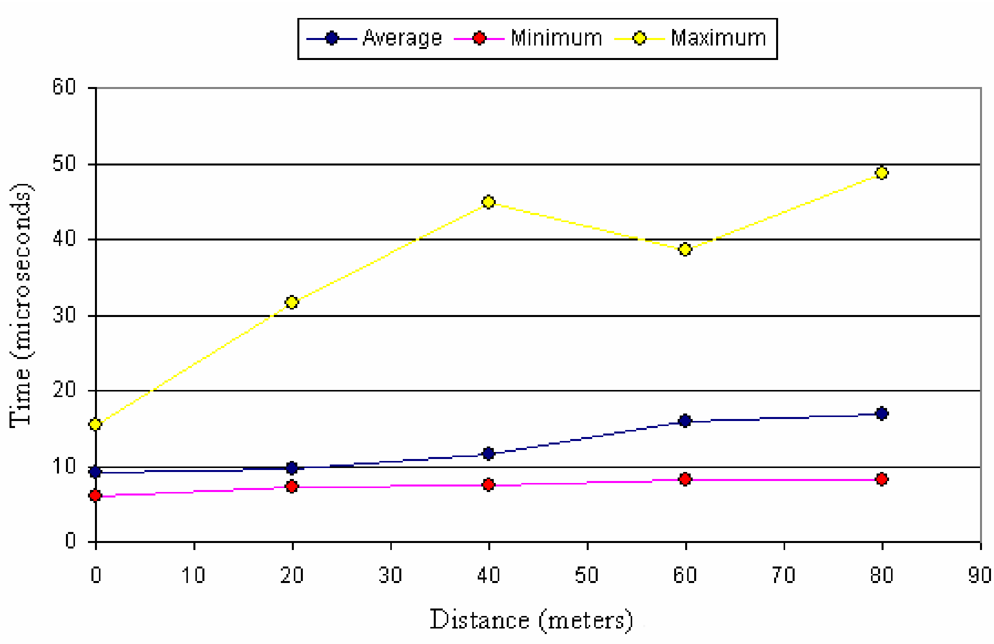

Figure 16 Average result of ICMPTest1

Yellow dots – maximal value of all measurements related to the selected value of distance. Red dots – minimal value of latency for the distance. Blue dots are the average latency for the distance.

Time for echo transmission for a package over ICMP protocol has a significant dependency on distance between devices. The most optimal propagation model is selected from a series of available models that come from the result of the analysis of dependency on distance between devices.

Average latency is added as a parameter to propagation model to make it more reliable and unsusceptible to randomness. 3 different propagation models are calculated in form of $y_x = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + ... + a_k x^k$ where regression coefficients $a_0, a_1, ..., a_k$ are selected with the help of Least Squares Method. Computed propagation models are shown in Figure 17.

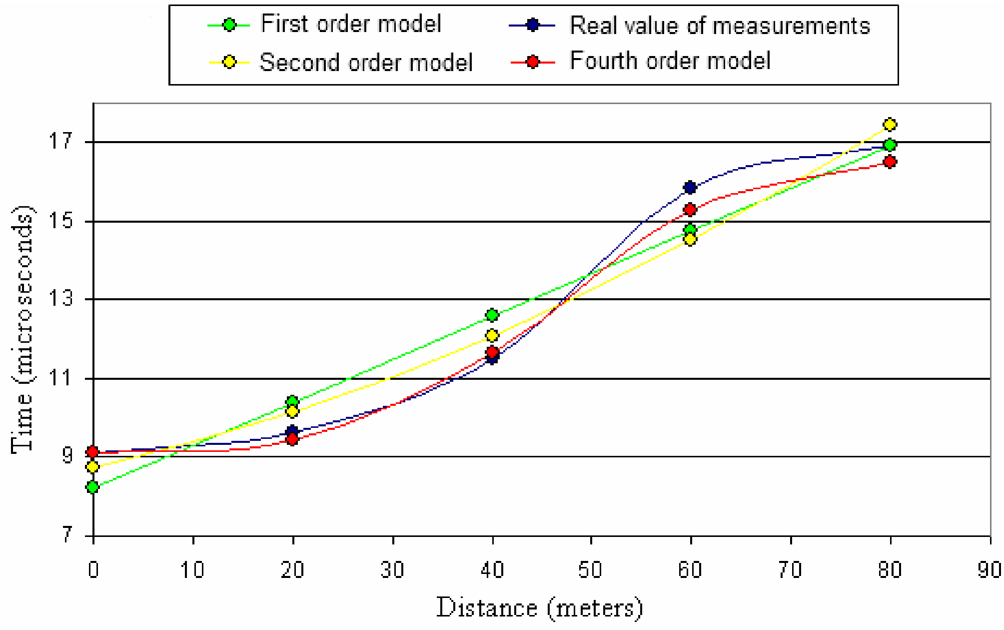

Figure 17 Propagated data by different models

In Figure 17, blue line corresponds to real value of measurements, green line represents the first model - a linear model of first order with computed formula

$$l(d) = 0{,}1089\ d + 8{,}2204 \tag{4}$$

where d -distance and l -latency, yellow line depicts the second model - a hyperbola presented in second order equation

$$l(d) = -0{,}6944\ d^2 + 26{,}5874\ d - 175{,}4476 \tag{5}$$

where red line represents the third model - a polynomial of fourth order

$$l(d) = -0{,}0000009\ d^4 + 0{,}0001\ d^3 - 0{,}0012\ d^2 + 0{,}0091\ d + 9{,}1079 \tag{6}$$

To transform measured latency to distance between mobile devices three models are calculated. They are depicted in Figure 18:

Green line - linear model is

$$d(l) = 8{,}5169\ l - 67{,}1423 \tag{7}$$

Yellow line - second order propagation model is

$$d(l) = \frac{144}{224000} l^2 + 0{,}0576\, l + 8{,}7332 \tag{8}$$

Red line - fourth order propagation model is

$$d(l) = 0{,}0009\ l^4 + 0{,}4492\ l^3 - 18{,}832\, l^2 + 255{,}67\, l - 1106{,}8 \tag{9}$$

Blue line presents real data of latency.

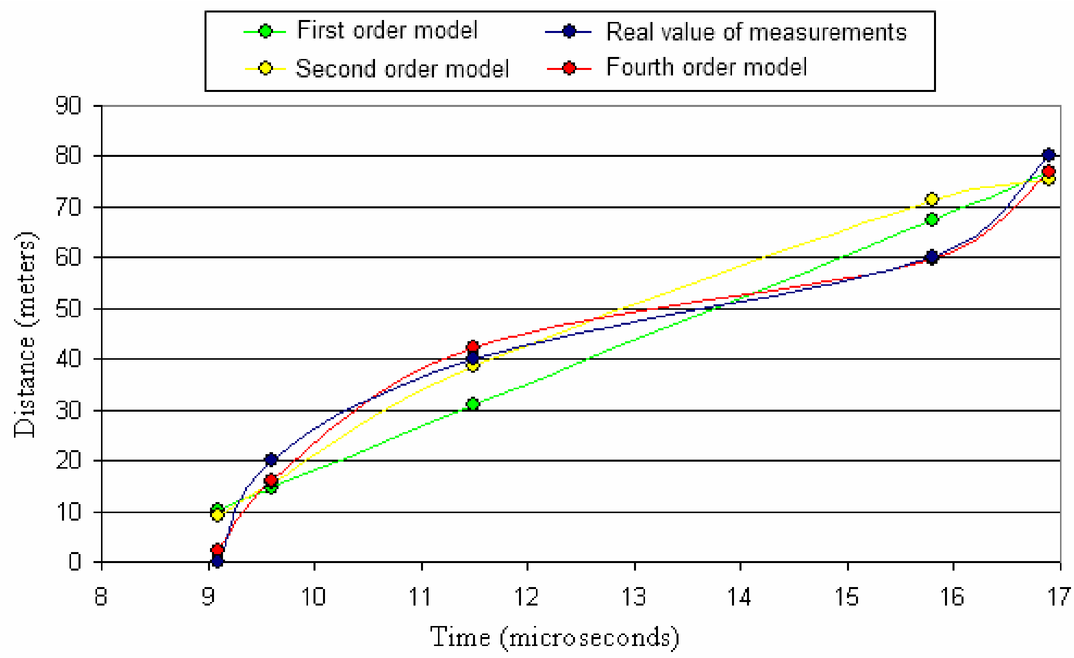

Figure 18 Propagation models for transformation latency to distance

For error analyzing the propagation model of distance calculation based on latency are involved. Propagation error can be seen in Table 1.

Table 1 Calculation of error of propagation models

Latency	1st order model	2nd order model	4th order model	Real distance	Error of 1st order model	Error of 2nd order model	Error of 4th order model
9,1	10,36	8,99	2,15	0	10,36	8,99	2,15
9,6	14,62	15,8	16,08	20	-5,38	-4,2	-3,92
11,5	30,8	38,47	42,21	40	-9,2	-1,53	2,21
15,8	67,42	71,28	59,66	60	7,42	11,28	-0,34
16,9	76,79	75,55	76,88	80	-3,21	-4,45	-3,12

Based on calculations presented in Table 1 the Least Square Error can be calculated for each propagation model. They are 286.32, 248.01 and 34.72 for 1st, 2nd and 4th order models accordingly. Hence, the 4th order propagation model is selected as the best one. The minimal difference in interested points equals to 0.34 and the maximal value is almost 4 meters. The experimental analysis discovered that distance evaluation demands at least 4 measurements of package transmission time delay.

5.3 Suggestion

Built and selected in subsection 5.2 propagation model appears as a reliable model that can provide distance definition with conventional error level of calculation. This model does not include other parameters (such as possible barriers on signal way) and influences that the signal can meet because it is not the main goal of this research. As example, this model can incorporate a number of walls in indoor utilization (see model with Floor Attenuation Factor in subsection 3.5). In propagation model additional optimization algorithms might be applied (see section 4). For example, applying the Extended Kalman Filter optimization algorithm (see subsection 4.3) allows achieving a more precise result regarding distance definition.

So far, in this document, possible approaches in a location definition technique and experimental analysis have been presented. The next section concentrates on a suitable approach for positioning system in changeable environment and its implementation, but before that, this section concludes previous discussions and makes some recommendations about developing the approach.

Nowadays, in spite of a big number of methods and approaches in a location services field, the topic is still actual, because of calculation problems of environmental features in the area where the service is used (see section 3, 4). Another reason is resource constraints of the mobile device (see section 3, 4). Therefore, some approach should be used to make an available utilization of all possibilities that existing techniques allow. The idea of a hybrid location technique is not a new one. It has not been considered in previous discussions because such kind of system is usually built based on before mentioned base methods. One of examples of a hybrid positioning system is presented in article [37]. The difficulty of this type of a system is complexity in implementation and its high cost.

The developing approach intends to be simple for implementation and, at the same time, it is able to provide useful information about the mobile device position. Based on the theoretical analysis, the defined preferences and constraints are as follows:

1. The context based conception was selected to store and manage useful information as the best approach to provide the corresponding substance with relevant information about always changing environment or constant parameters on which the operation process is working.
2. GPS (subsection 3.1) and WLAN (subsection 3.5) positioning are selected for implementation part because they are able to cover outdoor as well as indoor positioning with an accuracy of 2-4 meters. (The current implementation of the application supposes that the system works with GPS and WLAN positioning, but the design considers ability for simple including other positioning techniques such as Bluetooth positioning.)
3. The calculation method for location estimation is originated from Observed Time Difference of Arrival method (subsection 3.2.2) with prominent improvements to be capable of working with different approaches.
4. The movement detector, based on accelerometer, as utilized to decrease a probable error of computation. (The developed system cannot provide real-time positioning by virtue of simplicity. Thus the movement detector is used to determine circumstances for location estimation.)

6 PROTOTYPE APPLICATION DEVELOPMENT

This section provides the answer for research question "How to define location of a device based on environment in which the device is?" and the answer is presented as designed method and developed architecture of positioning system application. Designing method has to represent all situations and environmental features that can happen with mobile device during operation phase. Context based conception is used in application core as information management system. Application is intended to provide location service by utilization current possibilities of environment when the main aspect gives consideration to communication constituent.

Foregoing will be explicated step by step in following subsections: requirements for approach in subsection 6.1; method explanation in subsection 6.2; 6.3 discusses details of use cases for location service application; class diagram for location service application is provided in subsection 6.4; use cases, class diagram for location service and daemon are in subsections 6.5 and 6.6 accordingly.

6.1 Requirements

As mentioned earlier, service location application being developed should be able to estimate location based on current environment. Such requirement supposes that the application behavior should have changeable algorithm. That algorithm follows the best sequence of location computation. Therefore, the context description of hardware as well as available nearby devices will be appeared as source information which will be utilized for planning calculation process of location definition. More specific requirements set for application are following:

1. Application should be able to show whether current location of mobile device or information about a reason on impossible location definition. Location presents current position in map and a position in global frame as coordinates of longitude and latitude.
2. For showing current location the application should be able to calculate location in the best possible way and estimate error of calculation. Method of calculation should analyze possible ways of calculation and select the most suitable one for a

situation where the device is working. As source information the environmental, spatio-temporal, device context should be utilized by method. Constraints about possible methods for location definition as well as features of environment have been discussed in theoretical part with conclusion in section 6 and have to be taken into consideration for developing method.

3. To provide data the application should have a context management processor to operate with contexts. This context processor manipulates with contexts of current device as well as other contexts of nearby devices and environmental contexts.
4. To provide necessary information about measurements and make context exchange between mobile devices possible, the application should have communication system.

In such a manner the application being developed should be realized with implementation of these requirements. During design and implementation the main question of this Master's thesis should be answered: how to define location of mobile device based on current environment in which the device is. The answer includes achieving two goals which have been established for research question: development of technique for definition and software which is implemented with this technique. The next subsection (subsection 6.2) shows the implemented method for calculation and the second goal is achieved during explanation of software architecture in subsections 6.4 and 6.5.

6.2 Method explanation

The method of computation is formulated in sequential actions of computation process. Computation process is operated in cases when the mobile device is stationary (see constraints in subsection 5.3). For this purpose before computation process the movement detector should estimate a state of device. Pseudo algorithm looks like this:

```
0:  IsGPSAttends = GetParameterOfContext(DeviceHasGPSModule)
1:  If IsGPSAttends
        If IsGPSfixed()
            currentLocation = GetGPSLocation()
        Else
            Goto 2
    Else
```

```
8   2:      IsStationary = GetParameterOfContext(DeviceMovementStatus)
9           If IsStationare
10              currentLocation = CalculateLocation()
11      delay = ComputeDelay(speed)
12      Wait IfExpired(delay)
13      Goto 1
```

Algorithm works in an infinite loop and provides the following:

1. If the mobile device has GPS internal module it will be used for location measurement because this information is considered as context source. It is necessarily to mark that the GPS device is not available in any place of usage. In case when the device is not workable to achieve location measurement with internal GPS such as urban area, indoor utilization, the algorithm involves environmental features for location calculation.
2. Compulsory requirement for environmental location calculation is - the device should be stationary.
3. After comparison and calculation blocks, the value of delay is computed based on speed and current location. If the device is stationary, delay is chosen as big as possible because it does not need to make request for location definition and the device does not change location since previous estimation. Current location and speed is needed to propagate movement direction (see subsection 4.3) thereby predict future position.
4. Based on the defined delay the loop stops execution till the time expires (line12). Delay utilization is reasonable by means of optimization algorithm (see subsection 4.3) that allows to save expenditure of energy.

Location calculation algorithm can be depicted like this:

```
counter = 0
savedMeasurements = null
While (counter<4) do
        context = GetBestDeviceContext ()
        If context = null
                break
        measurements = DoMeasurements(context)
        SaveMeasurements(savedMeasurements, measurements)
        counter = counter + 1

measurements = GetMeasurement(savedMeasurements)
while (measurements<>null)
        currentLocation = MakeLocationCorrection(measurements)
```

```
14          measurements = GetMeasurement(savedMeasurements)
```

The logic of the algorithm can be explained as follows:

1. A counter (line 1) is used for performing steps of measurements. It is experimentally established that for achieving quite good result of location estimation, four measurements should be made. Supplementary measurements of fifth and more give insignificant contribution for result accuracy. Therefore, the algorithm utilizes only fourth measurements which are presented as the first loop.
2. The function GetBestDeviceContext() in line 4 supposes temporal storage of contexts about nearby devices exists in the application. Context of a device includes necessary information about hardware device (it is used in selection suitable communication channel for measurements), achieved location, accuracy of achieved location. GetBestDeviceContext selects the best suitable context to perform measurements and includes result into location calculation phase. The function uses such characteristics of the device as accuracy already achieved location and a type of channel for measurement (propagation models of measurements give different accuracy of result).
3. The result after step 2 can be null that means there are no available devices nearby. In this case the loop stops and algorithm moves to calculation phase.
4. The function DoMeasurements(context) gets selected context as information about remote device and with help of available channels makes measurements to estimate distance based on delay and propagation model related to selected channel. Performed experiments and made analysis of propagation model in section 5 determined that at least four measurements should be performed for correct delay estimation.
5. Measurements are saved by calling function SaveMeasurements with two input parameters: savedMeasurements is a list of temporal measurements; measurements are the current measurements to be saved in the list. In modest way the measurements contain: context of device (with including location), distance in meters and accuracy of computed distance.
6. Four last lines of algorithm forms loop by list of measurements (lines 12-14). Each step of the loop receives one line of the list by function GetMeasurement and makes location calculation by function MakeLocationCorrection according to these additional data.

7. The function MakeLocationCorrection gets next scheduled result of measurements as input parameter. The function is organized in such a manner that it has internal storage of pre-calculated data and steps' counter. This inclusion allows making location correction with new data. The calculation algorithm will be presented hereafter.
8. Value of variable currentLocation is considered as a result of location estimation. After measurements collection phase the achieved data are directed to location calculation algorithm for further processing.

The calculation algorithm is presented as working aspects:

1. If list of measurements is empty than calculation location is not possible and user of device should be informed about this situation.
2. First step supposes that location of estimating mobile device is inside coverage area of device with a known location, right picture of Figure 19. An unknown location of device D0 is considered to be the same as location of device D1 and accuracy is the distance between mobile device and base station.
3. Involved measurements of second known device results to the case when the location of estimating device can be in two possible locations. Middle picture of Figure 19 shows this case. An unknown device can be in possible locations D0 and D0' because in these points the measured distances to two known mobile devices are equal. Accuracy of this case is considered as a distance from mobile device to the nearest base station.
4. The third measurements determine the exact position of the unknown device. Left picture of Figure 19 shows that only location D0 matches to known distances. Achieved result has accuracy that calculation method can provide with taken into consideration accuracy of known locations D1, D2 and D3.
5. Calculation with fourth distance measurements is similar as shown on right picture of Figure 19.

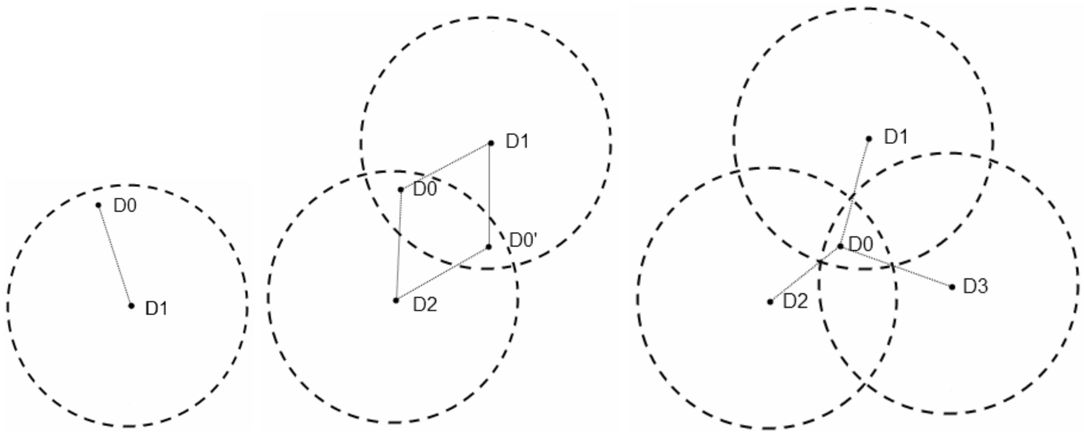

Figure 19 Possible cases during calculation

6.3 Use cases of location calculation application

The use cases for location service application are presented in Figure 20. As it can be seen the client includes four action initiators: Graphical User Interface (GUI), CalculationEngine, ContextEngine and CommunicationEngine which are working jointly. Explanation of use cases are in the following list from MapMoveLeft to GetCurrentLocation.

Pseudo-algorithm for calculation phases (CalculationEngine) was discussed in subsection 6.2.

- **Cases MapMoveLeft, MapMoveRight, MapMoveDown, MapMoveUp, ZoomIn, ZoomOut**

Manipulation with map application area is possible by four presented actions: MapMoveLeft, MapMoveRight, MapMoveUp, MapMoveDown accordingly for actions shifting of visible map area to left, right, up and down directions. They are included to GUI. In addition, two actions: ZoomIn and ZoomOut are used to increase and decrease zooming of scale. This row of function provides a user with necessary tools to clearly see the actual location where the device is because only coordinates latitude and longitude do not appear to be satisfied and have to be applied for a map.

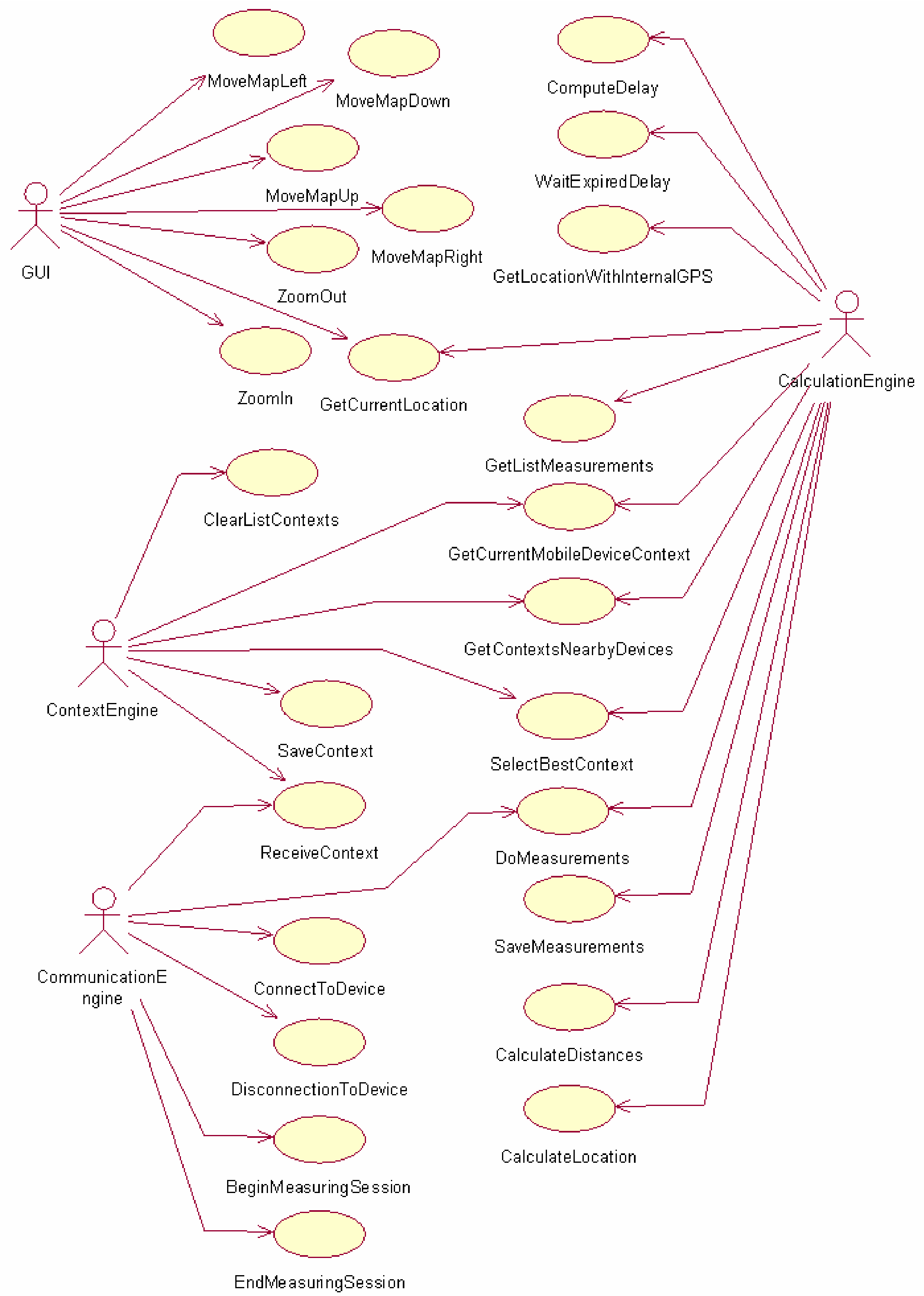

Figure 20 Use cases of location service application

- **ComputeDelay**

This action is run after each calculation location phase. ComputeDelay is given current speed and previous calculated location as input parameters. They are needed to adjust the most optimal mode where delay is varied based on situation. In one side frequency of calculation requests for location estimation should be increased but in another side decreasing frequency saves power consumption. Therefore, the delay is more frequent in movement state than the device is stationary.

- **WaitExpiredDelay**

WaitExpiredDelay is a state of CalculationEngine when there are no any location calculations but the component is able to return the last calculated result. The time for waiting is taken from ComputeDelay.

- **GetLocationWithInternalGPS**

It supposes that an external GPS device is presented in mobile device. If there is no internal GPS device, this sequence of actions is ignored by algorithm. GetCurrentMobileDeviceContext action provides the needed information about current device by parsing device context.

- **ClearListContexts**

Clearing context list with contexts of nearby devices happens before scanning performance. It is done when application starts and it does not need during working period because list is changed when new device is registered or unregistered in cases of coming or leaving coverage area.

- **ConnectToDevice, DisconnectionToDevice**

Before any information can be exchanged the connection should be established. The action of ConnectToDevice does it. It is not compulsory for wireless because the selected protocol for data transfer is UDP and measurements are performed by virtue of ICMP protocol. For Bluetooth piconet must be formed that defines one master and up to 7 slave devices.

Communication channel should be closed if it has been opened. DisconnectToDevice action closes communication channel. This operation is actual for Bluetooth channels but wireless communication is not required for this application because data transmission is through UDP and measurements with ICMP.

- **BeginMeasuringSession, EndMeasuringSession**

Operations BeginMeasuringSession and EndMeasuringSession are responsible for measurement session and they open and close channel and session preparation. These operations are used if selected protocol needs channel establishment such as Bluetooth. As in case with information channel through Bluetooth the measurement session should be opened and closed. For measurements with ICMP, session is not needed.

- **ReceiveContext**

ReceiveContext includes a sequence of operations, after running which a context of nearby mobile device can be received by requested device. This action is performed after connection established in the cases if it is needed (for example Bluetooth). Since developed application works with WLAN to communicate between devices and protocol is UDP, connection establishment is not needed.

- **SaveContext**

Received context as the result of action ReceivedContext is passed to ContextEngine components to be saved in context storage. The context can be interesting for CalculationEngine in the part of collection data about nearby devices. If characteristics of mobile device that is presented by this context is quite good (the algorithm for selection is discussed in SelectBestContext), for further proceeding the context is used for getting information about location and distance.

- **GetContextsNearbyDevices**

ContextEngine is responsible for manipulations with contexts. Therefore, the sequence of operations for reading and preparing list of contexts about nearby devices with utilization of local context storage is implemented in ContextEngine. Achieved list is passed to CalculationEngine for involvement in location estimation process in data collection. This list contains contexts of all nearby devices (communication abilities, current location and date-time of calculation, presence and availability of internal GPS device and so on).

- **SelectBestContext**

Before execution of SelectBestContext action GetContextsNearbyDevices should be run and the result list should be passed to CalculationEngine. SelectBestContext is the second phase of calculations. This action searches the most suitable context for performance of measurements. The algorithm for selection includes consideration of such characteristics as accuracy of location estimation of nearby device, accuracy of propagation model for distance estimation between devices, technology to communicate and so on.

- **DoMeasurements**

After measuring session was established by command of BeginMeasuringSession measurements can be done. DoMeasurements includes N times measuring delay of information transmission. N is defined by empirical verification for each protocol and specific communication unit such as network adapter. For example, N equals 4 and it was proved in experimental part of this Master's thesis for WLAN measuring on discussed equipment. The result after DoMeasurements action is the average delay of N delays.

- **GetCurrentMobileDeviceContext**

This action is used to get information about current mobile device when the client is running. GetCurrentMobileDevice mainly works with context of current device as a source of information. Context of device provides exhaustive information about internal units (for example internal GPS device, Bluetooth), possible channels for communication, propagation models for distance estimation and so on. Context of current device is used during all circles of computation in CalculationEngine.

- **SaveMeasurements, GetListMeasurements**

SaveMeasurements stores the collected information as well as the actual context of a remote device in local temporal storage for being proceeded in distance propagation phase of CalculationEngine component.

As reverse operation to SaveMeasurements, GetListMeasurements is intended for preparing data for DistanceCalculation. GetListMeasurements presents a current list of measurements that was formed in measurements performance phase and saved in local temporal storage.

- **CalculationDistances**

CalculationDistances is the phase when collected after measuring phase data is translated into specific data for location calculation phase. Videlicet, data includes actual location of nearby devices and the distance to them. Distance estimations are constructed on propagation models which are specific for channel and hardware units.

- **CalculationLocation**

CalculationLocation is the last step of calculating current location of mobile device. Based on data about distance and current locations (as result of execution of action CalculationDistances) with utilization of mathematical approach, current location is defined with modulus of precision for estimated location.

- **GetCurrentLocation**

As the part for which the application was created, an action of GetCurrentLocation is. GUI utilizes result of calculations after transformation the result to readable format and shows it on the map. The calculation itself is being performed in CalculationEngine and GetCurrentLocation reads the last estimated location.

CalculationEngine works in background of GUI component and it updates the value of location. Frequency of update is varied and defined by ComputeDelay.

CalculationEngine estimates internal GPS module (if it is presented in current model of mobile device) for ability of fixing sufficient amount of satellites and location calculation. In successful case, the location will be updated by virtue of internal GPS.

If internal GPS module is not available, the calculation is performed based on current environment which involves operations of CalculationEngine, ContextEngine and CommunicationEngine.

6.4 Class Diagram of location service application

Figure 21 shows class diagram for location service application. To design a structure of the application N-tier architecture is utilized.

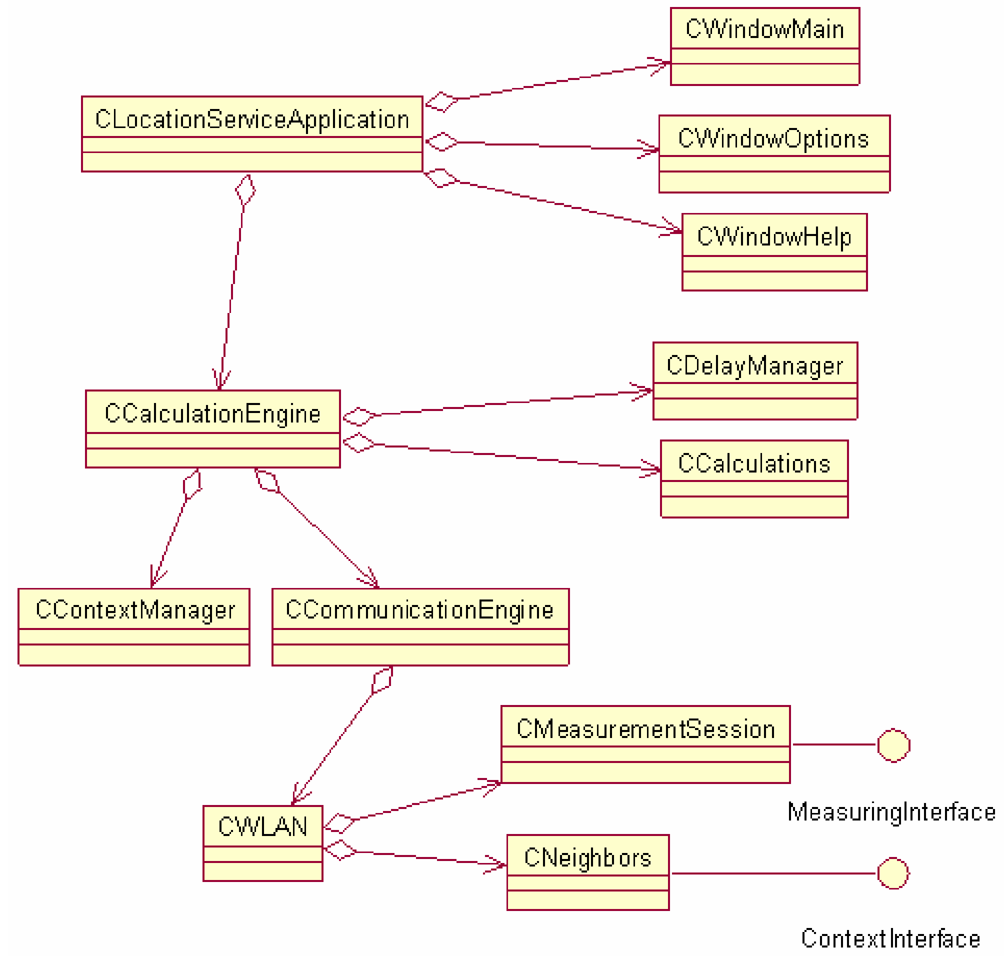

Figure 21 Class diagram for location service application

In this implementation of program only three tiers are needed:

- First tier - graphical user interface (CLocationServiceApplication, CWindowMain, CWindowOptions, CWindowHelp);
- Second tier - classes are responsible for functional logic (CCalculationEngine and supplementary classes: CDelayManager and CCalculations);
- Third tier – classes are responsible for specific small amount of functions (CContextManager, CCommunicationEngine and its extensional classes CWLAN that includes: CNeighbors with operations for scanning and context exchanging; CMeasurementSesion for establishment measurements session and measuring performance).

Location service application is implemented as executable binary module packed in "dpkg" package. It can be easily installed and used on a mobile device.

The first tier intends for interaction with user. CWindowHelp class contains functionality to window form, which can show information about application and possible scenarios of interaction. CWindowOptions class contains window creator which is able to change base settings of application, such as base delay between location definitions.

The second tier is mainly represented by CCalculationEngine. This class calculates location and in these calculations it involves classes: CDelayManager – responsible for delay calculations and internal timers' observation; CCalculations – complement of mathematical functions for location calculation such as CalculateLocation function in final phase of calculations (see subsection CalculationLocation for further information).

The third tier is responsible for interaction: with hardware descriptors (device contexts), environmental descriptors (environmental context); with nearby mobile devices and other devices which can provide validated interface to communicate and has known location. CContextManager class works with hardware and environmental descriptors, CCommunicationEngine class presents common interface for available communication modules. In this implementation WLAN module is appended as class CWLAN. Communication module has to guarantee two constituents:

– Finding nearby devices and context transfer (class CNeighbors through ContextInterface);

– Establishment measuring session with measurer’s accomplishment (class CMeasurementSession through MeasuringInterface).

6.5 Use cases for location service daemon

Use cases diagram for location service daemon is demonstrated in Figure 22.

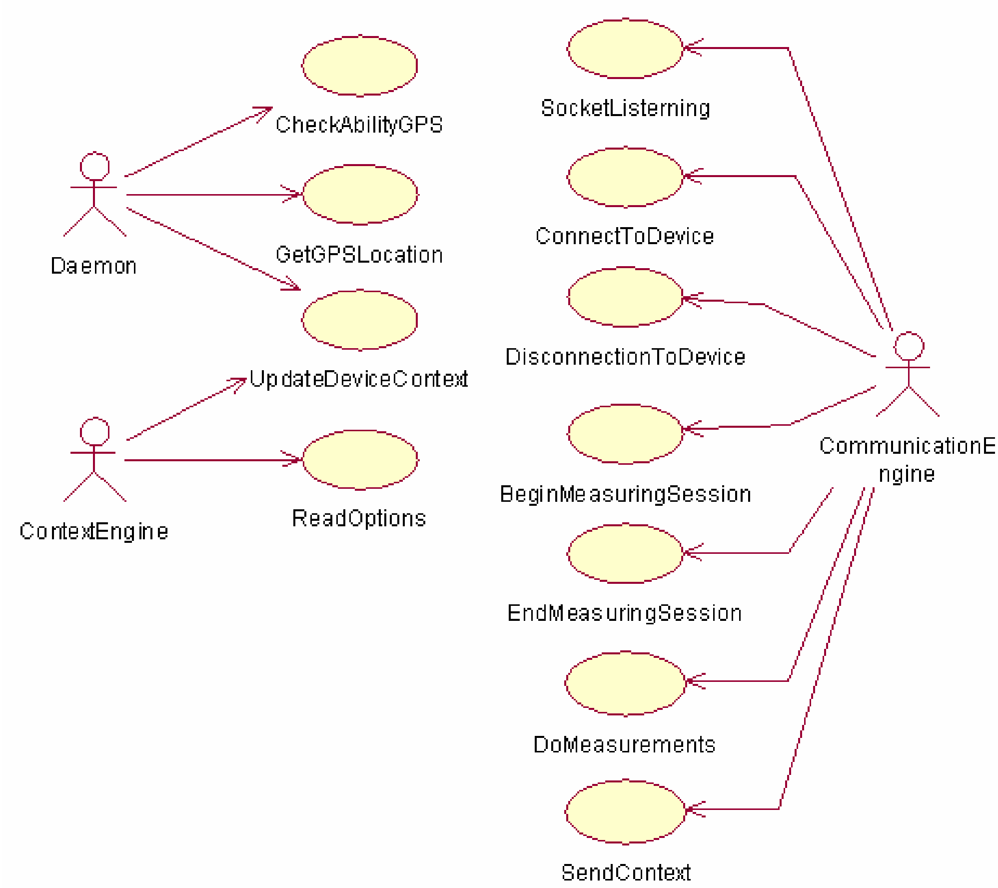

Figure 22 Use cases diagram for location service daemon

Daemon application includes three action initiators: Daemon, ContextEngine and CommunicationEngine. The main purpose of daemon application is a provision other mobile devices by context information about know location and possible accessors to make measurements. Each use case will be discussed in details later in the list from CheckAbilityGPS to DoMeasurements**.**

- **CheckAbilityGPS**

CheckAbilityGPS is sequence of actions that directed to appreciate the state of internal GPS receiver. Checking ability of GPS was made each time stamp that had been adjusted in options of the current device by user of application. This time a stamp is saved in local device context and uploads by ContextManager during starting of application. Receiver can be unavailable in following states: turn off, does not have necessary amount of captures GPS satellites. Availability allows execution of the next step – GetGPSLocation.

- **GetGPSLocation**

This action is run after successfully completed CheckAbilityGPS. GetGPSLocation receives current coordinates of the device and they will be saved in updating local device context in action UpdateDeviceContext.

- **UpdateDeviceContext**

This action updates local context of mobile device with new parameters: achieved new value of location and accuracy, time of updating. Local context is used to form a context to be sent.

- **ReadOptions**

Set of actions which are read in start of daemon application from local context. It contains settings of daemon and its constant values for communication.

- **SocketListerning**

In this implementation of application WLAN module is applied. Context transfer is going through UDP protocol. Therefore, it does not need connection establishment but for communication subcomponent the opened port should be listened. SocketListerning listens on predefined port.

- **ConnectToDevice, DisconnectionToDevice**

Before any information can be exchanged through the network, a connection should be established. The action of ConnectToDevice does it. It is not compulsory, as was

mentioned before, for wireless because selected protocol for data transfer is UDP and measurements performed by virtue of ICMP. For Bluetooth piconet must be formed that defines one master and up to 7 slave devices.
Communication channel should be closed if it was opened. DisconnectToDevice action closes communication channel. This operation is actually for Bluetooth channels.

- **BeginMeasuringSession, EndMeasuringSession**

Operations BeginMeasuringSession and EndMeasuringSession are responsible for measurement session and they open and close channel and session preparation. These operations are used if selected protocol needs channel establishment such as Bluetooth. As in case with information channel through Bluetooth, the measurement session should be opened and closed. For measurements with ICMP session is not needed.

- **SendContext**

SendContext includes sequence of operations for preparing and transmission a context to requested nearby mobile device. This action is performed after connection established in the cases when it is needed (for example Bluetooth). Since developed application works with WLAN to communicate between devices and protocol is UDP, connection establishment is not needed.

- **DoMeasurements**

After measuring session was established by command of BeginMeasuringSession measurements can be done. DoMeasurements includes N times measuring delay of information transmission. N is defined by empirical verification for each protocol and specific communication unit such as network adapter, see DoMeasurements in subsection 6.3.

6.6 Class Diagram for location service daemon

Class diagram for location service daemon is depicted in Figure 23.

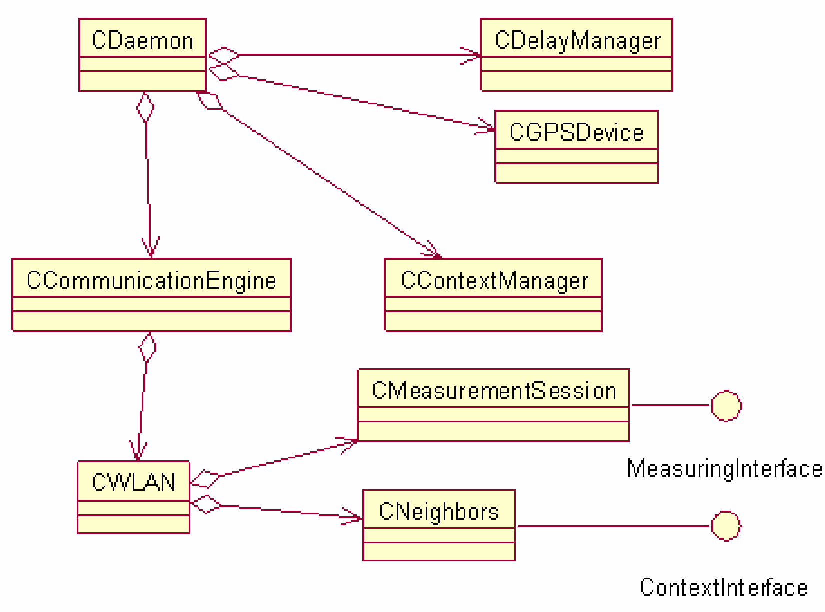

Figure 23 Class diagram for location service daemon

Likewise architecture of location service application the daemon was constructed in N-tier structure.

Only 2 tiers can be separated. First tier implements logic of daemon, classes: CDaemon and CDelayManager. Second tier is responsible for base operations with GPS receiver, context and communication constituents and includes classes: CCommunicationEngine, CContextManager, CWLAN, CNeighbors, CMeasurementSession and CGPSDevice. Location service daemon does not have graphical user interface because it is purposed to work as daemon in background. It works all time and ready to answer for requests from nearby devices as well as updating local context for location service application. CDaemon class arranges the main loop where CDelayManager is used for fixing time stamps of timers. CGPSDevice reads location coordinates of internal GPS receiver. CContextManager class works with hardware and environmental descriptors. CCommunicationEngine class presents common interface for available communication modules. In this implementation WLAN module is appended as class CWLAN. Communication module has to guarantee two constituents:

- Finding nearby devices and context transfer (class CNeighbors through ContextInterface);
- Measuring session establishment with measurers' accomplishment (class CMeasurementSession through MeasuringInterface).

7 IMPLEMENTATION

The location service is implemented in two parts: client application and daemon were accomplished between January and August of 2009. Design and implementation were fulfilled completely. The hardware for development part is composed of a stationary PC, a laptop PC, Nokia N810 mobile devices. Maemo 4.2 Diablo was selected as programming environment; xserver-xephyr was utilized to show and testing graphical part of client application. C++ programming language was used for software development due its efficiency and availability in programming for mobile devices series of N8XX. The examples and tutorials were used to get a better understanding of Maemo environment.

7.1 Application description

During the design part, the context solution has come as the best possible way to describe and present changeable information about device and surroundings in mobile environment. Two types of context exist in different parts of service:

- Local device context is used only internally by the device. This context contains: full information about communication possibilities of the device, current location (two modes - calculated with environmental usage or obtained from internal GPS device), accuracy of location, available nearby devices and access points with known location and maintenance of suitable interface.
- Transmitted context is sent through a possible communication channel. This context contains short information of the described device: current location, way of achieving this location and its accuracy; available technologies for communication. The context is formed from information of local device context correspondently.

Since it is the pilot project, an assumption concerning the used area is done. Therefore, for simplicity, this release of location service application does not have dynamic map uploading, but has a map of Lappeenranta with surrounding regions. It is assumed that the system will be used within this region.

Another restriction that was discussed before and has to be mentioned is protocol selection. This release of the client application and daemon is built with existence of Wi-Fi communication technology. It assumes that location service would be working on device which has a Wi-Fi network adapter. As an alternative variant the application can work only based on data from an internal GPS receiver but this deployment solution excludes adaptation ability of the application that makes functionality similar with usual GPS client.

This approach can be improved with addition communication module as well as propagation model for distance definition. This module can work instead of used WLAN in the following cases:

1. The system is built for devices that do not have WLAN adapter;
2. The applied module can propagate value of distance more precisely.

The security aspect should be considered, since it has not been done so far. Current client application and daemon are not equipped by any instruments to make the service secured. There are two ways for future development:

1. The service will be made for common utilization and will not have security means. Service actually provides new information and does not support transmission confidential data or sensitive information.
2. The service will be deployed in some region and provision by location information can cost some amount of money. This system deployment has to maintain authentication and authorization procedure as well as secured communication and payment accounting.

The second scenario of deployment requires additional research, but this solution intends to work as a commonly available service.

Since the client application has a graphical user interface, it could be reviewed shortly now.

The current solution has a very simple user interface that provide the main goal of application. Thus menu contains following items:

– Show current location – the action includes a sequence of operations for location definition (see subsection 6.2 for more information);

- Options – shows the window for editing parameters of calculation process and options of the program;
- Help – window to see a help and information about program;
- Close – closes application.

The main window of application has a working area with map that is depicted in Figure 24. The map is automatically retrieved at the application start up. The map can be moved to right, left, up and down direction by clicking on it.

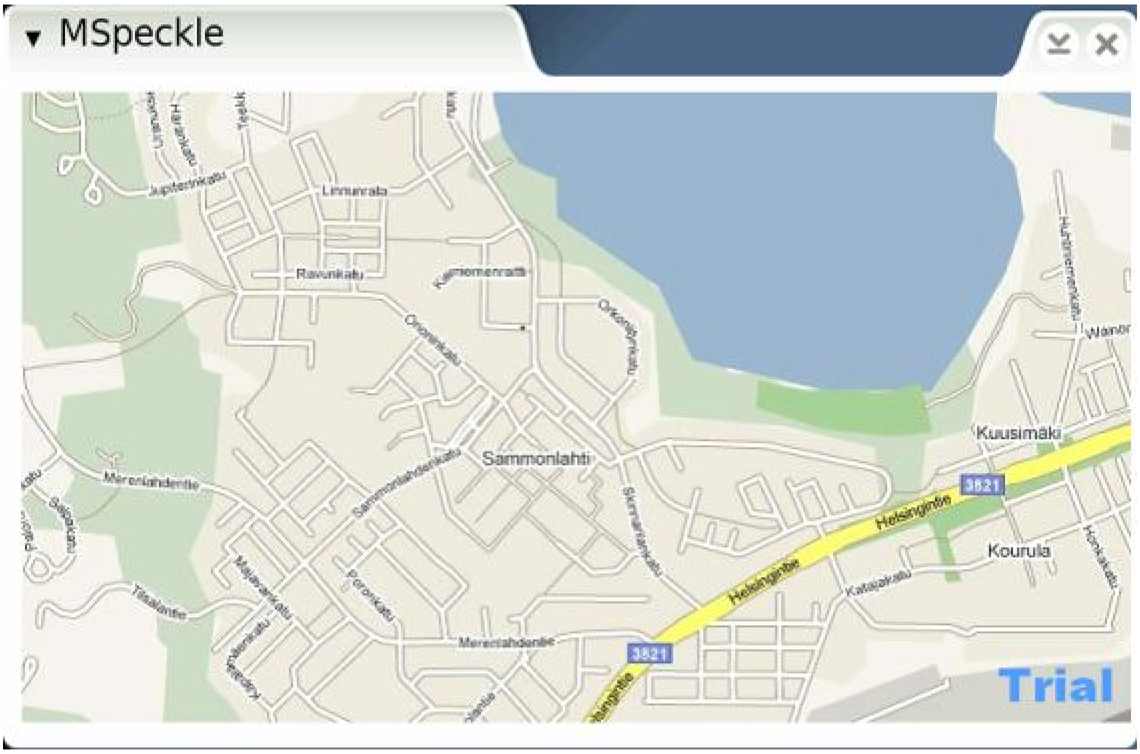

Figure 24 GUI of location service application

A small cross on the map points to the calculated location of mobile device.

7.2 Testing

Testing was performed in especially created situations in reality, in which the functionality of location service was analyzed. Since location service includes two components: location service application and daemon, the test was specified partially for each functional part. There is GUI in location service application which has been tested for correctness of performance of user commands. The client successfully retrieved map and did navigating process by moving current visible part of the map. Graphical part for setting up program options after checking lets transfer data to responsible module and writes them into local device context. The daemon application does not have UI because it suppose to work as a background application seamlessly to the user. In addition, a suggestion on communication ability of client application with daemon was presented and data context was updated.

The next phase of the testing process has to reveal issues of communication performance between two or more mobile devices with intention to collect necessary data and estimate distances between current device and nearby devices. Thus client application and daemon were estimated for correctness and time spent for calculating the result. The issue was met in the case when some packages were lost during distance measuring process and application was working very slowly. This issue had been fixed by decreasing waiting time for timer from 1 second to 0.1 seconds. Other parameters of communications on measuring performance as well as for context transfer were not found to cause problems.

It should be mentioned that this application is the first release to proof a concept and since the main idea is not a development of the best propagation model, the application gave bad accuracy in situations when distance measurement signal met some barrier on data transmission path. A way to solve this problem is recommended in section 8.

7.3 Accuracy estimation

Since the Master's thesis intends to determine a location, the accuracy of obtained results will be analyzed in more detail. For this estimation two tests were performed:

- Outdoor test - rural area which was especially selected for the reason of having buildings and trees;
- Indoor test – testbed was located on third floor of the 6th building in Lappeenranta University of Technology.

For accuracy estimation the client application was modified for showing nearby devices as well as temporal computational data that is presented in Figure 25 and Figure 26. Figure 25 displays an arrangement of mobile devices in the rural area. L0 is the test position of measuring device; L1, L2, L3 and L4 are mobile devices with known location of itself and daemon application was run on them. d1, d2, d3 and d4 are approximate coverage areas for devices L1, L2, L3 and L4 respectively.

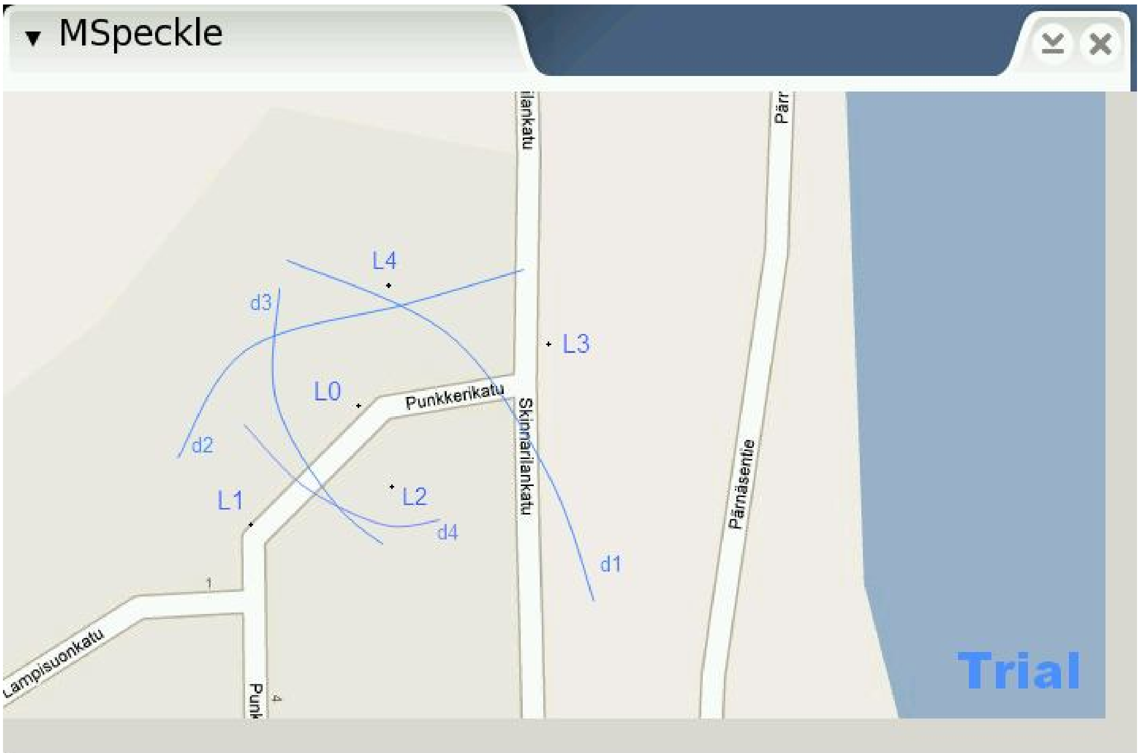

Figure 25 Outdoor test

The measurements were done in the point L0 and the result is presented in Table 2.

Table 2 Result of outdoor test

Number of experiment	Calculated longitude	Calculated latitude	Real longitude	Real latitude	Difference of longitude	Difference of latitude	Distance in meters
1	61,060412	28,102315	61,060332	28,102392	0,000080	-0,000077	9,6
2	61,060189	28,102448	61,060332	28,102392	-0,000143	0,000056	9,9
3	61,060319	28,102465	61,060332	28,102392	-0,000013	0,000073	8,2
4	61,060304	28,102368	61,060332	28,102392	-0,000028	-0,000024	3,0
5	61,060430	28,102420	61,060332	28,102392	0,000098	0,000028	6,1

There were 5 experiments performed. The longitude and latitude calculated by the client application is presented in the second and third columns of Table 2. Real longitude and real latitude were measured with GPS receiver on the place L0. Also, Table 2 shows differences of the longitude and latitude between real position of the device and the determined one and then the distance is expressed in meters. Based on this analysis the average distance between of location determination and real location equals 7.4 meters, minimal distance – 3 meters and maximal is about 10 meters.

Indoor test was arranged on the third floor of the University where the mobile devices with daemons were placed on special positions with known locations. The client application for indoor test is shown in Figure 26.

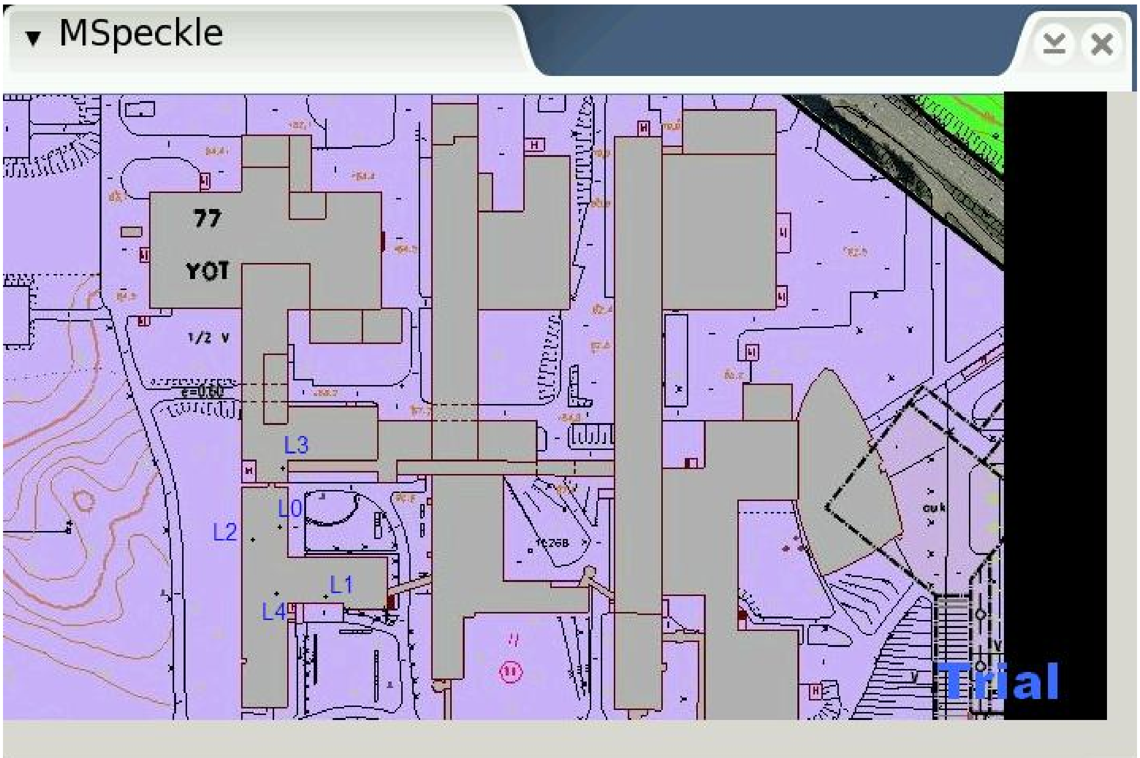

Figure 26 Indoor test

The result of experiments, analogically with outdoor analysis, is presented in Table 3.

Table 3 Result of indoor test

Number of experimen t	Calculated longitude	Calculated latitude	Real longitude	Real latitude	Difference of longitude	Difference of latitude	Distance in meters
1	61,065357	28,092603	61,065343	28,092542	0,000014	0,000062	3,2
2	61,065331	28,092661	61,065343	28,092542	-0,000012	0,000120	5,4
3	61,065373	28,092528	61,065343	28,092542	0,000031	-0,000013	4,1
4	61,065350	28,092493	61,065343	28,092542	0,000008	-0,000048	2,3
5	61,065314	28,092412	61,065343	28,092542	-0,000029	-0,000130	6,8

The distances of the measured location and the real location of the device are within the 2.3 to 6.8 meters spread. The average distance is 4.4 meters. It is worse than outdoor test because for indoor test nearby devices are located closely to target device. For relative error accuracy calculation, additional external location were selected at a 100 meters distance from the original point (L0). Table 4 shows results of outdoor. The external position was located at latitude 61.062191 and longitude 28.102392 and for indoor test, which is shown on the Table 5, the external position was located at latitude 61.064601 and longitude 28.093008. The difference between the original distance i.e. 100 meters and the new obtained distance is calculated. The average difference in distance calculated from the set of experiments is found to be approximately 4 meters for outdoor (last column of Table 4) and 2.5 meters for indoor test (last column of Table 5).

Table 4 Calculation relative error for outdoor test

Number of experiment	Calculated longitude	Calculated latitude	External position longitude	External position latitude	Distance from external position to real position in meters	Distance from external position to calculated position in meters	Difference in meters $\|\Delta d\|$
1	61,060412	28,102315	61,062191	28,102392	100,0	96,1	3,9
2	61,060189	28,102448	61,062191	28,102392	100,0	107,9	7,9
3	61,060319	28,102465	61,062191	28,102392	100,0	101,0	1,0
4	61,060304	28,102368	61,062191	28,102392	100,0	101,5	1,5
5	61,060430	28,102420	61,062191	28,102392	100,0	94,8	5,2
						Average $\|\Delta d\|$:	3,9

Table 5 Calculation relative error for indoor test

Number of experiment	Calculated longitude	Calculated latitude	External position longitude	External position latitude	Distance from external position to real position in meters	Distance from external position to calculated position in meters	Difference in meters $\|\Delta d\|$
1	61,065357	28,092603	61,064601	28,093008	100,0	101,9	1,9
2	61,065331	28,092661	61,064601	28,093008	100,0	98,1	1,9
3	61,065373	28,092528	61,064601	28,093008	100,0	104,7	4,7
4	61,065350	28,092493	61,064601	28,093008	100,0	102,0	2,0
5	61,065314	28,092412	61,064601	28,093008	100,0	98,1	1,9
						Average $\|\Delta d\|$:	2,5

With this calculated average error parameters, it can be concluded that the relative error accuracy for outdoor test is approximately 4% and the same for indoor test equals 2.5% approximately.

8 CONCLUSIONS AND FUTURE DEVELOPMENT

This Master's thesis described the development of location service for Nokia N8XX series mobile devices. Performed experiments, for different communication protocols, examined the matter how distance between mobile devices influences channel characteristics such as bandwidth and latency. Based on this influence the propagation model was built.

Location definition approach, that had been developed with help of existing methods and approaches, was discussed in details and based on it the architecture of applications were designed. Testing application included an analysis of 5 experiments differently for indoor and outdoor measurements. The analysis showed that relative error accuracy for outdoor test is approximately 4% and for indoor test equals 2.5%.

Possible future researches and improvements for application and approach may include following:

- Additional experiments and approaches of optimization techniques should be applied in the part of movement detector and this part has to be thoroughly tested.
- Calculated location coordinates should be corrected to be more accurate by Authorized Company because each region has specific level of deviation and its own algorithm for location calculation.
- A significant disadvantage of implemented service is inability to define precise distance in the case when measurement signal meets a barrier. It can be solved by applying a more advanced propagation model, for example, which was presented in article [21].
- Authentication and authorization issues have to be solved if the system is going to work as a commercial release but current project intended to be a commonly available service.
- Location service could work on different platforms. Developed package can be compiled without fundamental code changes to be run on platform Nokia N900 with Maemo 5.0 Fremantle. However, to support the Symbian platform, the application should be rewritten completely with usage of approach of this Master's thesis. If the system has to serve devices on Bluetooth communication

technology then appropriate communication module should be studied and implemented with propagation model.

In front of the thesis, the following research question was formed: “How to define location of the mobile device based on environment in which the device is?” The answer was presented by describing the approach for location definition and architecture of applications which implement this approach. Aims - development of the technique and application which are providing definition of location - were achieved.

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