Bjarte Stien Karlsen

# Enabling a Ubiquitous Location Based Service on Campus

Trondheim, February 2006

Norwegian University of Science and Technology
Faculty of Information Technology, Mathematics and Electrical Engineering
Department of Computer and Information Science

Master's thesis
Programme of study: Master of Science in Informatics

Supervisor: Hallvard Trætteberg, IDI
Co-Supervisor(s): Dag Svanås, IDI

NTNU
Innovation and Creativity

NORWEGIAN UNIVERSITY OF TECHNOLOGY AND SCIENCE

FACULTY OF INFORMATION TECHNOLOGY, MATHEMATICS and ELECTRICAL ENGINEERING

**MASTER THESIS**

---

**stud.techn:** Bjarte Stien Karlsen

**Dicipline:** Informatics

**Thesis title:**

Enabling a Ubiquitous Location Based Service on Campus

**Abstract:**

This thesis have looked at two subjects that are a necessary part of a Location Based Service. Guidelines on how to make a *Location Model* of the campus has been suggested. The proposed model enhanced already existing suggestions and provides support for different queries. Testing was done with Ekahau WLAN positioning technology to *obtain location information*. The results of the testing showed that the technology was suitable to provide a services that required accuracy at room-level. Services that required a finer grained location estimate where not feasible.

---

| | |
|---|---|
| Thesis started: | January 15, 2004 |
| Thesis delivered: | November 30, 2005 |
| Department: | Department of Computer and Information Science |
| Councilor: | Hallvard Trætteberg |

Trondheim, [7ex] Hallvard Trætteberg
Associated Professor

# Acknowledgements

First I would like to thank associated professors Hallvard Trætteberg and Dag Svanæs for proposing the thesis to me and guiding me through the process. The process started with discussions around the field of indoor location based services, and how WLAN technology could be used for obtaining location information. The assignment where refined and in March 2004 the final suggestion was made.

Secondly I want to thank Reza S. Mirzaei who cooperated with me on the first part of the thesis, Location Modeling. Cooperating with such a productive student was satisfying and motivating.

I would like to thank Arne Dag Fidjestøl, Sigbjørn Ørjanvik, Knut-Helge Vinheim and Reidar Martin Svendsen for helping me setting up my testing setup with Ekahau WLAN technology. I would also like to thank Aina C. Wennberg for letting me borrow her laptop PC during the experiments.

For motivating me and giving advice on how to write a thesis and just general helpful words during the process, I would like to thank Magne Syrstad and Yngve Dahl.

Thanks to Kjartan Karlsen, Håkon Skappel and Lena C. Wennberg for proof reading my thesis.

And finally I would like to thank my fiancee Lena C. Wennberg for her endless support, motivation and help during the work with this thesis.

Bjarte S. Karlsen
Trondheim November 30, 2005

# Contents

# List of Figures

# List of Tables

# Abbreviations

| | |
|---|---|
| B-MAD | Bluetooth Mobile Advertising |
| BTS | Base Tranceiver Stations |
| CM | Communication Model |
| CPPP | Carrier-phase point positioning |
| DAG | Directed Acyclic Graph |
| EAS | Ekahau Application Suite |
| EPE | Ekahau Positioning Engine |
| ER | Entity-Relationship |
| GIS | Geographic Information Systems |
| GPS | Global Positioning System |
| GPRS | General Packet Radio Service |
| GSM | General System for Mobile Communication |
| GUI | Graphical User Interface |
| IBM | International Business Machines |
| IM | Instant Messaging |
| IR | Infrared |
| IPS | Indoor Positining System |
| ITV | IT-Vest |
| LBS | Location Based Service |
| LM | Location Model |
| LRM | Location Representation Model |
| NSEP | Norsk Senter for Elektronisk Pasientjournal |
| PDA | Personal Digital Assistant |
| RAUM | Relation of Application objects for communicating Ubicomp event Messages |
| RF | Radio Frequency |
| RFID | Radio Frequencey Identification |
| RSSI | Received Signal Strength Indicator |
| RTLS | Real Time Location System |
| SDK | System Development Kit |
| SSID | Service Set Identifier |
| UML | Unified Modeling Language |
| VIS | Versus Information System |
| WLAN | Wireless Local Area Network |

# Chapter 1

# Introduction

In recent years mobile computers that can communicate wirelessly have become very popular. With this new trend in technology users expect and demand new services.

A *Location Based Service* (LBS) is a type of application that can open doors to entirely new possibilities. An LBS is 'aware' of the location of a device and enables the user to perform tasks based on this information. The technologies that enables us to do this are already in place, and more solutions are appearing every year. In a society where information is part of our everyday life these kinds of services can become useful in many contexts.

Outdoor positioning has become common with *Global Positioning System* (GPS) [60] used in navigators and map plotters. GPS is a satellite-based navigation system that works very well outdoors but lacks support indoors and in urban areas with tall buildings. There are many suggested technologies and techniques that will offer the same functionality as a GPS indoors. Still there is not yet a de-facto standard for indoor positioning.

The possibilities for an LBS in an indoor environment are promising. Tracking or locating an object within a given domain could be used to manage equipment and personnel. This would enable a manager to know the position of the tracked objects at all times, and even find out where they have been during the day. This information could be used to physically store the object in the most efficient position. The end result would be that the usage of the object and the entire process would be more optimized. The same service could be used to track office personnel to improve the process of their work. Another interesting possibility is the optimal placement of a worker compared to who the worker is usually communicating with.

However, there are several issues that should be taken into consideration when creating an LBS. Privacy, security and legality as well as economical issues are all important factors when working to enable an LBS.

In order for an LBS to work properly a model that describes the domain is needed. This *Location Model*(LM) must have a functionality that allows the position of an object to be shown in a way that is informative for the user. Knowing the geometric location of an object inside a building can be valuable, but often it is more interesting to know what room the object is in. Then, when you know the room, the geometric location inside that room can be of value.

Obtaining location information in an indoor environment can be done in several ways. In many office buildings you must have an electronic access card to gain entrance. This information could be used to tell if a user is inside the building or not. Using technology that register when a small 'tag' that a user keep on his person moves in the proximity of a sensor is another possibility.

A *Wireless Local Area Network* (WLAN) can also be used to position a user and produce location information. Since WLAN is more and more common it is a great advantage to use it to obtain the location information. Not only would this decreased the cost of the positioning system, but it would also shorten the time it would take to develop an LBS on the campus. In this thesis the experimentation with technology to obtain location information will be based on a WLAN based position system from Ekahau Inc, the *Ekahau Positioning Engine* (EPE).

## 1.1 Research Questions

The main purpose of this thesis is to ***propose guidelines for location modeling and obtain useable location information in a campus environment***. The research done in this thesis will be based on answering the following questions:

1. What are the requirements of location modeling and how are these requirements fulfilled in order to create location models used for symbolic as well as geometric positioning?
2. What kind of LBS scenarios are interesting in a campus-like environment and what location information do the scenarios need?

3. How can location information be obtained in a campus-like environment in order to support an LBS?

## 1.2 Cooperating with Reza S. Mirzaei

Part of this thesis is done as a collateral work with Reza S. Mirzaei [44]. This includes part of the related research, methodology and the location modeling chapters.

## 1.3 Limitations

In the work done to enable an LM an early demand was that the model should be independent from the positioning technology. The proposed LM should be able to locate trackable devices from several different positioning technologies. The process of creating guidelines for location modeling is therefore limited in that it must be generic. In addition to this the LM must support both symbolic and geometric location information.

The work of obtaining location information is limited to the available technology. It was early decided that EPE was to be used as the positioning system. This decision was based on early experiences with the technology, discussions with supervisors and the connection to the NSEP [1] usability lab. The technology used is purchased for the NSEP lab and this project is the first to try it out. The testing to obtain the location information will therefore be limited by the way EPE works.

The infrastructure of the campus is another limitation to the testing to obtain location information. The testing in the corridor environment at *IT-Vest* (ITV) is done in an ordinary corridor where people are present at all times. Because of this it was not possible to gain entrance to all the offices. Setting up extra base stations was not allowed because of the policy of the IT department on NTNU. In order to test an improved infrastructure the NSEP usability lab was used. At NSEP the only limitation is the time schedule of the usability lab.

## 1.4 Structure of the thesis

This thesis starts of with an introduction to motivate the user and introduce the work that has been done.

[1] Norsk Senter for Elektronisk Pasientjournal, Norwegian center for electronic patient journal

The second chapter describes research methodology, especially the methodology used in both main parts of this thesis.

The third chapter discusses related research that are relevant in order to get a basic understanding of the work that will be done.

The fourth chapter, Location Modeling, discusses location modeling in more detail and describes the modeling technique suggested in this thesis.

The fifth chapter, Obtaining Location Information, looks at what location information is needed at a campus to support interesting scenarios and how to obtain that information.

The sixth chapter discusses the results in this thesis, reflect upon them and give advice for further work.

The seventh and final chapter concludes this thesis.

The thesis has two appendices. The first shows the test figures used in the fifth chapter. The second appendix elaborates the testing application that was made to achieve the tangible data from the testing in the obtaining location information chapter.

# Chapter 2

# Research Methodology

In this chapter different paradigms, approaches and methods for doing research in informatics are presented. The purpose of this is to familiarize the reader with the theory and terms of research methodology. Then the specific methodologies used in this thesis are presented.

## 2.1 Research in Informatics

Computer and information science, also referred to as "informatics", is a multi-disciplinary field. Research conducted in such broad sciences allows for different directions concerning approach and method. Exactly which approach or method that is selected depends on the research questions and how the researcher wishes to answer them.

### 2.1.1 Paradigms

The term *paradigm* comes from the Greek words *paradeigma* meaning "pattern" or "example" and *paradeiknunai* meaning "demonstrate". According to Kuhn [39] a paradigm is a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality for the community that shares them, especially in an intellectual discipline. The paradigm involves valid research methods, topics and criteria for solution of scientific problems. Two well known research paradigms in informatics, as described by Cornford and Smithson [13], are the *positivist* and the *interpretive*.

The positivist paradigm aims at explaining different phenomena by specifying relationships between variables. The basis for these explanations are laws and theories.

The positivist paradigm is based on natural science and assumes a reality independent of human perception. It separates facts from values and explains events by relating them to general laws [48]. It is:

> *an approach that directly reflects the methods of (natural) science and a belief in their generality for all spheres of enquiry.*
>
> *[13, p. 38]*

Unlike the positivist paradigm, the interpretive does not assume an independent reality [48]. The purpose of research within this paradigm is to explain and understand different phenomena based on human perception, i.e. based on the way the reality is perceived and the meanings which our surroundings are given. An information system is thus something that:

> *can only be 'interpreted', never fully specified or reduced to theories*
>
> *[13, p. 47]*

### 2.1.2 Perspectives

Research in both paradigms can be conducted with either a *quantitative* or a *qualitative* perspective. The quantitative approach describes the topic and analyzes the data by developing metrics and providing generalizable knowledge. It is based on theories and laws and uses a set of standardized tools.

The qualitative stance relies on other means than numbers and seeks to provide specific knowledge through deep insight and descriptions. Data using this approach is often gathered through observation and documented in the form of text, images or audio/video recordings (e.g. videotaping an interview). It has an exploratory style and the tools used are often adapted to, i.e. made to fit the research topic.

As further perspectives to research, Cornford and Smithson [13] speak in loose terms of "theoretical" (non-empirical) and "empirical" research. Theoretical research is carried out by systematically applying a theory or hypothesis to existing knowledge with the intention of uncovering, changing or integrating new knowledge.

The main focus is on ideas and concepts. Empirical research is carried out by observations of the real world where the purpose is to thoroughly explain the observed phenomena. Here, the emphasis lies on observation and data. These two styles of research influence each other mutually:

> *Theory gives motivation to empirical research; [. . . ] Empirical research, in turn, provides evidence to drive processes of theory development.*
>
> *[13, p. 42]*

The positivist paradigm relies to a large extent on empirical research [13, p. 37], [48, p. 20]. However, while theoretical knowledge only belongs in the interpretive paradigm, empirical knowledge can be done with a interpretive as well as positivist paradigm. Research in both paradigms can be conducted using either one of the perspectives. Interpretive research can for example be done by observing some phenomenon over time to describe its behavior, just as positivist research can be conducted using theories to prove/reject laws or theories.

### 2.1.3 Approaches and Methods

Regardless of a positivist or interpretive basis, there are three major approaches to research: *constructive*, *nomothetic* and *ideographic* [13, p. 43]. The approaches are used to define how the research is to be conducted and what type of results the scientific work is aimed at yielding.

The constructive approach is concerned with answering questions through the construction of models, diagrams and plans. Nomothetic research has the purpose of discovering, supporting or rejecting general laws of behavior through the principles of creating, testing, and applying scientific knowledge. Research based on the ideographic approach seeks to give deep, "thick" descriptions of phenomena by getting involved with the research subject and observing general principles and behavior over time.

Although this classification is helpful in organizing different approaches, further specialization is required in order to define specific methods that can be used to perform scientific work. The different methods systematically define steps that have to be taken along with tools that are to be used when researching a topic.

These methods can be either quantitative or qualitative. Typical quantitative ones are *surveys* and *laboratory experiments*. Surveys are conducted using questionnaires and structured interviews, while experiments are performed in controlled environments by testing a theory through manipulation of data.

Examples of qualitative methods are *action research* and *case studies*. Action research requires a high degree of subject and researcher involvement. It is a participatory process concerned with integrating action and reflection, practice and theory. Case studies are systematical empirical studies of individuals, groups or events in their natural environment.

The methods are each somewhat "specialized" for a specific approach. For example, ideographic research is usually conducted using case studies or action research. Nomothetic research is often done with the aid of experiments and surveys. Constructive research is somewhat different because it relies on *design research* and other conceptual or technical development methods. Here, the main objective is to design new or extend existing construction and evaluation techniques such as methods, algorithms or models. This can be done either conceptually or technically.

## 2.2 Research Approach for Location Modeling

Research in the location modelling part of this thesis is conducted using a positivistic *constructive* approach. The scientific basis is thus empirical observation to find out what concepts that are useful to describe specific geometrical objects for an LBS. The view is positivistic because subjective relationships towards these objects are irrelevant: they are there and change regardless of our perception of them.

The empirical observation is done with a *qualitative* perspective. The concepts are described relatively to other objects with using terms such as "contains", "belongs", "traverses" "intersects" and "crosses". These description are given with respect to time, meaning that relationships between geometrical objects exist/are valid over a given timeframe.

The constructive approach in informatics is aimed at creating frameworks and guidelines for technical design and development. It is also referred to as "design-oriented research". Cornford and Smithson [13] classify two styles of research within the constructive approach: *conceptual development* and *technical development*. Conceptual development in informatics seeks to express the requirements of applications without the use of computer metaphors. It is used to describe a system in terms that are independent of computer systems. Technical development in informatics is the design and development of new software or hardware. Our research is aimed at developing frameworks for modeling and is a conceptual development.

The steps in our "design research" are:

1. Awareness of the problem
2. Suggestion for solution
3. Development of an artifact (i.e. modeling technique) to test the solution
4. Measurement and evaluation of the results
5. Form a conclusion based on (4).

Figure 2.1, taken from [52] depicts the steps in the design cycle.

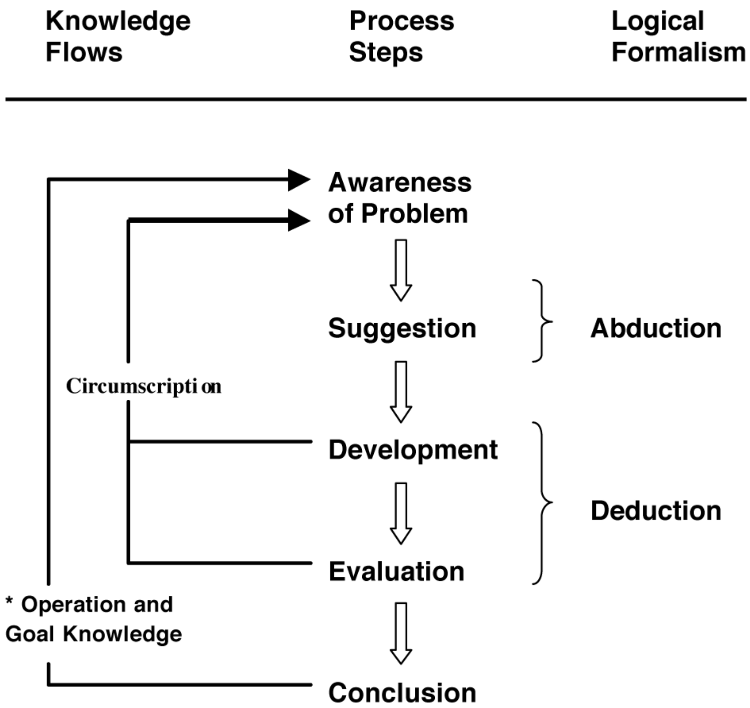


Figure 2.1: Steps in design research, as shown in [52]

The steps do not have to be followed strictly. A researcher may at any time during the development or evaluation of an artifact decide to take a step back to redefine the problem. The complete set of steps may be performed several times, based on whether or not the conclusion satisfies the problem the researcher wished to solve.

## 2.3 Research Approach for Obtaining Location Information

Research in the obtaining location information part of this thesis is an Ideographic quantitative “laboratory experiment” approach with a positivistic paradigm.

The empirical experiment is done with a quantitative perspective. The data gathered in the experiments are measured and compared to each other and a predefined set of requirements.

The steps in this method are:

1. Find scenarios that asks for interesting location information
2. Select some scenarios for testing
3. Test each scenario
4. Use the obtained results to discuss what scenarios are feasible.

For each scenario tested the following method where used:

1. Set the required quality of the location information and other requirements
2. Test in existing infrastructure
3. Test in improved infrastructure
4. Use logic to improve results or work around problems
5. Discuss the results.

## 2.4 Summary

This chapter has introduced research methodological principles in informatics research and presented the methodologies that are used in this thesis.

The location modeling part of this thesis (chapter 4) uses ’design-research’ a positivistic paradigm with a quantitative constructive approach.

The second part, obtaining location information (chapter 5) uses a positivistic paradigm with an ideographic quantitative approach.

# Chapter 3

# Related Research

This chapter will introduce technology and concepts in order to ease the understanding of the work that is done later in this thesis. Existing work from the fields of location modeling, location based services, positioning technologies and positioning techniques are discussed.

## 3.1 General Location Based Services

LBS's are becoming possible due to advances in wireless communication and computer science. These services are often described as applications which operate according to geographic information. An LBS can be used to offer services to users based on their location, user profile and context. Applications like these are used for many purposes and are constantly increasing in popularity. Vendors and operators regard LBS as an integral and inevitable part of their service offering, allowing them to become more competitive and increasing their revenue [2, 41, 47]. Future predictions of LBS's are therefore positive. Kamil and Kirk [22] say:

> *These services, which include personal security, navigation, gaming, security and fleet management, have experienced tremendous growth over the last few years. By looking at the factors contributing to this successful growth, LBS can be deployed in Europe with equal success.*
>
> *[22, p. 105]*

These positive predictions are also supported by the independent analyst and consulting company *Ovum*, which in 2001 estimated that the LBS-market in Western

Europe would reach USD 6.6 billion by 2006, with 44% of mobile users using some kind of LBS [2]. Although this estimate might seem extremely positive, it still remains to see if it will be fulfilled.

An introduction to a few, currently available outdoor LBS's are given below.

### 3.1.1 Geographic Information Systems - GIS

*Geographic Information Systems (GIS)* are used to store, retrieve, map and analyze spatial (geographic) data. This is usually done by storing spatial data in a coordinate system which refers to a particular geographic area. In reality, this means that GIS operate with digitized maps and presents geographic and thematic information [3, 20]. According to Leonhardt [40], the functionality of GIS can be extended to track the position of mobile objects. Examples of GIS software are *ArcView* [19] and *ArcInfo* [18].

### 3.1.2 Global Positioning System - GPS

GPS[1] is based on a constellation of 27 *Navstar* satellites developed originally for the *U.S. Department of Defense*. Each satellite transmits a unique digital code sequence which is picked up by a GPS receiver. The receiver uses these codes sequences to determine its altitude, latitude and longitude and thus its position within sub-meter accuracy. Besides 3-dimensional positions, GPS also offers velocity and highly accurate time information to users with GPS receivers. GPS is currently a *dual-use system*, i.e. both military and civil. It is controlled by a joint civilian/military executive board of the U.S. government and monitored by the U.S. Department of Defense [60].

### 3.1.3 GSM-Positioning

*General System for Mobile Communication*(GSM) is a mobile digital cellular radio-communications system. It was introduced in commercial form in 1991 and is currently the most popular standard for mobile phones in the world. A GSM-network is divided into cells containing *base tranceiver stations (BTS)*, usually referred to as *base stations*. The base stations provide the radio interface with the mobile devices. They regularly send out beacon signals which are used by the mobile devices to

[1] Also referred to as the *Navstar Global Positioning System*.

monitor the quality of available cells. Based on this measurement, the mobile device decides when to switch cells. The process of switching cells is known as a *handover* (also called handoff). Because each cell covers a given geographic area, the position of a mobile device can be determined by knowing which cell it is currently in, often by using information from more than one base station. During a handover, a location update is performed by the network, that is, location information about the mobile device that changed cell is updated [6, 50].

## 3.2 Location-Awareness

The term *location-awareness* is used to describe the capability to detect the exact or relative location of a device (e.g. wireless device like a laptop). Leonhardt [40] defines location-awareness as follows:

> *Generally, location-awareness facilitates an application's awareness of its environment or context.*
>
> *[40, p. 16]*

Location-awareness is used by components in a system to interact with each other based on location. In order to support location-awareness, a data model is required that can adequately represent the location of mobile and fixed objects. Such a model, referred to as an LM , can be designed in two principal ways: as an n-dimensional coordinate system or as a set of symbols with relationships between them [15, 17, 35, 40].

## 3.3 Location Models

At the core of most positioning systems there is an LM. This model is used to define the domain that the location service is meant to cover and thus supply the necessary support for location-awareness. It is therefore important to create location models that are accurate enough in modeling the real world according to the needs of the system.

Leonhardt [40] distinguishes between *geometric* models which define locations using geometric coordinates, and *symbolic* models which define locations and relationships between them using symbols. This classification is also used by Domnitcheva [15]:

> *In a "geometric model", both locations and located objects are represented by sets of coordinate n-tuples, better understood by a human as points, areas and volumes. [...] "Symbolic models" refer to a location by some abstract symbols.*
>
> *[15, p. 3]*

The symbolic approach is better suited for describing relationships between locations in the model, such as a building containing rooms. Such relationships are known as *spatial containment relationships* , where a spatial object like a building contains other spatial objects like floors and rooms. Spatial relationships may also be used to describe the connection between two or more spatial objects, i.e. to describe *closeness*. However the symbolic approach does lack the possibility for accurate positioning. Models based on the geometric approach are more suited for this purpose. The geometric approach is also better suited for calculations such as determining the euclidean distance between two objects, but it cannot describe spatial relationships.

As mentioned above, the model must be designed so that it corresponds to the requirements of the system. If the system, for example, requires that spatial relationships like containment or closeness between location are presented in the model, the symbolic approach is preferable. If the system is meant to perform accurate positioning and complex calculations according to locations, the geometric approach is advised. There are, however, systems which require the use of both the symbolic and geometric approaches. For this purpose, Leonhardt [40], Jiang and Steenkiste [35], and Dürr and Rothermel [17] propose a combination of the two approaches referred to as a *hybrid* model. This approach allows the model to show locations as symbolic elements with spatial relationships between them, and at the same time allows these elements to define geometric coordinate systems used for accurate positioning.

### 3.3.1 Hierarchical (Set-Based) vs. Graph-Based

Designing an LM can be done using either a *hierarchical* (also called *set-based*) or a *graph-based* structure. The hierarchical approach organizes objects into a treelike branch structure where each component has only one owner or is contained in one higher level object (a $1 : N$ structure). It is "based on the containment relation" [8, p. 25], and is best suited for describing spatial containment and closeness relationships. Data organized using this structure is best suited for *range-queries* . These queries retrieve data according to some range, for example containment. A specific example of this may be to query the data about who has been in a particular room at a given time, or which rooms are contained in a specific floor of a building [8].

Graph-based solutions (e.g. lattice) are $N : N$ structures where there is no clear hierarchy between the objects. Any object can be symbolically connected to any number of other objects, depending on the relationship between them. According to Becker and Dürr, this approach "supports the definition of the topological relation *connected to* as well as the explicit definition of distances between symbolic coordinates" [8, p. 26]. These structures do not describe spatial relationships like containment as well as hierarchical structures, but they are better for so called *nearest-neighbor-queries* , i.e. queries concerning distance between objects. Examples of such queries may be to find the nearest color printer or to find the shortest route between two locations. It is important to emphasize that the distance discussed here are not euclidean, but distance in buildings where door between locations, stairs, corridors and elevators have to be considered (personal correspondence with Frank Dürr[2]).

#### Combined Location Model

As seen from the discussion above, the set- and graph-based symbolic location models each have their benefits. In order to utilize these benefits, Becker and Dürr propose a combination of the two, referred to as *combined symbolic location model* [3]. The combined model consists of two parts:

1. The set-based part represents locations as a set of symbolic coordinates with a set/sub-set relationship such as building containing floors, which again contain rooms etc. This part is best suited for range-queries.
2. The graph-based part connects locations in the model with edges if such a connection between those locations exists in the real world. An example of this can be stairs between different floors, or a door between two rooms. This part is best suited for nearest-neighbor-queries.

[2]Frank Dürr is a scientific staff member of the "Distributed Systems" section of the "Institute for Parallel and Distributed High-Performance Systems (IPVR)" of the *University of Stuttgart*. His current fields of research are geographic communication and context-aware computing.

[3]This combination must not be mistaken for the combination of symbolic and geometric location models (hybrid location model). The combination presented here concerns two different types of *symbolic* location models.

In addition to combining these benefits, Becker and Dürr show that the combined approach can be used to "generate views with different levels of detail" [8, p. 26]. By this they mean that a combined symbolic LM can on one level be used to show the rooms on a particular floor along with connections (doors) between them, and on a higher level only show connections between the floors of the same building via their stairways [8].

### 3.3.2 Examples

All LBS's need an LM to function properly. In most LBS's that are discussed in section 3.5 the LM is an internal working of the LBS itself. Most of these services uses simply a pure geographical LM that does not give the service the advantages of a symbolic model as shown in section 3.3.

There are however a few LBS's that uses the LM as an external part of the positioning system itself. A few of those will be elaborated below to show how a typical LM can look like.

#### RAUM

RAUM [4](**R**elation of **A**pplication objects for communicating **U**bicomp event **M**essages) is an LM created at TecO in Karlsruhe, Germany. It is the LM used in MediaCup (section 3.5.4), MemoClip(section 3.5.4) and Smart-Its(section 3.5.4). RAUM consists of two parts, the *Location Representation Model (LRM)* and the *Communication Model (CM)*. The LRM defines how location information is represented, stored and communicated between artifacts in a system. The CM is the higher level of the system that concerns how the location information is used in the communication of artifacts belonging to the RAUM environment.

An example of location model based on RAUM is given in figure 3.1. The location-tree consists of three general layers:

- Tree-root: The tree-root consists of a textual description (e.g. name) of the organization running the system and a unique identifier (e.g. IP or IPv6 address of the organization). The identifier is used for communication between different systems.

[4]In German the word *raum* stands for *space* as well as *room*.

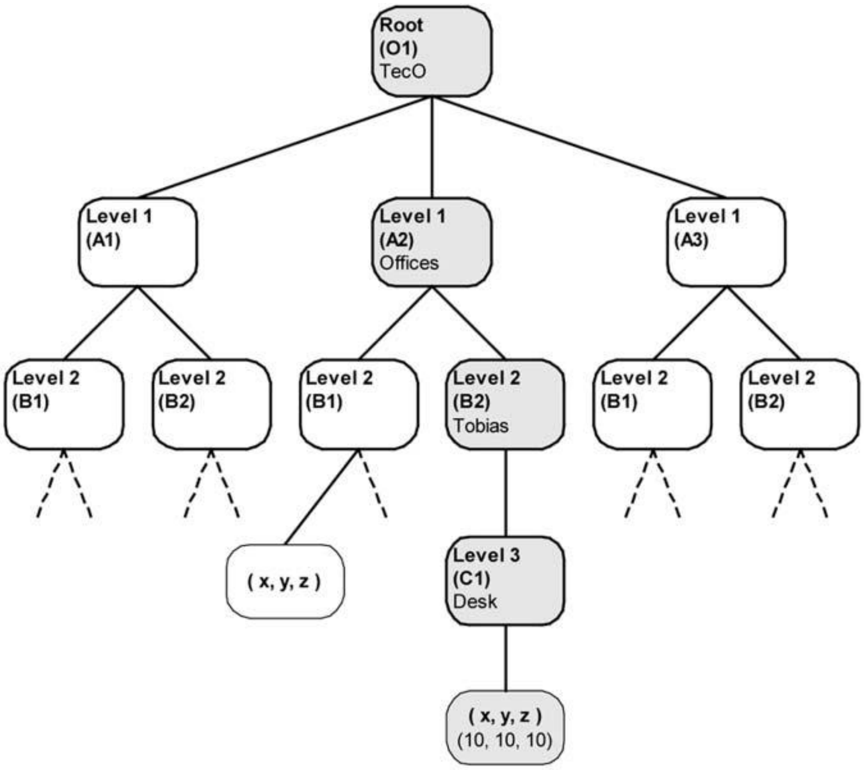


Figure 3.1: Example of a RAUM location model, as shown in [9]

- Semantic sub-layers: The semantic sub-layers are used to define different physical sub-layers of the organization running the system, such as for example rooms, offices, desks or cupboards. Up to three semantic sub-layers are optional to provide flexibility.
- Three-dimensional coordinates: These are Cartesian coordinates used to state the position of artifacts accurately within a predefined sphere of interest (e.g. in a room or on a desk).

Despite the RAUM model's flexibility and support for geometric as well as symbolic positioning, it has an apparent weakness: *the ordering of location information into a tree*. The structure of locations represented by a tree does not allow an object in a sublayer to have more than one parent. This causes problems in situations where the symbolic representation of a building enforces multiple parents, e.g. a room that belongs to a section as well as a floor, and the section and floor are on the same level in the hierarchy [17, 35, 40].

## 3.4 Positioning techniques

In order to understand the different LBS's that will be explained in section 3.5 a basic understanding of techniques for computing a positioning estimate is needed [58, 61]. Most of the LBS's described uses the basic techniques elaborated below, however there are some of them that use their own proprietary techniques. These techniques are not covered in detail here.

There are three principal techniques used to compute a positioning estimate: Triangulation, scene analysis and proximity [10].

### 3.4.1 Triangulation

In order to compute a positioning estimate the Triangulation positioning technique uses the geometric properties of triangles.

One way to use a triangulation technique is using *laternation* . In order to compute the positioning estimate with triangulation using laternation the distance from the points are measured. The number of measurements vary depending on how many dimensions you want in your estimate and local conditions. Laternation has three main approaches: Direct approach measures the the distance with physical action or movement, Time-of-flight measures the distance from the object to a point at a known velocity, Attenuation uses the relative decrease in intensity of a signal the compute the positioning estimate [10].

The other main way to use Triangulation is with *angulation* . In this technique angles between the estimation points are used instead of distance. A precise two dimensional estimate requires one length measurement and two angle measurements. If three dimensions are needed an additional azimuth measurement is needed [10].

### 3.4.2 Scene Analysis

This techniques observes a scene from a particular vantage point and computes the location information using features from this observation. *Static* scene analysis uses a predefined dataset of features that are mapped to locations. *Differential* scene analysis on the other hand uses the difference between the successive scenes to compute a location.

### 3.4.3 Proximity

Proximity computes its positioning estimates based on determining if the tracked device is "near" a known location. There are several ways of using proximity based positioning techniques. Detecting the physical contact between with a pressure sensor or a touch sensor, using automatic ID systems such as bank terminals or access cards or monitoring the range of access points or other sensor based systems.

## 3.5 Indoor Location Based Services

Research in the field of LBS and positioning systems has enabled the design and implementation of functional *indoor* LBS that are precise and effective to use. These are applications which operate within a limited area, like a building or a campus.

In order to power an Indoor-LBS a technology that can compute accurate location information inside the designated area is needed. The definition of what such a system should be designed like and the name for it varies in the literature. Some use the term *Indoor Positioning System(IPS)* [14, 5, 54] while others use the term *Real-Time Location System (RTLS)* [56, 29]. In this thesis this part of the LBS will simply be referred to as the location system to more easily compare different approaches.

In this section different indoor location technologies will be presented, and for each of these a couple of existing applications or proof-of-concepts will be looked at. The summary of this can be seen in table 3.1.

| Name | Technology | Technique | Accuracy |
|---|---|---|---|
| Active Badge | IR | Cellular Proximity | Room-level |
| Active Bat | Ultrasound | Time-of-flight laternation | 9cm |
| B-MAD | Bluetooth | Proximity | Room-level |
| BIPS | Bluetooth | Proximity | Room-level |
| Bluepulse | Bluetooth | Proximity | Room-level |
| Cordis Radioeye | WLAN | Analysis | 0.5-1m |
| Cricket | Ultrasound | Proximity, Laternation | 1.2x1.2 m regions |
| Locata | GPS | Carier-phase point positioning | 1cm - 1m |
| MemoClip | IR/RF | Proximity | Room-level |
| MediaCup | IR | Proximity | Room-level |
| RADAR | WLAN | Scene analysis, Triangulation | 3-4.3m |
| Radianse IPS | RFID | Proximity | Room-level |
| Smart-Its | RF | Proximity | Room-level |
| SmartLibrary / Ekahau | WLAN | Scene Analysis,Site Calibration | 1m |
| Sonitor MediaTrac | Ultrasound | Proximity, Triangulation | Room-level or 2cm |
| VIS | IR/RFID | Proximity | Room-level |

Table 3.1: Summary of Indoor LBS.

### 3.5.1 GPS

GPS is a valid solution for an outdoor LBS as mentioned in section 3.1.2, however, since the positioning technique used requires line of sight it is not well suited for indoor positioning [61].

#### Locata

Locata is a technology that aims to enable a GPS like positioning system inside buildings. This proof-of-concept technology is developed at the SNAP group at the University of New South Wales, Australia (UNSW) in cooperation with the Locata company. Locata uses several small time-synchronised pseudolite transceivers that sends GPS like signals. These pseudolite transceivers called *LocataLite* communicate together to form a *LocataNet* [36].

The advantages of this technology is that it requires no data links, has reduced latency, uses intelligent signal transmissions, estimates time along with position and has theoretically greater precision than GPS.

LocataNet uses carrier-phase point positioning (CPPP) from at least four LocataLites to give its three-dimensional positioning estimate. Locata can position a static device with sub-cm accuracy and a moving device with sub-meter accuracy.

### 3.5.2 Wireless Local Area Network(WLAN)

WLAN is a set of protocols that enables high speed data exchange over a wireless connection. The initial standard 802.11 was accepted in 1997 and it have the capacity of 1-2 Mbps. The standard uses the unlicensed 2.4GHz-band and depending on the environment the signals can travel from 30 to 100 metres.

In order to enjoy high-speed wireless data exchange with WLAN you need a wireless base station. This station hooks up with an ordinary RJ-45 cable to a hub/switch and then sends data to all clients within range. There are several ways of restricting what clients that can use the access point. WEP-keys and MAC address filters are the most common.

Since 1997 then there has been three new standards to the 802.11 family. 802.11a uses the licenced 5.0 GHz band, it has shorter range than the others and it is not compatible with 802.11b/g. 802.11b is an enhancement to the original standard that increases the speed to 11 Mbps. 802.11g was accepted in 2003 and it is the most used variant of WLAN today. It uses the same band as the original standard, boosts a 54 Mbps speed and has more safety protocols than it's predecessors. It is also compatible with 802.11b so that users of old 802.11b WLAN cards can get a connection from a 802.11g base station [14, 53].

#### SmartLibrary with EPE

SmartLibrary is a mobile location-aware service at the University Library in Oulu, Finland. The service uses an PDA to help users find books in the library based on Ekahau positioning technology, the EPE. [4, 27, 29].

EPE uses a patented process called SiteCalibration to create a model of the desired space. The software then uses some patented algorithms, and scene analysis on the signals to compute a location estimate. This process results in a positioning estimate that can be as accurate as 1 metre under optimal conditions.

Ekahau is the technology that was used in the testing in this thesis. More in dept information about it can be found in section 5.3.1

#### Cordis RadioEye

At Nidarosdomen Cathedral in Trondheim, Norway in 2003/2004 a couple of Master Students at NTNU created a service based on Radionors Cordis RadioEye technology called "Lokasjonsbasert Guiding" (Location Based Guiding in English). The service enables an PDA to show location sensitive information to the user [12, 49].

The Cordis RadioEye is a proprietary WLAN base station that enables the service to compute a positioning estimate by analysing the WLAN signals from the client to just one base station. This is done with a pure analysis of the emitted signals and results in a positioning estimate that can get as good as +/- 50 cm [12].

#### RADAR

RADAR is a WLAN LBS developed at Microsoft in 2000. This proof-of-concept technology uses the signal strength and signal noise of a WLAN signal to compute a 2D positioning estimate within a building. This can be done either with scene analysis or laternation. The former method yields 3 metre accuracy while the latter yields 4.3 meter accuracy, both with 50 % probability.[7, 26] There are also several derivatives that are made based on RADAR like WhereNet and Pinpoint [26].

### 3.5.3 Bluetooth

Bluetooth is a short range, low powered, low bandwidth data communication protocol that was released in May 1999. It was first designed by Ericsson to replace Infrared (IR) systems for small electrical equipment. Bluetooth is commonly used in a wireless handsfree set for a mobile phone or in wireless keyboard/mouse for a computer [14, 58].

Bluetooth signals travel up to 100 metres depending on the power class used. The most common setting is Class 1 that uses 1 mW of power and sends signals up to 10 metres. Class 2 uses 2.5 mW and sends signals 20 metres while Class 3 uses 100 mW and sends signals up to 100 metres.

In the same way that a mobile phone connects to a network a bluetooth network with enough bases could form a cell map that could be used for positioning. Like all radio-signal based techniques its accuracy is limited by its range. A network that has many cells with overlapping areas will have good accuracy [58].

#### BIPS

BIPS is a proof-of-concept mobile based LBS developed at the Italian Universities of Pisa and Trento in cooperation with the National Research Council in Italy [5].

The service uses a bluetooth based positioning technology with a proximity based positioning technique to report all devices in range of a bluetooth network.This gives the service room-level positioning of all the bluetooth devices.

#### B-MAD

Bluetooth Mobile Advertising (B-MAD) is a proof-of-concept cooperation between the MediaTeam at Oulu University in Finland and the University of Linköping. The service is a mobile based LBS for delivering permission-based location-aware mobile advertisement to cell phones [1].

The service uses bluetooth proximity based positioning to report room level accuracy of the device to the system.

#### Bluepulse

Bluepulse is an Australian Company that will enable an LBS at the Broadway Shopping Centre in Sydney, Australia. This mobile LBS will use bluetooth for communicating data to users inside the shopping centre [42].

Bluepulse uses proximity based bluetooth positioning in order to locate friends and enable their friends finder services.

### 3.5.4 Infrared(IR)

IR is a technical solution that is getting old. Bluetooth devices are taking over where IR was formerly used. IR uses direct line of sight and you therefore need an IR sender in every location where a device might be located. This solution is perhaps the oldest positioning technology available [14].

#### Active Badge

The *Active Badge System* [25, 59] was first developed at the *Olivetti & Oracle Research Laboratory* during the years 1989-92. The purpose of this system is to locate people and equipment (objects) within a building. This is done using small devices (active badges) worn by people or attached to equipment. These devices periodically transmit infrared signals (containing a globally unique code) that are detected by sensors placed within the building. The location of the badge, and hence the bearer, can be determined by the information received.

Active Badge from AT&T Cambridge is an old proximity cellular system where a badge broadcast its unique ID every 10 second on demand. This provides the room-level location of the device [10].

#### The Versus Information System (VIS)

VIS is a positioning solution developed by Versus Tech. The service is in use and yields great success in Memorial Health Systems, CoxHealth, St. John's Medical Center and Summa Health Systems in the United States [57].

The system uses IR based proximity positioning to give a room level positioning estimate to the system. It also uses Radio Frequency (RF) signals as a supervisory function ensuring that messages are received [56].

#### MemoClip

MemoClip is an LBS designed at TecO in Karlsruhe, Germany that reminds people of important information based on location information. IR location technology is used for fine-grained detection and RF based location detection for room-level detection [9].

#### MediaCup

MediaCup is an IR driven LBS that is a collection of applications centered around information derived from a location aware coffee cup. MediaCup is the first prototype of LBS created at the TecO in Karlsruhe, Germany. The cup uses IR technology to communicate its room-level location to the server [9].

#### Smart-Its

Smart-Its is according to [9] a work in progress. It is a platform that is intended to provide a hardware and software platform for integrating a trackable functionally into everyday things. The Smart-Its itself has RF communications built into it and can be located with RF technology. According to [21] there are now several different kinds of Smart-Its that also use Bluetooth and IR technology.

### 3.5.5 Ultrasound

Ultrasound is a technology that sends sounds that are so high frequent that a normal human ear cannot hear it, approximately 20 kilohertz. Ultrasound are most commonly used in the industrial and medical applications.

Ultrasound used in combination with a radio frequency signal can be used for positioning. This is made possible since radio frequency signal and ultrasound signals travel at different speeds [14].

#### MediaTrac

At Rikshospitalet in Oslo, Norway a service called MediaTrac has been installed. MediaTrac is an ultrasound based solution delivered by Sonitor. The solution tracks users and equipment in the hospital and records usage patterns and other useful information [54].

MediaTrac uses a proximity based ultrasound location technology to give room level accuracy from its Sonitor IPS system. It also has a more accurate system called Sonitor 3D Positioning System that uses triangulation ultrasound positioning technique to give a 2-3cm location estimate [55].

#### Cricket

Cricket is a proof-of-concept LBS developed at MIT Laboratory for Computer Science [45].

Cricket uses a RF signal to trigger an ultrasound receiver and then estimates a position within a 1.2x2. metre square using both RF and ultrasound to compute the positioning estimate [26]. A device can even be equipped with the Cricket Compass in order to yield even better results [46].

#### Active Bat

Active Bat is a more recent work from AT&T in 1999 aims to enable positioning where Active Badges (section 3.5.4) could not reach. The system installs ultrasound transmitters in the ceiling and uses an ultrasound time-of-flight laternation technique to give a 9cm accurate positioning estimate under ideal conditions [10].

### 3.5.6 Radio Frequency Identification Tags (RFID)

RFID is a technology where a small tag communicates with a transceiver using radio signals. The technology behind this method dates back to the start of the 20th century but has been greatly improved.

This system is based on small tags that are placed on items that should be trackable. These tags can either be active or passive. If passive they will not send their own signal but will on receiving a signal use the power it gives the tag to send a response back. An active tag will use its own battery and send a signal either on request or regularly. The active tag has far greater range than the passive [14].

#### Radianse RFID

At Massachusetts General Hospital (MGH) in Boston they have enabled an LBS where they use a RFID based solution delivered by Radianse AS. In this service patients, doctors and equipment are tagged with active RFID tags. The tags are scanned at various places in the MGH and the information is processed and shown in a web-interface [16].

Radianse IPS uses proximity based RFID location technology to enable room level accuracy.

## 3.6 Summary

The purpose of this section has been to present related research and existing systems in the field of location modeling and LBS. Various LBS have been presented in order to show the extent in which such systems may be applied. A more detailed presentation of research in the field of location modeling and indoor location based services have been given in order to draw knowledge related to location modeling.

# Chapter 4

# Location Modeling

In this chapter an introduction to location information and its properties is given. Guidelines which should be followed when building an LM is then defined. The symbolic and geometric approaches to location modeling are described and their strengths and weaknesses discussed. The hybrid location modeling approach will be introduced in order to cope with the shortcomings of the geometric and symbolic approaches. Finally a suggestion to model a hybrid LM using *Unified Modeling Language (UML)* [23] syntax will be suggested.

## 4.1 What is a Location Model?

The notions of location and location representation are quite familiar to most people. Surely all of us have at some time in our lives seen and possibly even used a map of some sort to find our way to a destination. Maps are an LM of a given environment, usually with symbolic names for buildings, streets, cities, countries, mountains, lakes etc. Maps may also have a coordinate system, showing the location of a particular object in geometric terms according to the map's defined coordinate system. The apparent weakness of these maps is that they only allow visualization and reference, but do not show the (often) complex hierarchical relationships between places and objects. More modern methods of location representation take this weakness into consideration and try to build models of environments in a way that not only visualize places and objects, but also show their relationships in a hierarchical manner. Such LM are used by location aware applications to relate objects, compute with them (for example compute distance between two objects) and present the results to users.

Just as humans depend on information about our environment in order to navigate, so do location aware systems depend on information about their environment. The success of these systems depends on how well they are fed with the necessary information. It is therefore important that systems which require *spatial data* [24], i.e. geometric information about objects in their environment, are based on an LM that supports the desired functions. For example, it would be difficult for a human to find the fastest way to his car if the car's position was given as $(38°18'N, 23°5'W)$. On the other hand, a computer would have a hard time calculating the distance between a car and its owner if all it had to work with were their symbolic names.

As computer systems become an integrated part of our everyday lives, they are expected to perform complex computations and at the same time communicate with their users in a humanly understandable way. Taking this into consideration, location modeling becomes a difficult and time consuming task, because it can be done in many ways depending on the application domain and the operations which the application using the model has to perform [37].

However, before different approaches to location modeling are discussed further, the practical use of an LM, the concepts of *location information* and general location modeling guidelines will be presented. Example scenarios in which an LM can be useful are also presented.

## 4.2 Practical Use of Location Models

An LM can be used as a basis for indoor location based applications by supporting different types of functions such as tracking the position and status of objects. Below scenarios in which an LM have practical use are presented. [1]

### 4.2.1 Office Management System

One area of applied use is the tracking of equipment and personnel in office complexes. The buildings can be modeled using the constructs of an LM , where the building itself along with its floors, wings and rooms can be modeled geometrically as 3-dimensional spaces. Transitions (e.g. doors) between these spaces can modeled as 2-dimensional spaces. Associations and relationships between these spaces, along with their symbolic names can be modeled symbolically using a branching structure such as tree or a graph. Equipment inside the buildings can be anything

[1] Both scenarios presented have privacy and legal issues associated with them. However this will not be discussed here since they are beyond the scope of our work.

from printers to tables or file cabinets. These can be modeled as objects with positions and the the ability to move to other locations.

Persons can also be considered as moving objects. They can have different roles, occupy offices and attend events. Examples of roles can be "project-manager" or "customer". Events can be meetings, workshops or presentations which take place inside a 3-dimensional space at some given time. The application can thus use these constructs along with their geometrical and symbolic information to determine the position and status of any object and present this in an understandable way to users.

### 4.2.2 Hospital Monitoring System

Another scenario of practical use is location based applications in hospitals, used to improve medical care. Patients, medical equipment and staff could be tracked at all times, along with their status and roles. Doctors would at all times know where the nurses are and what they are doing, and vice versa. The staff would also know where different equipment is and what condition it is in. Events related to spaces would for example be surgery or planned CAT-scans[2]. Using this information, necessary and available resources could be kept or sent where they are most needed. In extreme situations, this could prove to be lifesaving.

As an example of roles and statuses of persons, a doctor can have the title "cardiologist" and the role of "attending surgeon on call" on a particular day. At a given time during this day, his status can be "available". The nurses can use the location aware application to access this information along with the current position of the doctor and call him if necessary.

## 4.3 Location Information

Location modeling of the physical world is an essential part of location aware applications. These applications require highly accurate and flexible information regarding the surroundings in which they are meant to operate. This type of information, referred to by Korkea-Aho and Haitao [37] as *location information*, may be used to query the position of a mobile object, or to calculate the distance between two stationary objects.

[2]Computerized Axial Tomography, also referred to as CT-Scan.

The location information describing an object (or a place) is contained in an LM, which also describes the relationships between the objects. The scope of the information in the model is defined by the operations that the application is designed to perform. The quality of the application thus depends on the properties of the underlying LM [11, 37]. These properties are:

- **Accuracy:** How accurate is the location information provided by the model? Does it represent the physical world accurate enough to the extent required by the application?
- **Representation of objects:** How are objects represented in the model? Are the object identifiers proper representations according to names and events associated with the objects?
- **Representation of relationships:** What are the relationships between the objects and how are they represented in the model? Do these representations reflect the relationships in the physical world?
- **Dependency:** What are the dependencies between the objects in the model? Are some objects dependent on other objects in order to exist, and are these dependencies coherent with the dependencies in the physical world?
- **Flexibility:** How flexible is the model regarding changes in the physical world? Is the model flexible enough to reflect such changes?

All of these factors have to be be considered in order to produce an LM of high quality. There are also apparent problems concerning accuracy and representation of objects. These properties are somewhat contradictive. Trying to model the physical world accurately with respect to precise positioning would demand an n-dimensional coordinate system, while making the model more understandable to humans would require objects to be represented by their symbolic names and associations. However, a symbolic representation could never be as accurate as coordinates used for precise positioning, while coordinates would be far more difficult for people to understand.

## 4.4 Modeling Guidelines

The purpose of an LM is to describe the physical world in an abstract and virtual way, so that physical objects (places) and their relationships (and dependencies) can easily be mapped to their equivalent representation in the model. Despite the fact that there are basic standard algorithms for how the technical visualization of physical objects to virtual objects is done, there are no standard demands on how an LM should be created. As already stated, the model has to be constructed according to the needs and specifications of those who want to use it. There are, however, guidelines that should be followed when constructing such a model. In the case with indoor positioning, Brumitt and Shafer [11], Funk and Miller [43] and Korkea-Aho and Haitao [37] suggest that the following questions be dealt with:

- What type of operations is the model supposed to support?
  - Activity, needs, purpose, surveillance or administration?
- How is the relationship between objects represented?
  - Absolute (geometric), descriptive or relative (symbolic)?

Once these questions have been dealt with, a decision has to be made as to building an implicit or explicit model. In an implicit model the application contains the model information, while in an explicit model, a service stores model information and allows an application to query the model data. To achieve better scalability, an explicit model is preferred because such a model is independent of the services which are provided, and can therefore be modified in an easier way. An explicit model would also reduce the workload performed by the clients when they need to access information in the model, because most processing based on the information in the LM would be done by the service provider.

Regardless of the model being implicit or explicit, Dürr and Rothermel [17] propose that it should be a *lattice*[3], where the nodes represent objects (places), and the edges represent the relationships between them.

An alternative to the lattice is a tree, as shown by Jiang and Steenkiste in [35]. The problem with a tree, pointed out by Dürr and Rothermel in [17], is that it allows objects to only have one parent, i.e. exclusive membership. They argue that this approach makes it difficult (if not impossible) to model objects that are subsets of more than one set (i.e. objects that have more than one parent). Because of this, trees will in most cases be too limited. Consider the following example:

[3]A lattice is a *Directed Acyclic Graph (DAG)* where there is at least one node that can reach every other node and there is at least one node that can be reached by every other node.

The building in figure 4.1 has two floors, $F_0$ and $F_1$. $F_1$ contains the room $R_{01}$, while $F_1$ contains the rooms $R_{11}$ and $R_{12}$. So far, it is easy to model this information as a tree. The rooms are all subsets of the floors where they are located, the floors are all subsets of the building, and each object has exactly one parent. But imagine now if the building was also divided into two wings, $W_{left}$ and $W_{right}$. In this case, wings and floors would overlap, and the rooms would be subsets of floors as well as wings, e.g. room $R_{01}$ would be on floor $F_0$ as well as in wing $W_{left}$, and rooms $R_{11}$ and $R_{12}$ would be on floor $F_1$ as well as wing $W_{right}$. An object would now have more than one parent, and thus it is not a tree anymore.

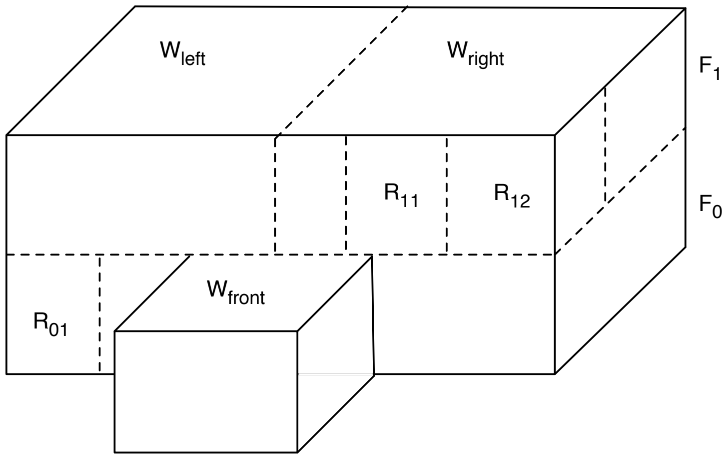


Figure 4.1: Building divided into sections, floors and rooms

The above example clearly shows why a tree might in some cases not be suited for modeling location information. The more general and powerful lattice overcomes the weaknesses of the tree in these situations, and is more suited. However, the solution proposed by Dürr and Rothermel [17] also has a weakness. Their model is hierarchical (set-based) and solely based on spatial containment relationship, i.e. a building contains sections which contain rooms. This makes it ideal for *range-queries* like "which objects are within $W_{right}/F_1/R_{12}$", but not suited for *nearest-neighbor-queries* like "find the fastest way between rooms $R_{11}$ and $R_{12}$". Using the building in figure 4.1, the problem can be described as follows:

Imagine if there was a door between the rooms $R_{11}$ and $R_{12}$. In the hierarchical structure proposed in [17], this door would be impossible to model. Nearest-neighbor-queries would thus be answered insufficiently, because all the possibilities of the building would not be modeled. The model would show the rooms connected only through a wing ($W_{right}$) or a floor ($F_1$), and the answer to the query would suggest either of these two as a path between the rooms.

To solve this problem, a graph-based LM that are well suited for nearest-neighbor-queries, can be applied. The edges in the graph may additionally be weighted to express distances between locations. A graph however, as opposed to a hierarchical structure, does not show the spatial containment relationships present in a building. These relationships are important factors concerning indoor positioning systems, and thus kept present in our location model. A combined structure is therefore used (described in section 3.3.1) as a basis for our LM in order to make it suitable for both types of queries.

## 4.5 Basic Location Models

The basic modeling types for location services are the symbolic and geometric approaches. These are also referred to as *hierarchical* and *coordinate* LM. For the sake of clarification and to avoid confusion, the already established terms symbolic (as opposed to hierarchical) and geometric (as opposed to coordinate) will be used.

### 4.5.1 Symbolic Modeling

In a symbolic location model, objects are referred to by names (i.e. abstract symbols), such as "Office 51", "second floor", or "Department of Computer Science". This approach stores information in a way that is meaningful to a person. Brumitt and Shafer [11] use the term *friendly names* which allow location queries performed on the model to be answered with replies that make sense according to the terms and values that people associate their surroundings with.

Since all objects are represented as symbols, they can be divided into *sets* and *subsets*, with basic mathematical set-operations. Consequently, an object is a member of another object if it is physically contained within that object, and objects that are present in overlapping areas between two other objects are members of both sets represented by the overlapping objects [17, 35, 40].

- Advantages of symbolic models:
  - Well suited for implicit representation of spatial relationships (e.g. containment, closeness).

  - Easy to read and understand for humans.
  - Supports better scalability, manageability and adaptation (supports multi-resolution processing).

- Disadvantages of symbolic models:
  - Lack of position accuracy.
  - Not suited for calculating distance between objects.
  - The number of objects in the model depends on the application domain. This could lead to a potentially large number of objects. Examples of this can be large buildings, containing several floors, wings, rooms, corridors, elevators, doors and open spaces.

A symbolic model of the building in figure 4.1 would look like the one shown in figure 4.2. The graphical syntax is taken from [17] and is to our knowledge the latest proposed syntax for location modeling.

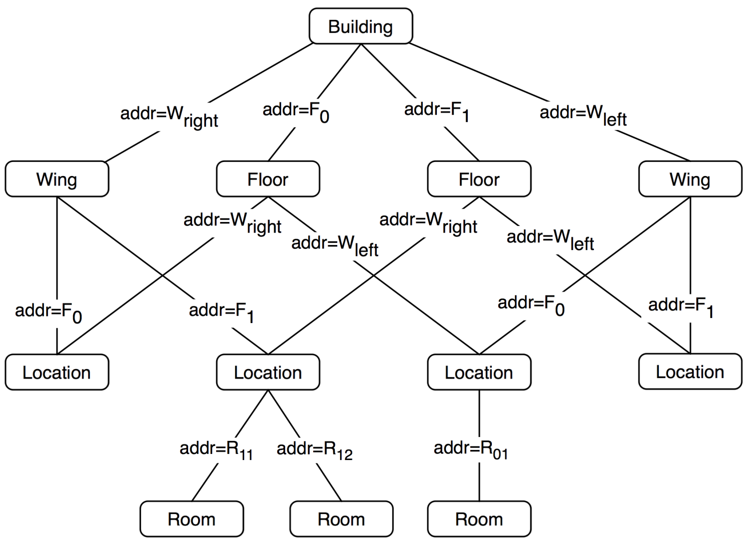


Figure 4.2: A symbolic model of the building from figure 4.1, as a lattice

The attribute "addr" in the figure is used to represent the symbolic path from one location to another in both directions of the hierarchy. As the model shows, neither floors nor wings are completely contained in each other. Furthermore, each room can be seen as a subset of both a floor and a wing. Modeling these aspects using a tree is impossible, as shown in figure 4.3. This is due to the fact that floors and wings can be seen as set/subsets of each other, and the different rooms would in this case have more than one parent (i.e. room $R_{12}$ is both in floor $F_1$ and wing $W_{right}$). These relationships are shown in the model (figure 4.3) with dashed lines and question marks, indicating that they are unfeasible when constructing a tree.

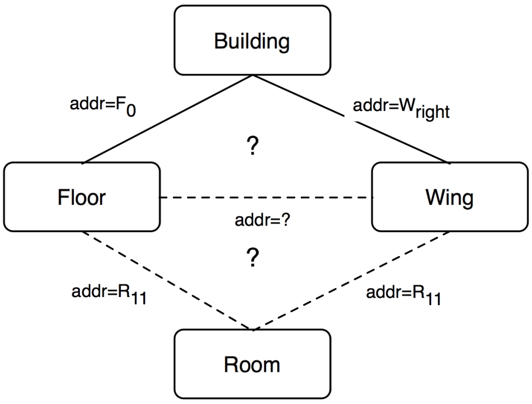


Figure 4.3: A symbolic model of the building from figure 4.1, as a tree

### 4.5.2 Geometric Modeling

In a geometric LM, objects are represented as points, lines or regions (or volumes in 3-dimensional applications) within one or more reference coordinate systems. Since everything in a geometric model is described by a set of coordinates, there is no set/subset relationship between the objects, which was the case with a symbolic LM. A well known example of an application based on the geometric model is the GPS coordinate system, in which locations are defined by longitude, latitude and altitude [35, 40].

- Advantages of geometric models:
  - Well suited for for specifying accurate positions.
  - Well suited for calculating euclidean distance between objects.
  - Offer a more flexible mean of retrieving location information.

- Disadvantages of geometric models:
  - Hide hierarchical relationships (cannot describe spatial relationships).
  - Geometric data is weakly structured (makes efficient design more difficult).

– Extra computing is needed to map coordinates into data that is meaningful to both applications and humans.

Two geometric models are shown in figure 4.4. In model **a)** a 2-dimensional geometric model of room $R_{01}$ in the building from figure 4.1 can be seen. It consists of a coordinate system used to locate objects accurately within the room. The location of an object within the room is given by a pair of coordinates as $(X, Y)$. The model can be extended to 3-dimensions by adding a third axis, as shown in model **b)**. An object's location is in this case given by an $(X, Y, Z)$ coordinate.

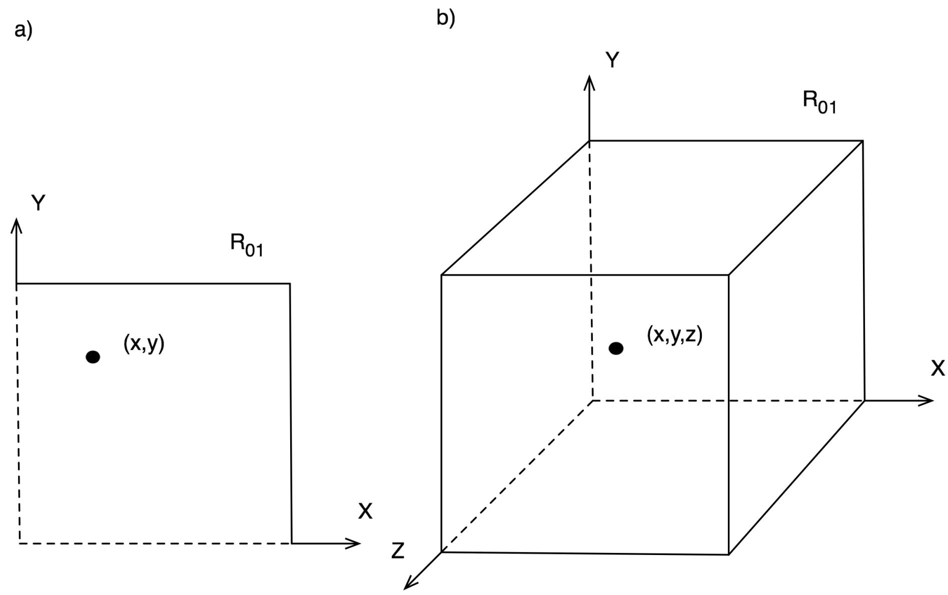


Figure 4.4: 2- and 3-dimensional geometric models of room $R_{01}$

A coordinate system may also be used to define subspaces within another space, as shown in figure 4.5. The figure shows a room divided into the subspaces $N$, $S$, $E$, $W$ and $C$. This may be necessary when a room or section is symbolically divided (not physically, i.e. by walls) into subsections. An example of this may be to consider the geographical space in front of a door as a separate area. This way, queries like "outside whose door am I standing" can be answered. These kinds of queries will be answered when the model is validated. For now, however, the important aspect is to design an LM, not to use it.

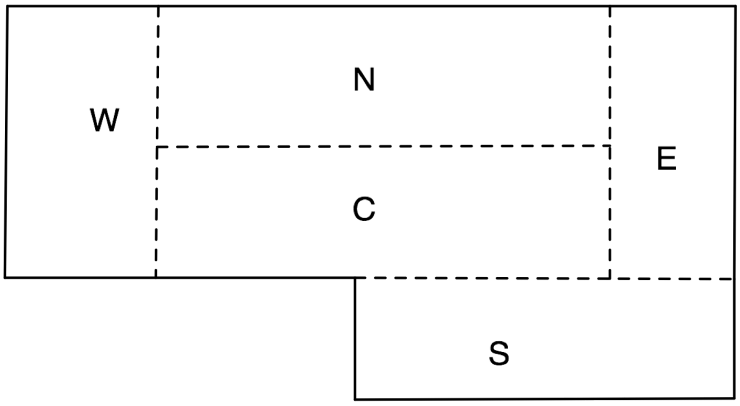


Figure 4.5: A space geometrically divided into subspaces

## 4.6 Hybrid Location Model

Symbolic and geometric models cover vastly different aspects used by location aware systems. Although either of these models can be used independently form the other, they cannot replace each other. In some cases, especially for closed systems with predefined, static requirements, one of the models alone can provide the necessary service. For example, GPS systems use geometric models, while the Active Badge system (section 3.5) is based on a symbolic model. However, for more general services where applications are required to perform precise calculations as well as submit the results to the users in an understandable fashion, it becomes clear that neither the symbolic nor the geometric approach alone is sufficient. To overcome their shortcomings, Leonhardt [40], Domnitcheva [15], and Jiang and Steenkiste [35] suggest a combination of the two, referred to as a *hybrid model*. This approach is also taken by Dürr and Rothermel in [17], where they propose a combination of the symbolic and geometric models.

A hybrid LM combines the benefits of both the geometric and symbolic model. The basis for this approach is the symbolic model, where objects are organized in a hierarchy in which every level is a refinement of the previous. The geometric model is then used to give every object in the hierarchy its own coordinate system, so that points, areas and volumes can be defined within that object.

The symbolic aspect of this approach divides the objects (spaces) into set/subset relationships. For example, the building shown in figure 4.1 will be divided into the sets $F_0$, $F_1$, $W_{left}$ and $W_{right}$ (floors 1 and 2 and wings left and right). As shown in section 4.5.1, there exists no set/subset relationship between the floors and wings.

They are all on the same level in the object hierarchy, so the following sets are also valid ($W_{left}$, $F_0$), ($W_{left}$, $F_1$), ($W_{right}$, $F_0$) and ($W_{right}$, $F_1$). These sets contain the subsets $R_{01}$, $R_{11}$ and $R_{12}$ (the rooms), and are in turn self subsets of the building as a whole. Since the symbolic approach produces a lattice, it will be easy to see whether a set/subset relationship exists between two or more objects.

The geometric aspect of the hybrid approach allows each object to define its own coordinate system. Within their coordinate systems, the objects possess geometric attributes such as points, shapes, areas etc. This is necessary if geometric relationships such as distance and intersection are to able to be computed. Once again, considering the building in figure 4.1. Imagine if wing $W_{left}$ was logically (not physically, for example with a wall) divided into two subsections: north and south, $W_{north}$ and $W_{south}$ respectively. Thus would wing $W_{left}$ be the *superspace* of the subwings $W_{north}$ and $W_{south}$, and the subwings would be *subspaces* of $W_{left}$. All wings would have their own coordinate system, and the position of an object in one of the subwings ($W_{north}$ or $W_{south}$) could be expressed in coordinates of either the superspace's coordinate system ($W_{left}$) or the subspaces' coordinate system. This is possible because the subspaces' coordinate systems are defined within their superspace's coordinate system, and coordinates can therefore be translated between the spaces [35].

## 4.7 Proposed Domain Model

In this section a purposed domain model to be used in an indoor-LBS will be presented.

The purpose of the domain model is to define the characteristics and relationships between objects that a system represents. The domain model is based on the discussion regarding the combination of symbolic and geometric modeling (i.e. the hybrid approach). The objects presented in the domain model are those deemed important for indoor location aware systems, including events occurring in different spaces, static and movable objects with their statuses, and persons moving, occupying spaces and having different roles.

The syntax proposed by Dürr and Rothermel [17] will yield complicated models when the building that is to be modeled is large and consists of several wings, floors, rooms and doors. Because of its rich and powerful syntax, UML will be used as the modeling language. A domain model describing the basic concepts and terms of the hybrid LM is for the sake of clarity divided into three separate models and presented in figures 4.6, 4.7 and 4.8. All three models use basic constructs from the UML syntax: Classes are modeled as squares, inheritance (generalization/specialization) is modeled with an open-headed arrow pointing from a subclass to its corresponding superclass, composition ("is part of" relationship) is modeled with a filled diamond at the end of a line, and associations are modeled with a straight line with a symbolic name and cardinality.

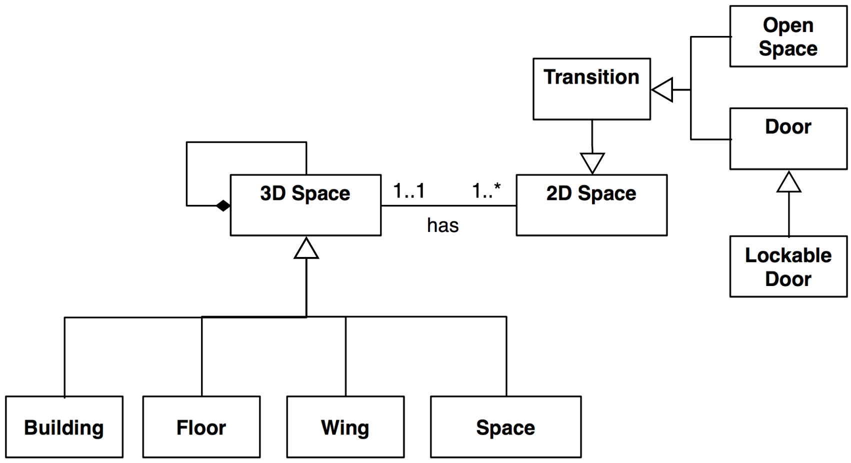


Figure 4.6: Basic domain model of the hybrid location model, constructed using UML

Figure 4.6 is the basic model. It shows a 3-dimensional space as a composite of itself (the class "3D Space"). This class contains geometrical information for all 3-dimensional spaces. Direct subclasses of it are "Building", "Floor", "Wing" and "Space". These classes are used to describe the basic concepts of a building. Floors and wings are contained within the building, while spaces are contained within floors and/or wings. Transitions between these spaces are given by "2D Space". The class "Transition", which is a subclass of "2D Space", can be a door or a logically defined border between two 3-dimensional spaces.

The geometrical information of 2- and 3-dimensional spaces is described in figure 4.7. The information is given by the classes "2D Geometry" and "3D Geometry". As the figure shows, these geometries can be implemented differently depending on the type of spaces that are to be modeled. 3-dimensional spaces are for example modeled as either polygons or boxes, while 2-dimensional spaces are lines or regions. The model can be extended with other types of geometries like for instance circles, cylinders and spheres. The geometries "Polygon", "Box", "Line" and "Re-

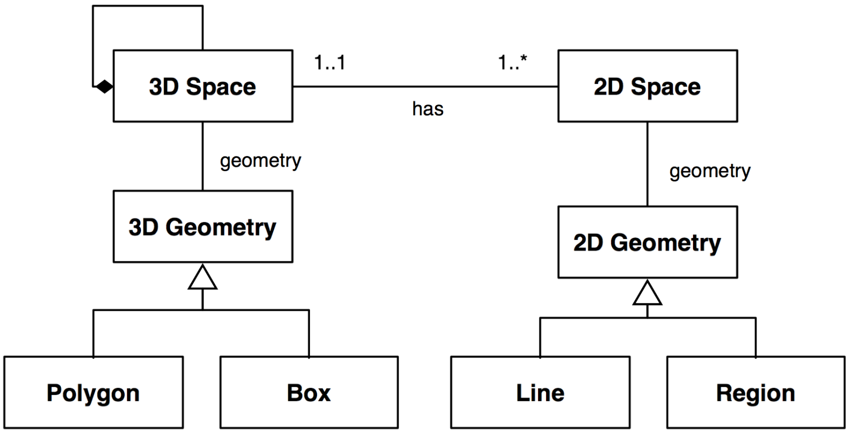


Figure 4.7: Detailed domain model of 2- and 3-dimensional spaces

gion" are chosen because it is assumed that most spaces and transitions within a building can be modeled using these classes.

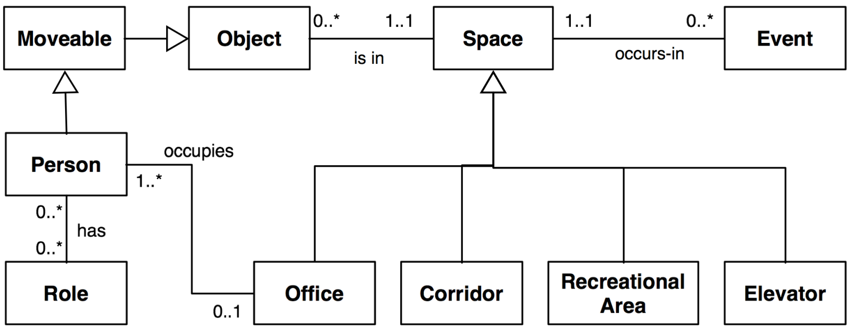


Figure 4.8: Detailed domain model of space, persons and roles

Figure 4.8 describes related classes of "Space" in more detail. A space is seen as any type of physically or logically defined area, such as offices, corridors, elevators and geometrically restricted areas ("Recreational Area"). Elevators are distinguishable from other spaces since they move and can therefore be in any floor. Spaces can have events occurring in them, or have movable or static objects placed inside. Offices can be occupied by more that one person (e.g. two persons sharing an office), but one person can occupy only one office. Similarly, an object can be located in one space at a time, while a space can be occupied by several objects at once. Because of this, relationships between objects and spaces are associated with time, indicating the interval in which an objects was located inside a space. Events are also associated with time describing when they are to (or did) occur.

Persons can have different roles at different times. This is shown in the model with the class "Role" and the relationship "has" between "Person" and "Role". The relationship "has" is time-dependent, indicating that the roles of persons may change with time. Roles are specific for persons, but all objects, static, movable or persons, can have a "'status". This property is also time-dependent, since the status of objects change over time.

The concepts of roles and status are here understood as temporary properties which persons possess during given time periods. They must not be mistaken for more permanent properties like title or profession, e.g. "professor".

### 4.7.1 Validation of the proposed Domain Model

Before an LM based on the constructs of the proposed domain model can be constructed, it must be validated according to the properties defined in section 4.3. These were: *accuracy, dependency, flexibility and representation of objects and relationships*. However, creating an LM of buildings using standard UML might yield complicated results. This is due to the fact that buildings often have many floors, wings, rooms, open spaces and doors. Because of this, a few changes to the syntax is proposed in order to make the models more comprehensible.

The first proposal uses plain text instead of association classes when modeling the associative relationship between two objects. Because of the many doors that may exist in a building, modeling each one as a class could lead to an unnecessarily complicated model. Since doors have no other properties besides being open or locked (and locked door being a specialization of a door), it is easy to model them using plain text. This will reduce the number of classes in the model, making it less complicated. Figure 4.9 shows an example of this.

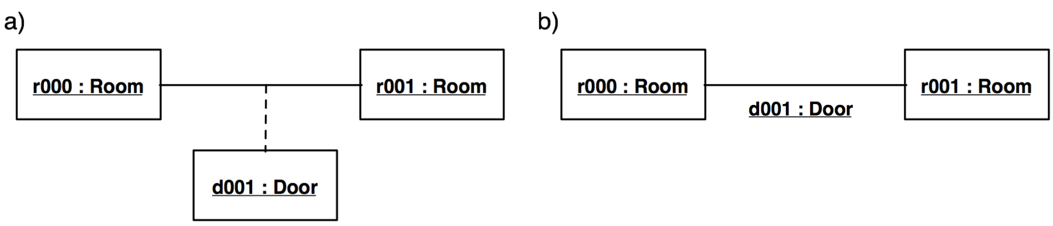


Figure 4.9: Association between two rooms, shown as an association class (a) and plain text (b)

The second proposal uses the package construct of UML instead of aggregation to describe that several objects are aggregated subsets of another. An example of this is shown in figure 4.10, where rooms belonging to a floor are modeled with aggregation (a) and as a package (b). The package syntax is "cleaner" since there are no overlapping lines. In cases where there are several floors, wings and rooms, the package syntax will reduce the number of overlapping and crossing lines, making the model easier to read and understand. It is important to emphasize that the package syntax used here does *not* imply a conceptual relationship between the objects within it. The syntax is used without applying the semantics.

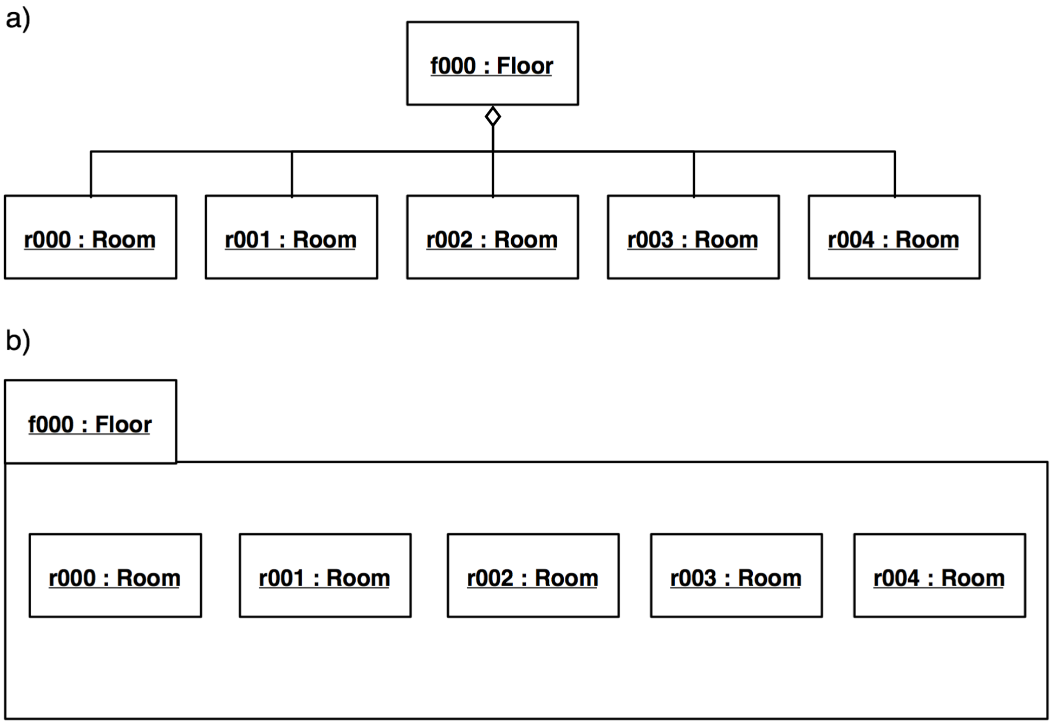


Figure 4.10: Rooms in a floor, shown as aggregation (a) and package (b)

As a scenario for an LM the building from figure 4.1 is used. A detailed cross section of both floors is given in figure 4.11, where floors, wings, rooms etc. are numbered. As a numbering scheme, the first letter(s) of each type of object are used as a prefix together with a unique identifier, for example "o01" for "office 01", "e1" for "elevator 1" and "c11" for the corridor in the first floor.

The numbering of doors and transitions between geometric areas are omitted in the model to make it easier to read. However, theses are numbered using the same scheme described above. The number of an office/corridor are prefixed with "d" to show a door that belongs to it. If a room has more than one door, a letter from "a" to "z" are used as a postfix to the number in order to distinguish between

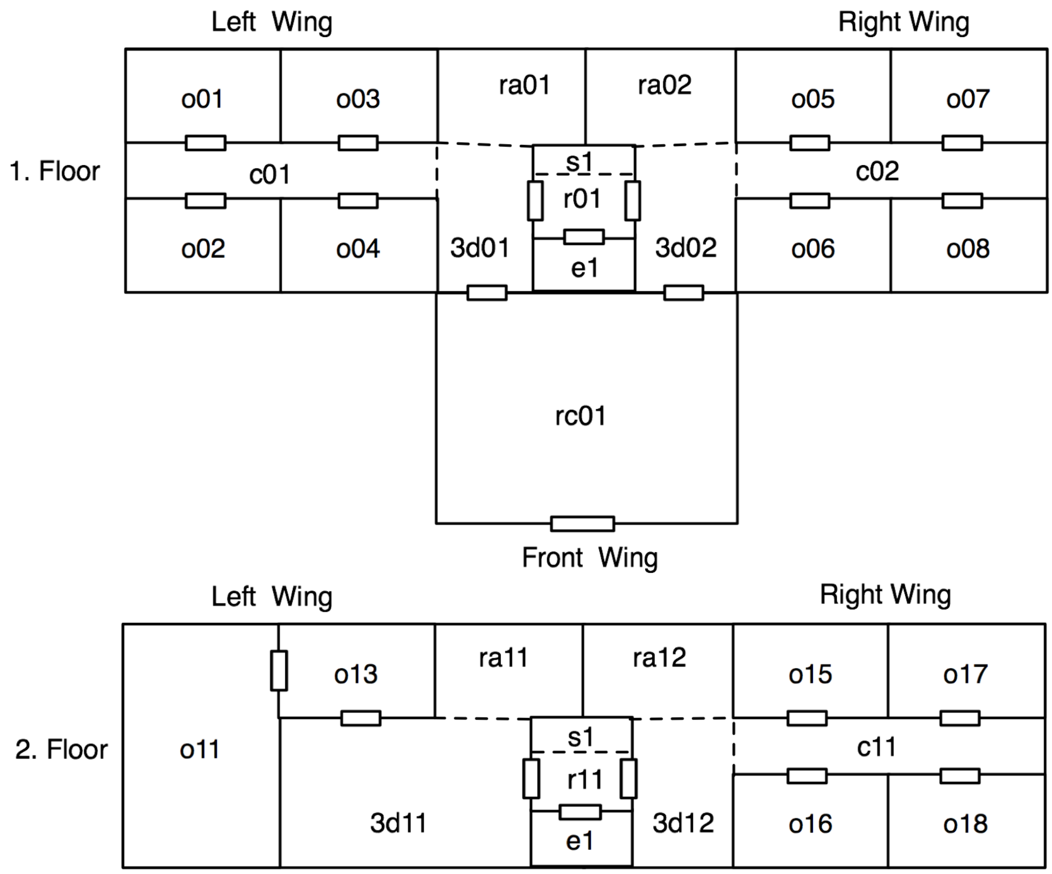


Figure 4.11: Plan showing both floors of building used for validation of domain model

them. For example, the door of office "o02" is numbered "do02" and the doors to stairway "sw01" are numbered "dsw01a" and "dsw01b". Transitions between geometric areas are numbered by prefixing the number of the area with "os" ("Open Space"). For instance, the transition between the recreational area "ra01" and the 3-dimensional space "3d01" is numbered "osra01".

Figure 4.12 shows how geometric areas can be defined outside different doors. These areas are numbered by adding the prefix "3d" to the object which they "belong" to, i.e. the object which is related to them. This concept can be used to answer queries such as "outside who's door am I standing?".

The LM for the example building is given in figure 4.13. The model assumes that floors are contained within wings, not vice versa. Because of this, floors are modeled as aggregated subsets of wings. The model also assumes that stairs between

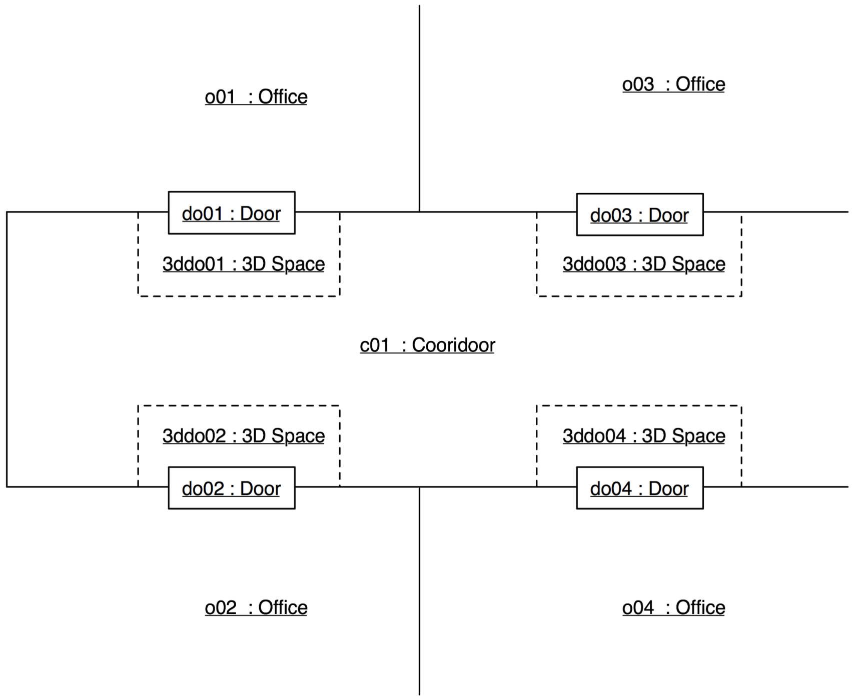


Figure 4.12: Geometric areas outside doors

two floors are contained within the lowest of the two. The stairs "s1" are thus a part of the ground floor, and together with the room "r01" they form the stairway "sw01" from the ground up to the first floor. Geometric areas outside doors are not included for the sake of clarity.

Validation of the domain model was done in two steps: first by checking if the model fulfills the required properties of an LM, then by attempting to answer the following queries:

- **Query 1**: You are in the reception. How do get from here to office "o02"?
- **Query 2**: You are standing in front of a door. Is there any way you can find out which door you are standing in front of?
- **Query 3**: Is it possible to find out if you are in an elevator or stairway? If so, which floor are you on?
- **Query 4**: Is an employee in his office?, If not, then where is he?

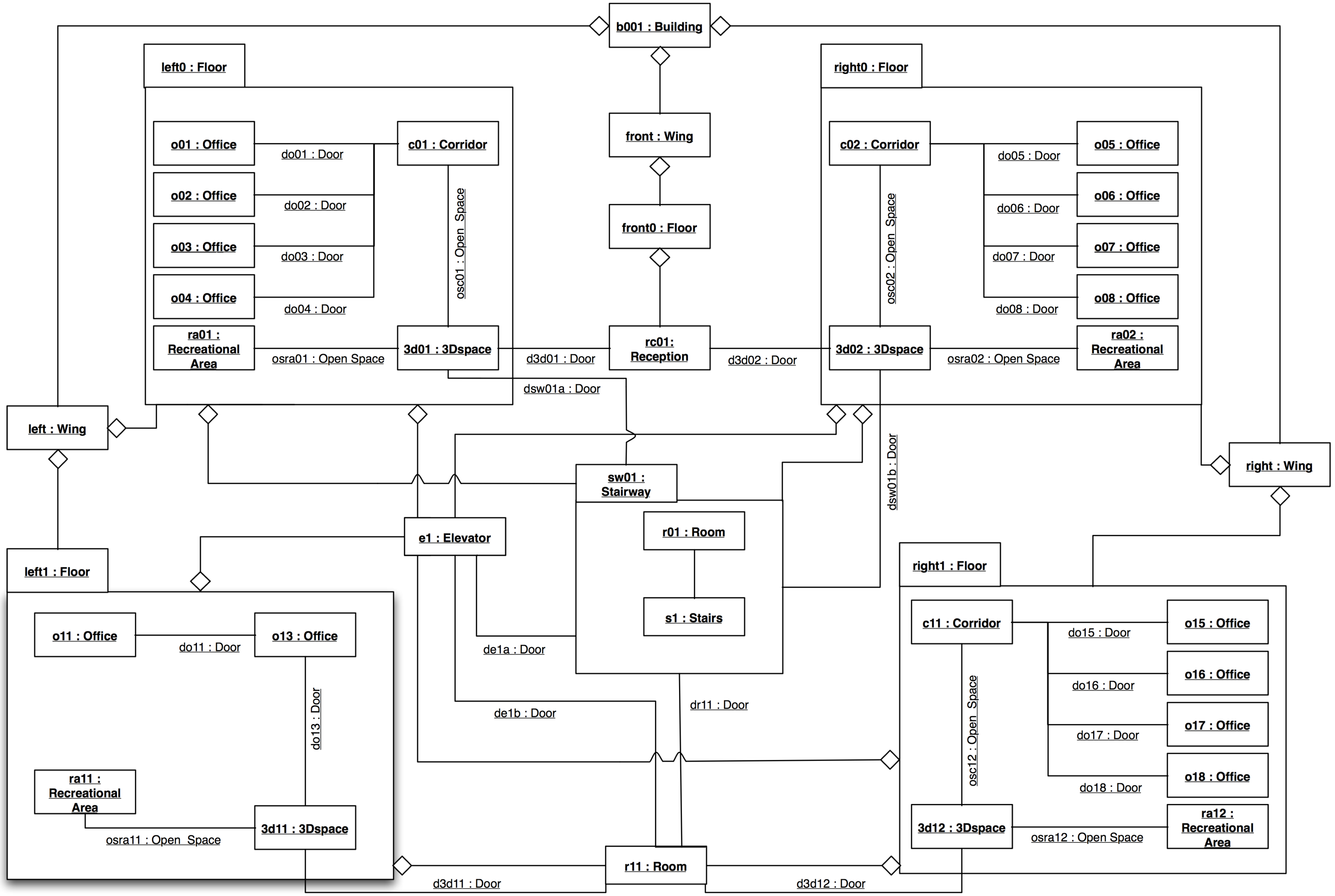


Figure 4.13: LM of the building described in figure 4.11

### 4.7.2 Validation Results

The domain model fulfills the required properties of accuracy, dependency, flexibility and representation of objects and relationships (section 4.3) acceptably. The first one, accuracy, depends on the particular needs the location aware application is meant to cover. In this case, that is to track the position and status of different moving objects within buildings. The domain model shown in figures 4.6, 4.7 and 4.8 contains the necessary constructs in great enough detail for this. Examples of such constructs are the building itself with its spatio-temporal properties, structure divided into wings, floors and rooms, and events occurring in it.

Representation of objects and their relationships are given so that they correspond closely to their real world occurrences. For example, a building is divided into floors, wings, rooms, spaces and offices, along with doors and open spaces to indicate transitions between them. Relationships between spaces are shows as containment or through transitions. This corresponds to how buildings are in reality. Objects within the building are modeled as separate entities with their own properties and are associated with different spaces based on their current position.

Dependency is shown as spaces containing others using the UML-symbol of composition. This indicates existence-dependency such as a building containing floors which in turn contain rooms. If the building ceases to exist, so do the floors and thus also the rooms.

Finally, regarding the issue of flexibility, new spaces can be added to others without having to change any of the higher levels in the hierarchy. For example, an office can be added to a floor without any consideration to the building as a whole. Similarly, spaces can change their symbolic names without affecting any of the other constructs in the model. Changing geometric information is somewhat more complicated, because this might affect other spaces. It is up to the application to resolve problems that might occur in these cases.

The queries asked in the previous section were also answered in good enough detail to validate the domain model. The result of the queries were:

- **Query 1**: Office “o02” is in the first floor (“left0”), left wing (“left”). In order to get there from the reception (“rc01”), go through door “d3d01”, cross the transition “osc01” and go through the door “do02” which leads to office “o02”. The model clearly shows this path.

- **Query 2**: An area outside a given door can be defined as its own geometrical area (figure 4.12). Such an area is numbered so that it "belongs" to that particular door. For example, the geographical area outside the door "do02" is numbered "3ddo02". Standing within this area thus means that the user is standing outside door "do02".
- **Query 3**: The elevator is modeled as a space of its own. It can therefore be determined if a person is inside it or not. The geometrical information in the model can be used to find which floor the elevator is currently in. Stairways are also modeled as spaces of their own. Stairways belong to the lowest of the two floors that they connect. Because of this, being in the stairway between two floors is regarded as being on the lowest one.
- **Query 4**: The domain model shows who occupies which offices. These persons are also considered as moving objects, so their position can be determined at any given time. To answer the query, it is checked whether or not the current position of a person is within the office the person occupies.

Based on fulfillment of the LM model properties and results of the queries, the domain model is deemed as complete for the modeling needs of indoor location aware systems. As previously emphasized, the model can be extended to include other types of spaces, objects, events and geometries. The hospital monitoring system scenario presented in section 4.2 is a good example of this, where it is needed to further extend the domain model by introducing new classes such as "Emergency Room", "Surgery", "Morgue" and other hospital related rooms. These new classes would be subclasses of "Space" and thus inherit all the properties of "3D Space". Other extensions could be "Hospital Bed" derived from the class "Object" and "Patient" from the class "Person". A new relationship "lies-in" could then be associated between "Patient" and "Hospital Bed", showing which patients currently lie in which beds.

The basic classes however, which describe the relationship between 2- and 3-dimensional spaces, objects, persons, roles and events are essential for all location aware applications.

## 4.8 Summary

The purpose of this chapter was to answer the first research question presented in section 1.1:*What are the requirements of location modeling and how are these require-*

*ments fullfilled in order to create location models used for symbolic as well as geometric positioning*?

In order to to this the basic concepts and requirements of location information and modeling were presented. Different approaches have been presented and a modeling technique, which includes both symbolic and geometric information, is given. The proposed model contains objects and relationships which were deemed as important for indoor location aware applications. It is also suited for nearest-neighbor- as well as range-queries. This chapter therefore answers the first research question.

The proposed model is created using UML, with some changes to the syntax in order to make models created with this technique less complicated. The model will be used throughout the thesis.

# Chapter 5

# Obtaining Location Information

In order to enable an LBS in a campus environment like NTNU, an extensive positioning system is needed. This chapter will describe some scenarios that opens up interesting possibilities for such an LBS. Some of these scenarios will then be selected for testing to find out if their location needs can be satisfied. Testing will be conducted in the current infrastructure and in an infrastructure specifically design to give good location information. The results will be analysed and the results learned will be applied to the scenarios to find out if they are feasible.

## 5.1 Suggested Scenarios

In order to find out what kind of location information is needed to enable an LBS on the campus several scenarios will be suggested. In this section some scenarios will be suggested and analyzed according to the categories below:

- **Accuracy:** The needed accuracy from a positioning estimate to make the location information acceptable. This variable is a number that indicates the minimum acceptable error margin in metres.
- **Complexity:** The degree of LM complexity needed in the scenario. If the value is low it would mean that the LM would contain rooms, corridors and doors between them. On the other hand if the value is high it would contain geographical areas outside doors and complex LM constructs.
- **Scope:** The scope of the LM need in the scenario. A string describing a common geometric shape that describes the scope of the LM.

- **Logic:** What logic that is needed in order for the scenario to work. A string describing the logic.

In table 5.1 a summary of the analyzation can be observed.

| | Accuracy | Complexity | Scope | Logic |
|---|---|---|---|---|
| Locator | 4 | Low | Building | Room detection |
| Proximity | 2 | Low | Floor | Proximity, Interest lists |
| Room Status | 4 | Low | Campus | Information gathering |
| Standing Still | 2 | High | Corridor | Standing Still Algorithm |
| The Guide | 2 | High | Building | Movement and Correction |

Table 5.1: Requirements of the suggested scenarios

### 5.1.1 Locator

A student or employee in a campus often wants to know the location of another person. This scenario offers a service that would give them the location of all the users on their buddy list. These buddies could be shown on a map that would at all times be updated with the latest position of the buddies.

The scenario requires a low detailed LM with a large scope. The accuracy of the positioning estimate does not have to be that good. As for logic it is very important to get an accurate estimate of the room the person is in. Knowing the position of the user inside the room is not that important.

### 5.1.2 Proximity

A user in a campus environment has a trackable device and walks down the hall. A notice from the service appears on his device telling him that two of his friends are having coffee at the café just across the hall. This is the kind of information a proximity based scenario could yield. As a student roam the area, the service triggers on the proximity of a set of predefined objects and bring up information about them.

A low detailed floor based LM with an accurate positioning estimate is needed in this scenario. A highly accurate estimation is needed to measure the proximity well. The basic of the logic is fairly simple but the proximity algorithm can also be very advanced to get better results.

### 5.1.3 Room status

On a campus there are several rooms of different kinds that are used for different tasks. The status of these rooms is often of interest to users. A student at the campus might want to find the closest free working room, or the nearest computer lab with a short printer queue. With the help of a trackable device the user can query the service for the status of nearby rooms.

This scenario requires a low detailed large scoped LM and an average accurate positioning estimate. The logic needed is dependant on how extensible the service should be. Checking printer queues or how many free computers at a lab, is one example. Another constraint on this scenario is that for it to work all students at the campus must be trackable or there must be some other way to find out if a work room is free.

### 5.1.4 Standing still

At a campus it often happens that somebody goes to see a professor or another employee and that the person is not in. This scenario offers a service that detects when a person is standing outside a door knocking at it. The service could also be used to detect somebody that stands in front of a billboard. Information can then be customized based on the location of the user and his profile.

A small scoped highly detailed LM and a high accuracy positioning estimate is needed to test out this scenario. The logic is fairly simple, find out if the position of the user is at the same spot for a predefined time period.

### 5.1.5 The Guide

A user wants to find something on the campus. This could be a specific location, a person or a book in a library. With the help a trackable device the user can get information on where to go to find what he is looking for. The device will also adapt to movement in order to show the shortest route to the target in real time.

This scenario is very demanding. It requires a highly detailed large scoped LM and a PS that can give an accurate positioning estimate. It also needs complex logic in order to direct the user the shortest way to its target. Error correction and adaptability when the users go wrong are also demanding features to implement.

## 5.2 Scenario Selection

In order to find out what scenarios that should be elaborated further and tested, several guidelines will be specified:

*G1. Fullfill Requirements*. The chosen scenarios must cover all the aspects of the requirements mentioned in table 5.1.

*G2. Easy Logic Implementation*. Programming complex logic is not necessary if you can get data with almost the same value with less programming.

*G3. Average degree of complexity*. Scenarios that are too simple will not yield data that is worth discussing. On the other hand, too complex scenarios would be too time consuming.

Based on these guidelines some scenarios will be selected and the selection process will be discussed.

### 5.2.1 Selection

As shown in table 5.1 the scenarios Locator and Room Status have many similarities. Both of them require a low level, large scoped LM and needs low accuracy location information. The difference between them is the logic implementation. Locator needs no more logic than the context of what room the device is located in, while Room Status needs more logic to work properly.

Of the other three scenarios, Standing Still and The Guide are fairly similar. They both require high accuracy location information in a complex LM. The difference is that while The Guide requires a large scoped LM and has advanced logic, Standing Still only needs a small scoped LM and almost no logic at all.

The last scenario, Proximity, is fairly different from the others. It requires a high accuracy positioning estimate in a low complex LM.

Logic-wise Proximity is similar to Room Status and The Guide in that they all require fairly sophisticated logic. On the other hand Standing Still and Locator does not require much logic at all.

#### Standing Still

The first scenario selected is *Standing Still*. It was preferred over The Guide according to *G2* since it has a much simpler logic implementation without loosing valuable data. It is also advantageous that it only needs a small scoped highly detailed LM instead of a large scoped highly detailed LM. Setting up a highly detailed large scoped LM would be very time consuming and not yield more valuable data than a smaller scoped example would.

The Standing Still scenario is a much simpler scenario than The Guide, but it is still advanced enough that is is worth testing according to *G3*.

#### Locator

According to *G1* the selection has to fulfill all the requirements listed in table 5.1. So since Standing Still is already chosen there is a need for a scenario with a low complex large scoped LM that does not require a high accuracy of location information.

The second scenario selected is *Locator*. It was preferred over Room Status according to *G2* since it has a much easier logic implementation and yield the same location information results. Locator is also advanced enough that it meets *G3*.

## 5.3 Test Setup

Before the testing can begin there are some issues that must be explained so that the reader has a better understanding of how the actual testing are done. In this section the technology used in the testing, the test locations and the test routines will be explained.

### 5.3.1 Ekahau Positioning Engine

The technology used for testing in this thesis is the *Ekahau Positioning Engine (EPE)* from the Finnish company Ekahau Inc. As briefly mentioned in section 3.5.2 the EPE is a WLAN positioning system made for indoor- and campus areas where GPS does not perform adequately. The solution requires no proprietary WLAN base stations and it does not need to know the location of the base stations.

The EPE software concept consists of the following components as shown in figure 5.1[28]:

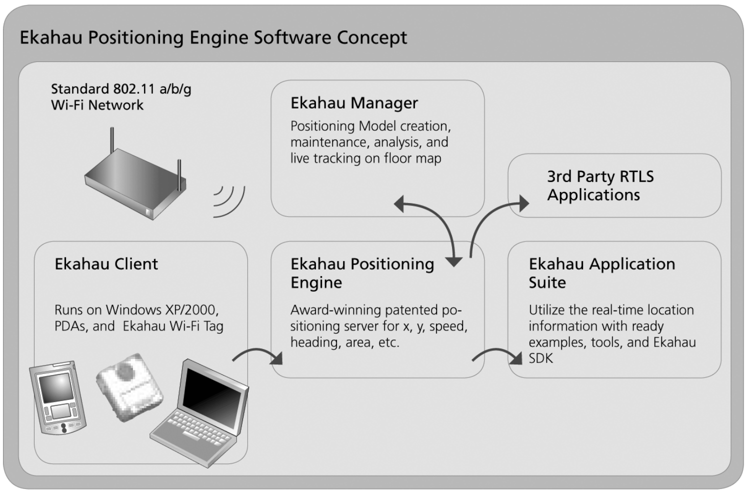


Figure 5.1: Architecture of the EPE from [28]

#### Ekahau Client

The Ekahau Client is a free downloadable piece of software that can be installed on any Windows compatible OS such as Windows XP, 2000, WinCE 3.0, PocketPC 2002/2003. The client software is also built into the proprietary WLAN tags *Ekahau T101 WiFi Tag* [33] and the *Ekahau T201 WiFi Tag* [34]. The client is responsible for sending the recorded Received Signal Strength Indicator (RSSI) WLAN signals to the server. These signals are used to position the user, and also by the Ekahau Manager application to do SiteCalibration. The T101 tag was used as a client device in the tests done for this thesis.

#### Ekahau Positioning Server

The Ekahau Positioning Server can run on any hardware platform with a minimum of a Pentium II processor, 256 MB of RAM, 200 MB of hard-disk and running Windows XP or 2000. Ekahau has a version for Linux out as well, but they do not provide support for it. The server is responsible for keeping track of all the devices, updating their position based on the information it gets from them and feeding the Ekahau Application Suite with data.

The EPE is a 2.5 dimensional positioning solution. It can not give a complete 3-D coordinate of the estimated position. What it can compute is x, y coordinates, the floor the device is in, the heading of the device and if the device is in a logical area on the map. [27, 28].

As mentioned in [30] there are several variables that will affect the accuracy of the positioning estimate of the EPE.

- **Number of access points:** The quality of the data improves at a decreasing rate as the density of the base station increase.
- **Device scan interval:** The average error margin drops as the scan interval drops at an almost even scale.
- **Client Device Speed:** The average error decreases with low speeds up to 1 metre per second. As speeds increases above 1 metre per second the average error increases progressively.
- **Calibration Density:** The average error is lower if the density of the sample points are higher.
- **Environment:** Test results have shown that it is easier to get good results in corridors than in open offices, open areas or rooms.

At the writing of this thesis the newest version of the EPE is 3.1, however in this thesis the 3.0 version was used in the testing.

#### Ekahau Manager

The Ekahau Manager is an application that runs on a Windows XP/2000 based laptop. The application is responsible for creating a model of the desired area. The Ekahau solution uses no explicit LM for this, instead it uses an accurate floor map image [1] of the area in which it is meant to operate. It requires explicit calibration in a patented process called SiteCalibration, in order to turn the map into a positioning model. The process of SiteCalibration is described in section 5.3.2

Ekahau Manager can also perform various analysis of the WLAN signals it has processed and even provide instant live tracking of a connected device.

The floor map used by the Ekahau Manager can be seen as an implicit location model when calibrated as a positioning model. The map does not show hierarchical or containment relationships between objects in a building, but is used to create a

[1] The image can be in JPG, PNG or BMP format.

coordinate system of each floor. Although symbolic names are used to identify different geographic locations on the map, this implicit LM must be said to be purely geometric, since no symbolic relationships are present and received coordinates are mapped to symbolic names by the EPE.

#### Ekahau Application Suite

The Ekahau Application Suite (EAS) is the part of the solution that communicates with third party LBS applications. There are two ways to communicate with the EAS, either a Java SDK (Software Development Kit) or a YAX based protocol [2]. When you acquire the EPE solution it ships with several examples that uses both the Java SDK and the YAX protocol. The testing application that is used for the testing for this thesis (section 5.3.3) is based upon one of these examples that came with the EPE 3.0 [31].

In the newer 3.1 version of the EPE the EAS contains applications such as Ekahau Finder to find objects, Ekahau Tracker to track objects in a web interface and Ekahau Logger to store the information in a database for later analyzation [29].

### 5.3.2 Calibrating a Positioning Model

As mentioned in section 5.3.1 the Ekahau Manager is responsible for the patented SiteCalibration process. The process of SiteCalibration is described below.

First import an accurate drawing of the wanted floor into the program. Then set the pixel/cm ratio in order for the program to translate the real-life measurements into correct pixels on the map.

Tracking rails are then drawn on top of the imported picture to symbolize walking paths. In figures A.1, A.2 and A.3, in the figure appendix, the tracking rails can be seen. The rails are draw in the middle of the corridors with samples on both the outside and the inside of some doors. The guidelines of calibrating a positioning model dictates that you should record sample points on both sides of a door, and at regular intervals in the walking paths. In open areas a grid of samples should be drawn.

The figures A.2 and A.3 are actually two floors in the same building with the former being the ground floor and the latter being the first. The two floors could have been

[2] The YAX protocol is a self developed asyncronous TCP location protocol

connected together in the positioning model, but because the WLAN signals are so week in the stairways this was not possible.

The procedure of calibrating the model is as following:

1. Enable the calibration mode.
2. Walk up to a sample point and left-click it with the mouse in the GUI.
3. Without moving from the spot, slowly turn around and record samples from all directions.
4. Move to the next sample and repeat the process.

### 5.3.3 Testing application

In order to achieve the results of the tests a testing application was made. The technical aspects of the testing application can be seen in appendix B. In this section the way the application works and the results it provides will be discussed.

The application has two modes. The first default mode is used to record an ordinary sample. The second extended version is used in order to try to estimate a better position using the average of several estimates. In figure 5.2 a view of the GUI of the testing application can be seen.

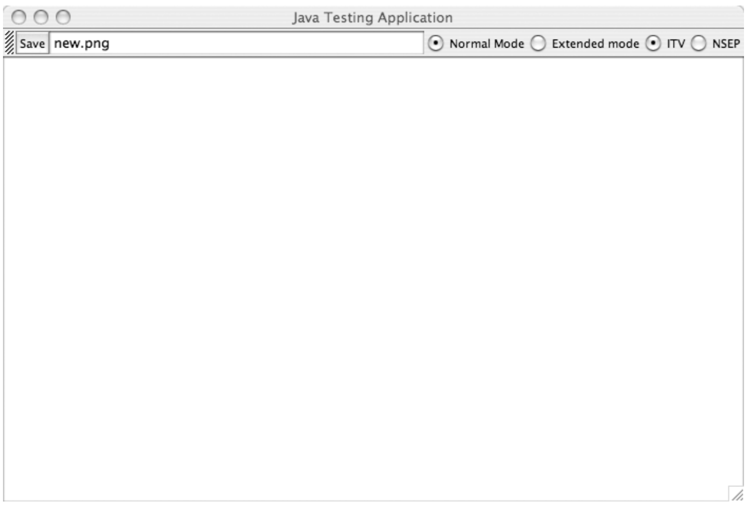


Figure 5.2: GUI of testing application

### Default Mode

The application shows a picture of the current floor. When left-clicking on a spot the application will paint this sample point with an empty circle. Then on the next recorded signal from the testing device, it will draw a line from the sample point to the estimated position represented with a solid circle. An identifier and the error from the sample point to the estimated position will be written next to the sample point circle. This syntax can be observed in figure: 5.3.

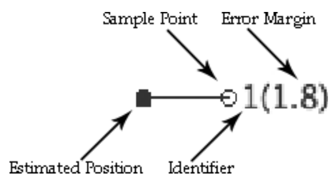


Figure 5.3: Syntax for the testing application normal mode

The procedure of the testing is:

1. Walk up to the sample point.
2. Wait 2 seconds for the positioning software to update itself and then take a sample.
3. Walk to the next sample point and repeat.

When all the samples are taken write the name of the test in a text field and press save. The application will save the result as a PNG image file and reset itself.

### Extended Mode

In the extended mode the results are shown is different way than in default mode. In figure 5.4 the syntax used for the extended mode can be observed. In this mode the application record several samples for each test and paint them as a number. If the sample is under 1 metre away from the sample point the number will be in black, if not the number will be in gray. An average position is then estimated, from the black numbers, and painted as a black dot.

With the extended mode every sample point has its own image since it would be difficult to produce an image that clearly differentiated on which estimations belonged to which sample.

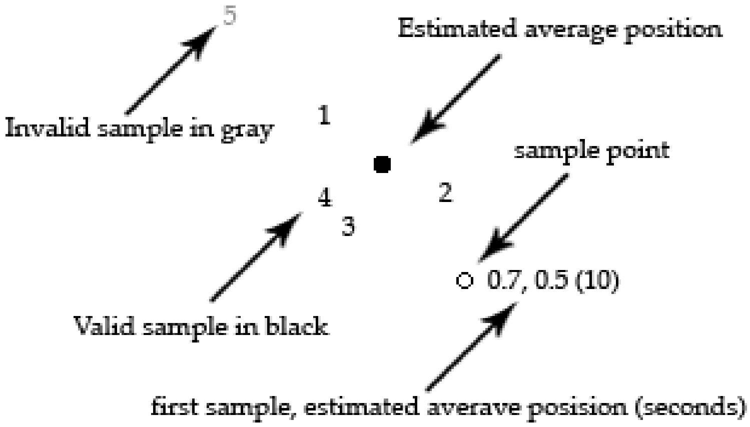


Figure 5.4: Syntax for testing application extended mode

The routine for this extended mode test is therefore a bit simpler than in the default mode.

1. Walk to the desired spot
2. Start to record a sample and stand on the same spot.
3. Turn around slowly and wait for the application to record the desired number of points.
4. Write the desired name of the test in the text field and press save.

### 5.3.4 Testing Location: ITV

It-Vest (ITV) is a building in the campus at Gløshaugen, where the institute of Informatics is situated. The building has 5 floors that are all dominated by a central corridor with offices on both sides of it.

Testing in this building will be done in the ground- and first floor. This is done in order to see if there are any difference when you have base stations located in the floor below you. The first floor will be able to pick up signals from the base stations in both the ground, first and second floors while the testing in the ground floor will only pick up signals from the base stations in the ground floor and in the first floor.

The layout of both the floors with tracking rails can be seen in the figures appendix in figures A.2 and A.3. Tracking rails are drawn down the central corridor and

Figure 5.5: Picture of the ground floor of the ITV testing location

Figure 5.6: Picture of the first floor of the ITV testing location

inside some offices along the way. All the rooms are calibrated with a single calibration point. The resting area in the centre of the corridor is calibrated with a net of points according to the recommendations in [32].

Pictures of the ground and first floor can be seen in figures 5.5 and 5.6.

The placement of the base stations in ITV are not shown in any of the pictures since this is against security policy.

### 5.3.5 Testing Location: NSEP

NSEP is an usability lab that is situated close to the St. Olav hospital in Trondheim, Norway. It is used for testing technology, among them positioning technologies, in a hospital environment. The lab is set up to look like a hospital corridor with 2 rooms and doors on each side of the corridor. In figure 5.7 room1 in this testing location can be seen.

Figure 5.7: Picture of room1 in the NSEP testing location

The layout of the NSEP testing area with tracking rails can be seen in figure A.1 in the test figures appendix. In this setup the placement of the base stations can be changed since it is a flexible usability lab. The placement of the base stations will be described with an 'A' symbol.

### 5.3.6 Test procedure

Before the testing of the selected scenarios can begin it is necessary to have a clear procedure to follow.

It is necessary to test out the existing WLAN infrastructure as well as to test how to get better results with optimizing the WLAN infrastructure for an LBS. It is also interesting to see if some form of logic can be applied to the results to improve the raw data from the positioning system. The following procedure will be used in the testing:

- **T1**: Test to find location information in the existing infrastructure specified in section 5.3.4.
- **T2**: Test to find location information in the improved infrastructure specified in section 5.3.5.
- **T3**: Apply and/or test general logic or logic from the LM to improve results or omit problems found in **T1** or **T2**.
- **T4**: Discuss the results and see if the original requirements can be modified to get better results based on **T3**.

## 5.4 Locator

In this section the scenario *Locator* will be elaborated further, and then tested according to the guidelines specified in section 5.3.6.

This scenario is all about the need to find something. With the help of this scenario finding your friends or equipment in an enabled environment would no longer be a problem.

BuddySpace [51] is an Instant Messaging (IM) application that has location information features built into it. The user manually plots in his location and you can then see where other users are when talking to them. With a small extension to this program the location information in the program could be made dynamic for all clients inside the campus. A student could be talking to another student, and at the same time observe his position in the application.

For the University itself a locator based service could also be very interesting. They could tag all their precious technical equipment and key staff crew and be able to see where they are at all times. There are privacy issues with an approach like this, these issues will not be discussed in this thesis.

In this scenario the key concept is, as the name implies, to locate something. The important thing is therefore to know in what room the object is in, and preferably what part of the room it is in. The exact position of the object is not that important. However if the service report the position to be in an adjacent room it is not that bad. If you are looking for a person and he is reported to be in the next room it is not that hard to look close to where the estimates say the person is. You know the general area of where the person is, and that might be enough. Therefore the needed probability of this scenario does not have to be more than 75 %. The problem is if the service estimates the position of the object completely wrong. This problem can probably be fixed with logic from the LM.

### 5.4.1 Testing exisiting infrastucture

In accordance with **T1** specified in section 5.3.6 the first test in this scenario is to test the raw potential of the test location ITV (section 5.3.4).

The test routes for this test can be seen in figures A.12, A.13, A.14 and A.15 in the test figures appendix.

The following categories will have to be fulfilled in order for the sample to be classified as **A**pproved for this scenario.

- **C1**: The estimated position is in the same room as the sample.
- **C2**: The error margin of the position estimate must not exceed 2 metre.
- **C3**: Applies only for samples not in the corridor. There are no samples from other rooms estimated in this room.

The color formatting in the tables describes the quality of the sample from a pure accuracy point of view. Samples that classify according to **C1** (<2 metre) are in white, samples that are close to classification are in light gray (2-3.5 metre) and finally samples that are far from classification are in dark gray (3.5> metre).

#### Ground floor ITV

The testing on the ground floor is not done in the entire length of the floor since part of this area do not have sufficient WLAN coverage to calibrate a positioning model.

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 3.5 | √ | - | √ | - |
| 2 | 2.2 | √ | - | | - |
| 3 | 1.3 | √ | √ | | √ |
| 4 | 0.3 | √ | √ | | √ |
| 5 | 3.6 | - | - | √ | - |
| 6 | 1.1 | √ | √ | | √ |
| 7 | 0.7 | √ | √ | | √ |
| 8 | 4.5 | √ | - | | - |
| 9 | 10.5 | - | - | √ | - |
| 10 | 6.5 | √ | - | | - |
| 11 | 0.6 | √ | √ | | √ |
| 12 | 3.9 | - | - | √ | - |
| 13 | 0.5 | √ | √ | | √ |
| 14 | 1.8 | √ | √ | √ | √ |
| 15 | 2.9 | √ | - | | - |
| Result | 2.93 | 80% | 47% | 100% | 47% |

Table 5.2: L-ITV: Ground floor test results

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 3.0 | √ | - | | - |
| 2 | 0.4 | √ | √ | | √ |
| 3 | 2.5 | - | - | √ | - |
| 4 | 2.9 | √ | - | | - |
| 5 | 4.5 | - | - | √ | - |
| 6 | 2.6 | √ | - | | - |
| 7 | 4.2 | √ | - | | - |
| 8 | 6.9 | - | - | √ | - |
| 9 | 1.1 | √ | √ | | √ |
| 10 | 2.4 | √ | - | | - |
| 11 | 1.3 | √ | √ | | √ |
| 12 | 3.5 | - | - | √ | - |
| 13 | 0.6 | √ | √ | | √ |
| 14 | 0.7 | √ | √ | | √ |
| 15 | 2.6 | √ | - | | - |
| Result | 2.61 | 73% | 33% | 100% | 33% |

Table 5.3: L-ITV: Ground floor reverse test results

Testing on the ground floor is done at even intervals down the hall and inside some selected offices as shown in figures A.16 and A.17. The results can be observed in tables 5.2 and 5.3.

The results of this test shows that the degree of approvement is not satisfying. In addition to this, there are some areas of the test that gives strange answers.

In figure 5.8 the central resting area and sofa group with the surrounding rooms can be seen.

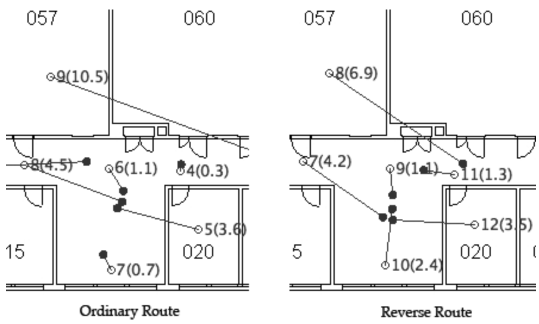


Figure 5.8: L-ITV: Ground floor problem area 1

The problem here is that all results are cluttered towards the middle of the resting area. As mentioned in the test setup, the resting area was calibrated with a matrix of calibration points. The offices, however, are calibrated with only a single central point in each office, and that might be the problem. The same problem can be observed from the samples in room 057 (sample 9 in ordinary route and 8 in reverse). Why it is so hard for the technology to estimate a position inside these rooms with just one calibrated point is unknown. In some rooms it works fine, but in others these kind of problems happen.

In figure 5.9 office 12 and 13 and the surrounding area of the ground floor can be seen.

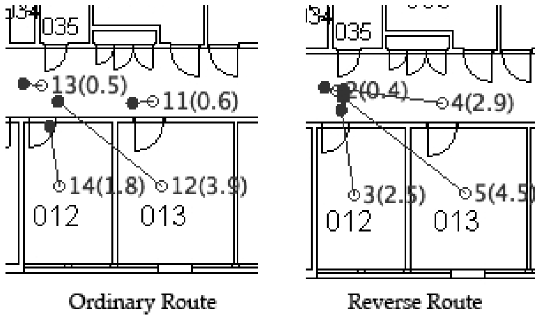


Figure 5.9: L-ITV: Ground floor problem area 2

In this second problem area the points are cluttered in the corridor outside office 12. The reverse route is the worst, where 4 samples are located very close to each other.

The result in this test shows that the degree of approvement is not very good in the ground floor. With a degree of approvement of 47% and 33%, it is not acceptable.

#### First floor ITV

In the first floor the entire floor is calibrated, so this test is more extensive than in the ground floor, as shown in figures A.18 and A.19. The results can be observed in tables 5.4 and 5.5.

The results in the first floor are in general much better than the ones found in the ground floor. This is not surprising since the technology should be able to pick up more base stations in the first floor. The degree of approvement is closing on the goal of 75% approvement. At 65% in both the tests it is almost acceptable.

In the first floor there is one problem area as can be seen in figure 5.10.

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.2 | √ | √ | | √ |
| 2 | 0.5 | √ | √ | √ | √ |
| 3 | 0.8 | √ | √ | | √ |
| 4 | 0 | √ | √ | | √ |
| 5 | 2.4 | √ | - | | - |
| 6 | 3.3 | √ | - | - | - |
| 7 | 2.6 | - | - | | - |
| 8 | 1.1 | √ | √ | - | - |
| 9 | 2 | - | √ | | - |
| 10 | 2 | √ | √ | √ | √ |
| 11 | 1.6 | √ | √ | | √ |
| 12 | 0.7 | √ | √ | | √ |
| 13 | 1.6 | √ | √ | √ | √ |
| 14 | 2.3 | √ | - | | - |
| 15 | 0.5 | √ | √ | | √ |
| 16 | 0.4 | √ | √ | | √ |
| 17 | 3.3 | √ | - | | - |
| 18 | 1.9 | √ | √ | | √ |
| 19 | 1.9 | √ | √ | | √ |
| 20 | 1.4 | √ | √ | √ | √ |
| Result | 1.53 | 90% | 75% | 67% | 65% |

Table 5.4: L-ITV: First floor test results

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.6 | √ | √ | √ | √ |
| 2 | 1.2 | √ | √ | | √ |
| 3 | 3 | √ | - | | - |
| 4 | 0.6 | √ | √ | | √ |
| 5 | 0.7 | √ | √ | | √ |
| 6 | 2.1 | √ | - | | - |
| 7 | 0.5 | √ | √ | | √ |
| 8 | 3.4 | - | - | | - |
| 9 | 1.2 | √ | √ | - | - |
| 10 | 7 | - | - | | - |
| 11 | 0 | √ | √ | | √ |
| 12 | 6 | - | - | √ | - |
| 13 | 1.2 | √ | √ | | √ |
| 14 | 0.7 | √ | √ | √ | √ |
| 15 | 0.4 | √ | √ | √ | √ |
| 16 | 2.3 | √ | - | | - |
| 17 | 1.5 | √ | √ | | √ |
| 18 | 0.5 | √ | √ | | √ |
| 19 | 0.6 | √ | √ | √ | √ |
| 20 | 0.7 | √ | √ | | √ |
| Result | 1.71 | 85% | 70% | 83% | 65% |

Table 5.5: L-ITV: First floor reverse test results

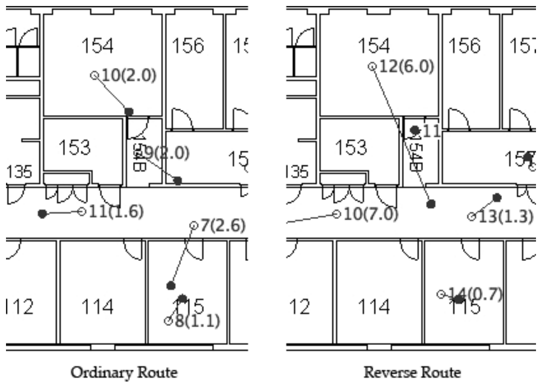


Figure 5.10: L-ITV: First floor problem area

Calibrating this particular area was pretty troublesome since the technology kept disconnecting from the server and strange results showed up during preliminary testing.

The sample point 8 in the ordinary route and 14 in the reverse route is a good sample point. However, all the others give strange results when comparing the two directions. Point 9 in the ordinary route and 11 in the reverse route are at one point on the spot accurate while on the other it is 2 metres away. The other points have similar differences and it is just strange that the results should be so different depending on what direction the device comes from.

### 5.4.2 Testing Improved Infrastructure

In accordance with **T2** specified in section 5.3.6 a test will be conducted in the improved infrastructure. The goal of this test is to find the potential of the Locator scenario in this environment.

In figures 5.11 and 5.12 the test routes that will be used in this test can be seen. A varying number of base stations will be put up at marked places and for each of these setups both the test routes will be tested.

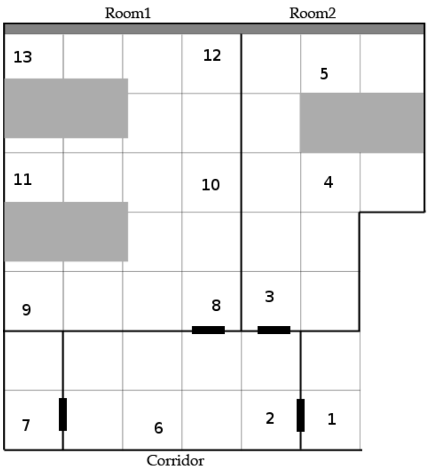


Figure 5.11: L-NSEP: Test route

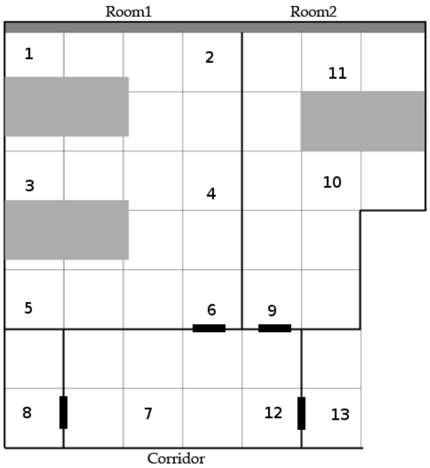


Figure 5.12: L-NSEP: Reverse test route

In order to classify a sample as approved for this scenario the following categories must be fulfilled. If all of the categories for a sample is fulfilled it will be an **A**pproved sample point.

- **C1**: The estimated position is in the same room as the sample.
- **C2**: The error margin of the position estimate must not exceed 1 metre.
- **C3**: The sample point is not cluttered towards several other sample points.

The results of all the tests are presented in table 5.14 and discussed briefly under each test.

The color formatting in the tables describes the quality of the sample from a pure accuracy point of view. Samples that classify according to **C1** (<1 metre) are in white, samples that are close to classification are in light gray (1-2 metre) and finally samples that are far from classification are in dark gray (2> metre).

### Test1

In this first test a single base station is placed in the middle of the setup marked as an 'A'. The test can be seen in figures 5.13 and 5.14. This test is done in order to have something to compare the other tests in this environment with. The results for this test can be seen in tables 5.6 and 5.7.

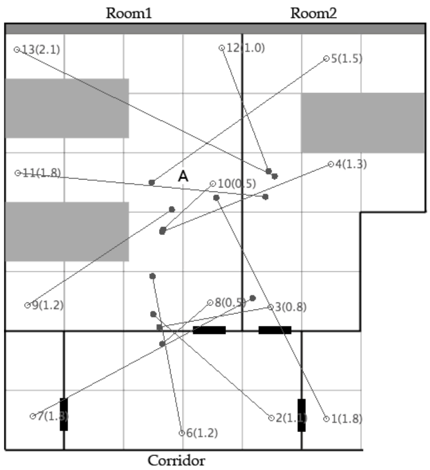


Figure 5.13: L-NSEP: Test1

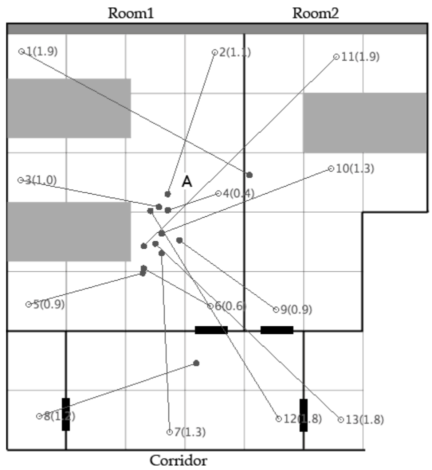


Figure 5.14: L-NSEP: Reverse Test1

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 1.8 | - | - | √ | - |
| 2 | 1.1 | - | - | - | - |
| 3 | 0.8 | - | √ | - | - |
| 4 | 1.3 | - | - | - | - |
| 5 | 1.5 | - | - | - | - |
| 6 | 1.2 | - | - | - | - |
| 7 | 1.3 | - | - | √ | - |
| 8 | 0.5 | - | √ | - | - |
| 9 | 1.2 | √ | - | - | - |
| 10 | 0.5 | √ | √ | - | - |
| 11 | 1.8 | - | - | - | - |
| 12 | 1.0 | - | √ | - | - |
| 13 | 2.1 | - | - | - | - |
| Result | 1.24 | 15% | 31% | 15% | 0% |

Table 5.6: L-NSEP: Test1 results

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 1.9 | - | - | √ | - |
| 2 | 1.1 | √ | - | - | - |
| 3 | 1.0 | √ | √ | - | - |
| 4 | 0.4 | √ | √ | - | - |
| 5 | 0.9 | √ | √ | - | - |
| 6 | 0.6 | √ | √ | - | - |
| 7 | 1.3 | - | - | - | - |
| 8 | 1.2 | - | - | √ | - |
| 9 | 0.9 | - | √ | - | - |
| 10 | 1.3 | - | - | - | - |
| 11 | 1.9 | - | - | - | - |
| 12 | 1.8 | - | - | - | - |
| 13 | 1.8 | | - | - | - |
| Result | 1.24 | 42% | 38% | 15% | 0% |

Table 5.7: L-NSEP: Reverse Test1 results

The level of approvement is 0%, and as observed in figures 5.13 and 5.14 the error margins and cross lines between estimations and sample points are pure chaos.

### Test2

In this second test the number of base stations are expanded to three and they are placed right outside the doors in the corridor and in the centre of room1. The base stations are marked down as an 'A' symbol. The test can be seen in figures 5.15 and 5.16. Results can be seen in tables 5.8 and 5.9.

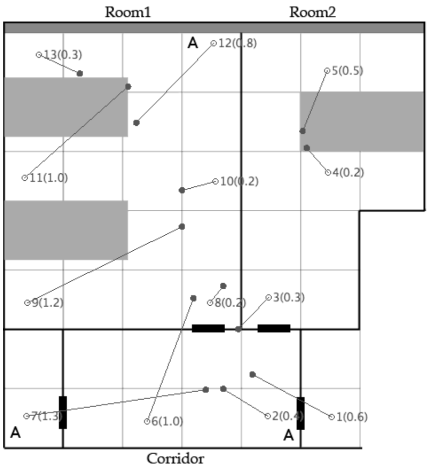


Figure 5.15: L-NSEP: Test2

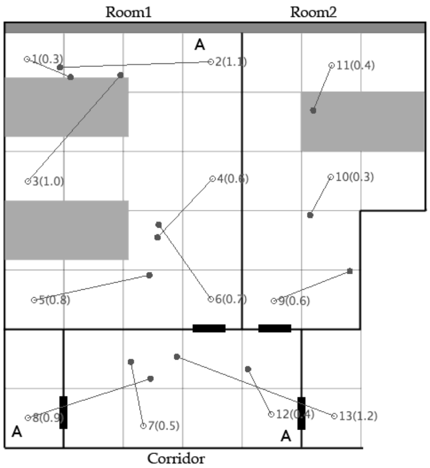


Figure 5.16: L-NSEP: Reverse Test2

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.6 | - | √ | - | - |
| 2 | 0.4 | - | √ | - | - |
| 3 | 0.3 | - | √ | √ | - |
| 4 | 0.2 | √ | √ | - | - |
| 5 | 0.5 | √ | √ | - | - |
| 6 | 1.0 | - | √ | - | - |
| 7 | 1.3 | - | - | - | - |
| 8 | 0.2 | √ | √ | - | - |
| 9 | 1.2 | √ | - | - | - |
| 10 | 0.2 | √ | √ | - | - |
| 11 | 1.0 | √ | √ | - | - |
| 12 | 0.8 | √ | √ | - | - |
| 13 | 0.3 | √ | √ | √ | √ |
| Result | 0.62 | 62% | 85% | 15% | 8% |

Table 5.8: L-NSEP: Test2 results

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.3 | √ | √ | - | - |
| 2 | 1.1 | √ | - | - | - |
| 3 | 1.0 | √ | √ | √ | √ |
| 4 | 0.6 | √ | √ | - | - |
| 5 | 0.8 | √ | √ | √ | √ |
| 6 | 0.7 | √ | √ | - | - |
| 7 | 0.5 | √ | √ | - | - |
| 8 | 0.9 | - | √ | - | - |
| 9 | 0.6 | √ | √ | √ | √ |
| 10 | 0.3 | √ | √ | √ | √ |
| 11 | 0.4 | √ | √ | √ | √ |
| 12 | 0.4 | √ | √ | √ | √ |
| 13 | 1.2 | - | - | - | - |
| Result | 0.68 | 85% | 85% | 46% | 46% |

Table 5.9: L-NSEP: Reverse Test2 results

The degree of approved samples in the ordinary route is very low at 8% while in the reverse route it is much better at 46%. the results are still disappointing. They are even worse than in the existing infrastructure.

### Test3

In this test the triangle made in the second test is reversed. Base stations are placed in the outmost corners of room1 and room2 and in the middle of the corridor. The base stations are marked down as an 'A' symbol. The test can be seen in figures 5.17 and 5.18 and the results can be seen in tables 5.10 and 5.11.

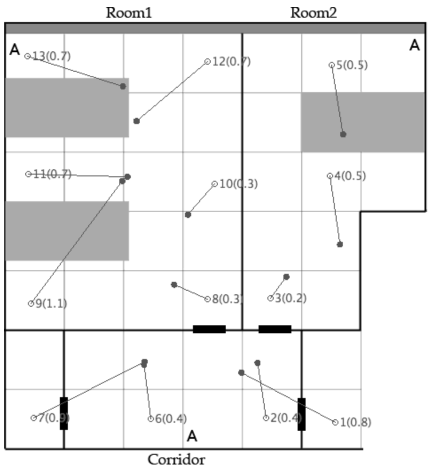


Figure 5.17: L-NSEP: Test3

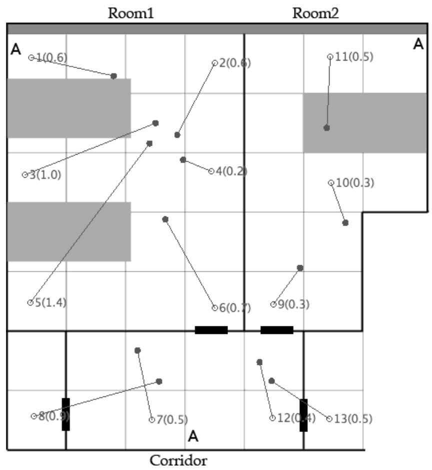


Figure 5.18: L-NSEP: Reverse Test3

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.8 | - | √ | - | - |
| 2 | 0.4 | √ | √ | - | - |
| 3 | 0.2 | √ | √ | √ | √ |
| 4 | 0.5 | √ | √ | √ | √ |
| 5 | 0.5 | √ | √ | √ | √ |
| 6 | 0.4 | √ | √ | - | - |
| 7 | 0.9 | - | √ | - | - |
| 8 | 0.3 | √ | √ | √ | √ |
| 9 | 1.1 | √ | - | - | - |
| 10 | 0.3 | √ | √ | √ | √ |
| 11 | 0.7 | √ | √ | - | - |
| 12 | 0.7 | √ | √ | √ | √ |
| 13 | 0.7 | √ | √ | √ | √ |
| Result | 0.58 | 85% | 92% | 54% | 54% |

Table 5.10: L-NSEP: Test3 results

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.6 | √ | √ | √ | √ |
| 2 | 0.6 | √ | √ | - | - |
| 3 | 1.0 | √ | √ | - | - |
| 4 | 0.2 | √ | √ | - | - |
| 5 | 1.4 | √ | - | - | - |
| 6 | 0.7 | √ | √ | √ | √ |
| 7 | 0.5 | √ | √ | - | - |
| 8 | 0.9 | - | √ | - | - |
| 9 | 0.3 | √ | √ | √ | √ |
| 10 | 0.3 | √ | √ | √ | √ |
| 11 | 0.5 | √ | √ | √ | √ |
| 12 | 0.4 | √ | √ | - | - |
| 13 | 0.5 | - | √ | - | - |
| Result | 0.61 | 85% | 92% | 38% | 38% |

Table 5.11: L-NSEP: Reverse Test3 results

In this third test the results are improving. It looks like this placement of base stations is much better than in the second test. The degree of approvement is now at 54% and 38%.

### Test4

Finally the test is done with the base stations placed in the middle of the rooms and in the middle of the corridor. The base stations are marked down as an 'A' symbol. The test can be seen in figures 5.19 and 5.20. Results from the test can be seen in tables 5.12 and 5.13.

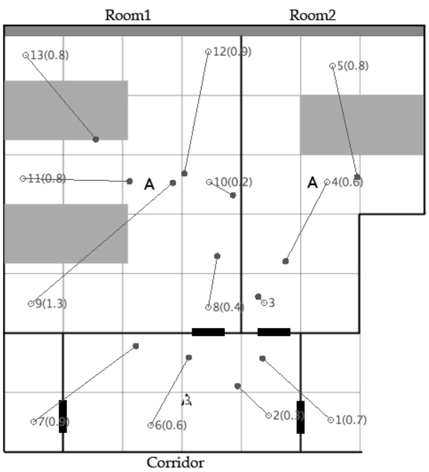


Figure 5.19: L-NSEP: Test4

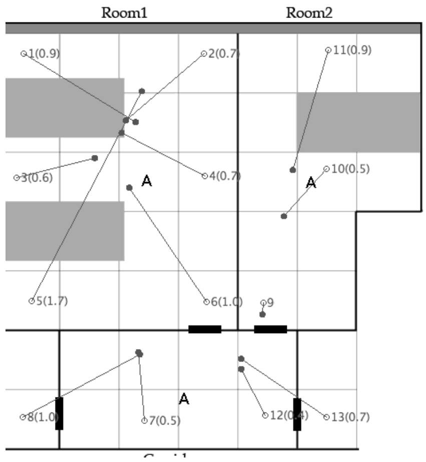


Figure 5.20: L-NSEP: Reverse Test4

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.7 | - | √ | √ | - |
| 2 | 0.3 | √ | √ | √ | √ |
| 3 | 0.0 | √ | √ | √ | √ |
| 4 | 0.6 | √ | √ | √ | √ |
| 5 | 0.8 | √ | √ | √ | √ |
| 6 | 0.6 | √ | √ | √ | √ |
| 7 | 0.9 | - | √ | √ | - |
| 8 | 0.4 | √ | √ | √ | √ |
| 9 | 1.3 | √ | - | - | - |
| 10 | 0.2 | √ | √ | √ | √ |
| 11 | 0.8 | √ | √ | - | - |
| 12 | 0.9 | √ | √ | - | - |
| 13 | 0.8 | √ | √ | √ | √ |
| Result | 0.64 | 85% | 92% | 77% | 62% |

Table 5.12: L-NSEP: Test4 results

| Sample | Error | C1 | C2 | C3 | A |
|---|---|---|---|---|---|
| 1 | 0.9 | √ | √ | - | - |
| 2 | 0.7 | √ | √ | - | - |
| 3 | 0.3 | √ | √ | √ | √ |
| 4 | 0.7 | √ | √ | - | - |
| 5 | 1.7 | √ | - | - | - |
| 6 | 1.0 | √ | √ | √ | √ |
| 7 | 0.5 | √ | √ | - | - |
| 8 | 1.0 | - | √ | - | - |
| 9 | 0.0 | √ | √ | √ | √ |
| 10 | 0.5 | √ | √ | √ | √ |
| 11 | 0.9 | √ | √ | √ | √ |
| 12 | 0.4 | √ | √ | - | - |
| 13 | 0.7 | - | √ | - | - |
| Result | 0.72 | 85% | 92% | 38% | 38% |

Table 5.13: L-NSEP: Reverse Test4 results

This test has, so far, the best test results in this testing location. The degree of approvement is at 62% and 38%.

| Sample | Test1 | Test2 | Test3 | Test4 | Average |
|---|---|---|---|---|---|
| 1 | 1.8 | 0.7 | 0.8 | 0.6 | 0.98 |
| 2 | 1.1 | 0.3 | 0.4 | 0.4 | 0.55 |
| 3 | 0.8 | 0.0 | 0.2 | 0.3 | 0.33 |
| 4 | 1.3 | 0.6 | 0.5 | 0.2 | 0.65 |
| 5 | 1.5 | 0.8 | 0.5 | 0.5 | 0.83 |
| 6 | 1.2 | 0.6 | 0.4 | 1.0 | 0.80 |
| 7 | 1.3 | 0.9 | 0.9 | 1.3 | 1.10 |
| 8 | 0.5 | 0.4 | 0.3 | 0.2 | 0.35 |
| 9 | 1.2 | 1.3 | 1.1 | 1.3 | 1.23 |
| 10 | 0.5 | 0.2 | 0.3 | 0.2 | 0.30 |
| 11 | 1.8 | 0.8 | 0.7 | 1.0 | 1.08 |
| 12 | 1.0 | 0.9 | 0.7 | 0.8 | 0.85 |
| 13 | 2.1 | 0.8 | 0.7 | 0.3 | 0.98 |
| Average | 1.24 | 0.64 | 0.58 | 0.62 | 0.77 |

Table 5.14: L-NSEP: Summary of tests

| Sample | Test1 | Test2 | Test3 | Test4 | Average |
|---|---|---|---|---|---|
| 1 | 1.9 | 0.3 | 0.6 | 0.9 | 0.93 |
| 2 | 1.1 | 1.1 | 0.6 | 0.7 | 0.88 |
| 3 | 1.0 | 1.0 | 1.0 | 0.6 | 0.90 |
| 4 | 0.4 | 0.6 | 0.2 | 0.7 | 0.48 |
| 5 | 0.9 | 0.8 | 1.4 | 1.7 | 1.20 |
| 6 | 0.6 | 0.7 | 0.7 | 1.0 | 0.75 |
| 7 | 1.3 | 0.5 | 0.5 | 0.5 | 0.70 |
| 8 | 1.2 | 0.9 | 0.9 | 1.0 | 1.00 |
| 9 | 0.9 | 0.6 | 0.3 | 0 | 0.45 |
| 10 | 1.3 | 0.3 | 0.3 | 0.5 | 0.60 |
| 11 | 1.9 | 0.4 | 0.5 | 0.9 | 0.93 |
| 12 | 1.8 | 0.4 | 0.4 | 0.4 | 0.75 |
| 13 | 1.8 | 1.2 | 0.5 | 0.7 | 1.05 |
| Average | 1.24 | 0.68 | 0.61 | 0.74 | 0.82 |

Table 5.15: L-NSEP: Summary of reverse tests

#### Results

In table 5.14 the estimation errors from the four tests can be observed. In table 5.15 the same can be observed for the reverse route tests.

In all these tests at NSEP there are some sample points that are problematic in almost every test. The sample point 1 in the ordinary route and 13 in the reverse route is always located inside the corridor. Sample point 7 in the ordinary route and 8 in the reverse route are likewise almost always estimated inside the corridor or Room1. Inside Room1 sample point 9 in the ordinary route and 5 in the reverse route is almost always placed diagonally into the centre of the room with a fairly high error margin.

### 5.4.3 Applying logic to improve the result

In accordance with **T3**, as specified in section 5.3.6, logic will be applied to the test results. In this case it is interesting to find out how logic from the LM can be used to improve the room-level location information.

In a typical office building like the one described in test setup ITV (section 5.3.4) a hybrid LM like the one this thesis suggested in chapter 4 can be of great help. In the figure 5.21 an office building not unlike the ITV building are shown. The associated LM with UML syntax for the building can be seen in figure 5.22.

In this particular example a device is located to be in the corridor o001 as shown with the mark $D_0$ in figure 5.21. When the user then moves, the raw location information from the EPE suddenly locates the device to be in room o002 as shown with mark $D_1$. With the use of logic from the LM it can be observed that this is not

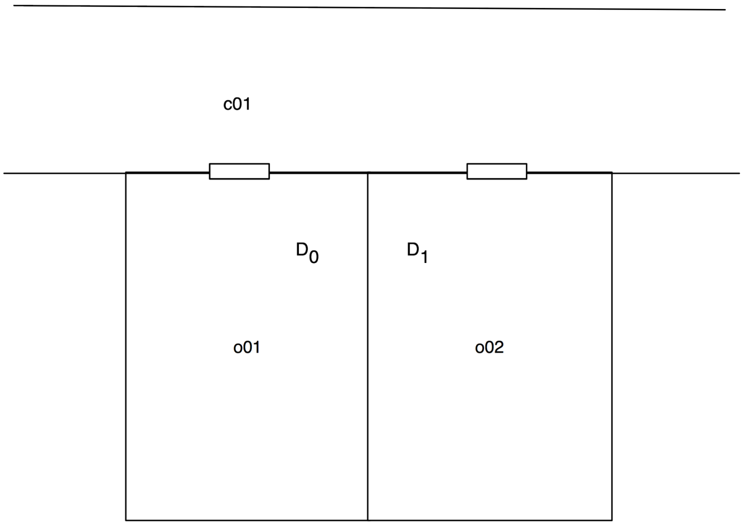


Figure 5.21: L-LOGIC: Graphical syntax of a corridor with two rooms

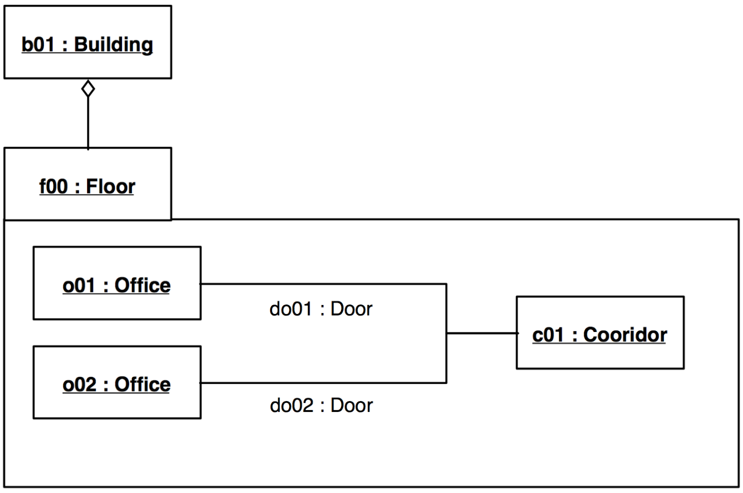


Figure 5.22: L: LOGIC: Syntax of the figure 5.21

possible. In order for the device to move from o001 to o002 it needs to first enter the corridor c01. A device cannot move from o001 directly into o002 without first moving past c01.

So with an LM layer that sits above the raw positioning layer of the technology the quality of the location information can be approved.

### 5.4.4 Discussion

In accordance with **T4** specified in section 5.3.6 the results of the testing will be discussed to see if the requirements can be modified.

The testing done in the existing infrastructure show poor results. There are several areas that are problematic for the technology. In the improved infrastructure the results are far better but still not quite satisfactory.

It is therefore interesting to look at the requirements for the tests and observe how the percentage of approved samples will change as the requirements are changed.

In figure 5.23 a graph showing the different degree of approved samples with the original requirements and with modified requirements. The modified requirements consists only of the accuracy of the positioning estimate, the **C2** category. The **C1** and **C3** requirements are excluded.

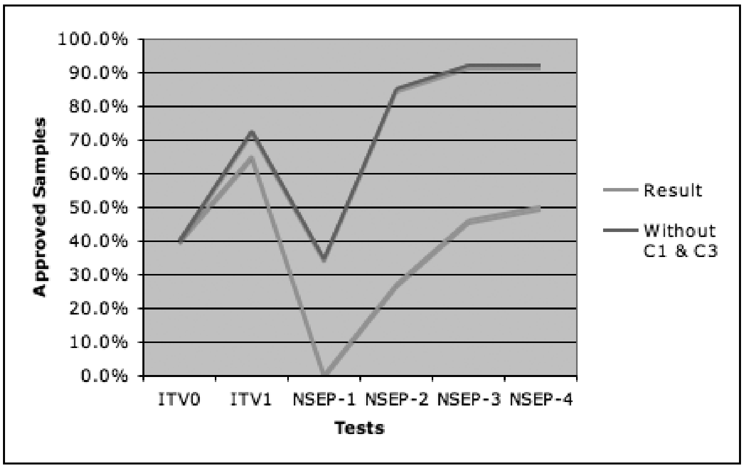


Figure 5.23: L: Requirements modification graph

The result of this modification reveals that the pure location estimation from the technology are actually almost acceptable in the ITV1 test and more than acceptable in all the NSEP tests except the first one.

The pure location estimation of the technology is good enough in the improved infrastructure. However, still there is the problem of detecting what room the sample is in. Fortunately logic from the LM can help us with this as discussed in section 5.4.3.

### 5.4.5 Summary

In this section testing on how to obtain location information in order to satisfy the requirements detailed in the *Locator* scenario has been done.

The results show that this scenario is possible in the improved infrastructure and in the first floor of the existing infrastructure. Initial requirements and testing showed poor results, but with the use of logic from the LM and a modification of the requirements the results improved drastically.

## 5.5 Standing Still

In this section the scenario *Standing still* will be elaborated further and then tested according to the guidelines specified in section 5.3.6.

Enabling a service that can sense when a user is standing still in front of a particular spot opens up the possibilities for many interesting applications. Such an application can record information based on who is standing at a particular spot, or serve data to that person that suits the persons preferences. In a campus environment this could be used for detecting when somebody tries to visit a professor who is not in, as mentioned in section 5.1.4. In addition to this you could create electronic billboards that would display information specific to your courses and your faculty thus giving each student the information the student wants.

Another situation in which this capability could be used is for access control. A door should open for a student with a trackable device simply when the student stands in front of it.

However, there are also some weaknesses with this approach. What if two users are looking at the same billboard? What should the system do then. Should it display the information to the first user and then wait and display the information to the second user? This actually makes this new improved version of the billboard worse than its original version. Or should the system display a mixed set of information, or even divide the billboard into two parts and show the information?

In the case of watching who has visited your office the scenario also has some weaknesses. Not everybody that wants to visit the office will stand in front of the door and knock on it. If a student has already knocked on the door and confirmed that the owner is not in, then other students that see this or talk to the knocker will not knock.

All in all, the scenario has great potential, but it also has it problems. In order for these possibilities to come to life one needs a very high probability of the location estimates. It would be very bad if a student stood outside a billboard but the technology did not sense that the student was there. So the technology must with almost 100% probability be able to locate a device in the given area for this scenario to work.

In figure 5.24 a typical setup of the LM to detect somebody in front of a door can be seen. A corridor with a door and an office behind the door. A logical area is placed in front of the door defining the space that the user needs to stand in to be registered as knocking on the door.

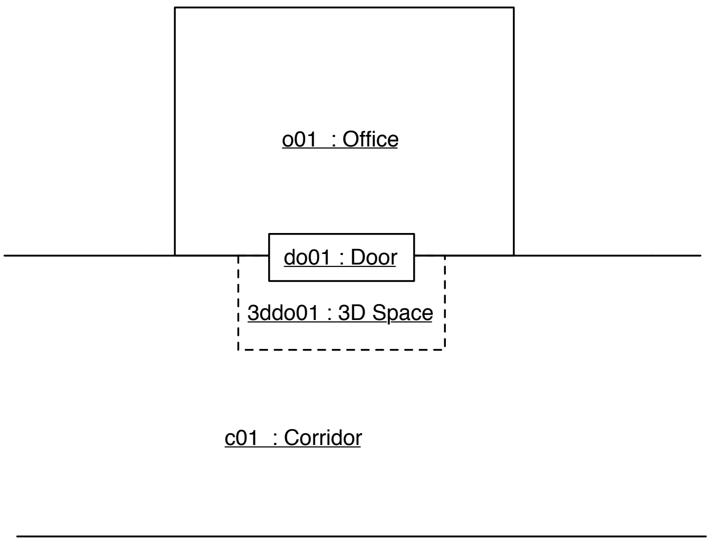


Figure 5.24: Logic area infront of door graphical example

### 5.5.1 Testing the existing infrastructure

In accordance with **T1** specified in section 5.3.6 a test will be done in the existing infrastructure specified in section 5.3.4.

The test routes can be seen in the test figure appendix in figures A.4, A.5, A.6 and A.7.

In order to classify a sample as approved for the given scenario it will need to fulfill the following categories.

- **C1**: The error margin of the positioning estimate must be below 1 metre.
- **C2**: Outside a door. In order to meet this category a sample must clearly be interpreted as outside the door in question. The direction of the error must be in the correct direction and the error margin must be small.

If all of the categories for a given sample point is fulfilled, it will be marked down as an **A**pproved sample point.

The color formatting in the tables describes the quality of the sample from a pure accuracy point of view. Samples that classify according to **C1** (<1 metre) are in white, samples that are close to classification are in light gray (1-2 metre) and finally samples that are far from classification are in dark gray (2> metre).

### Ground floor ITV

In the ground floor a sample point is taken outside all the doors that has calibrated rooms inside them. The tests can be seen in the figure appendix in figures A.8 and A.9. The test results can be observed in tables 5.16 and 5.17.

| Sample | Error | C1 | C2 | A |
|---|---|---|---|---|
| 1 | 1.8 | - | - | - |
| 2 | 4.4 | - | - | - |
| 3 | 0.3 | √ | √ | √ |
| 4 | 0.5 | √ | √ | √ |
| Result | 1.75 | 50% | 50% | 50% |

Table 5.16: SS-ITV: Ground floor test results

| Sample | Error | C1 | C2 | A |
|---|---|---|---|---|
| 1 | 0.5 | √ | - | - |
| 2 | 1.2 | - | - | - |
| 3 | 3.4 | - | - | - |
| 4 | 0.9 | √ | - | - |
| Result | 1.5 | 50% | 0% | 0% |

Table 5.17: SS-ITV: Ground floor reverse test results

The result from this test is disappointing. The ordinary route show 50% degree of approved samples while the reverse test show 0%.

### First floor ITV

The same procedure, as in the ground floor, is done in the first floor. The tests can be observed in the test figures appendix in figures A.10 and A.11. The results can be observed in tables 5.18 and 5.19.

In the first floor the results are not much better than in the ground floor. Both the test routes show here 14% degree of approved samples.

| Sample | Error | C1 | C2 | A |
|---|---|---|---|---|
| 1 | 2.3 | - | - | - |
| 2 | 2.8 | - | - | - |
| 3 | 0.7 | √ | - | - |
| 4 | 7.2 | - | - | - |
| 5 | 0.2 | √ | √ | √ |
| 6 | 3.9 | - | - | - |
| 7 | 0.7 | √ | - | - |
| Result | 2.54 | 43% | 14% | 14% |

Table 5.18: SS-ITV: First floor test results

| Sample | Error | C1 | C2 | A |
|---|---|---|---|---|
| 1 | 1.4 | - | - | - |
| 2 | 3.3 | - | - | - |
| 3 | 1.0 | √ | - | - |
| 4 | 0.2 | √ | √ | √ |
| 5 | 2.1 | - | - | - |
| 6 | 4.0 | - | - | - |
| 7 | 2.5 | - | - | - |
| Result | 2.07 | 29% | 14% | 14% |

Table 5.19: SS-ITV: First floor reverse test results

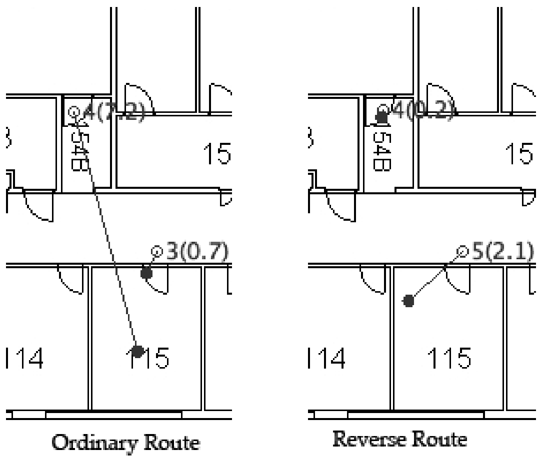


Figure 5.25: SS-ITV: First floor problem area

In the first floor there is one area that is particulary troublesome for the technology. In figure 5.25 this area with the results for both the test routes can be seen. In the ordinary test route the estimate is far off into room 115 with a very high error margin, while in the reverse test the result is almost spot on.

So even without the logic to check if the estimated position is there over a number of seconds it can clearly be said that the existing infrastructure does not support this kind of scenario.

### 5.5.2 Testing Improved Infrastructure

In accordance with **T2** specified in section 5.3.6 a test will be done with an improved infrastructure. This will be done to see if a more optimized setup will yield better results.

The test routes can be seen in figures 5.26 and 5.27. Note that the placement of the base stations is here defined in the test routes with the 'A' symbol. The same placement will be used in all the tests since it was found to be very good in the testing in section 5.4.

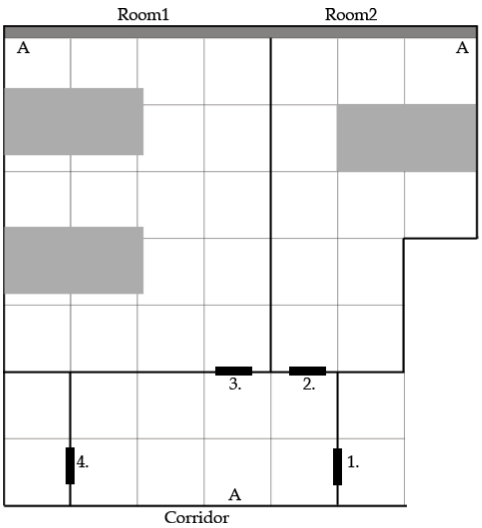


Figure 5.26: SS-NSEP: Test route

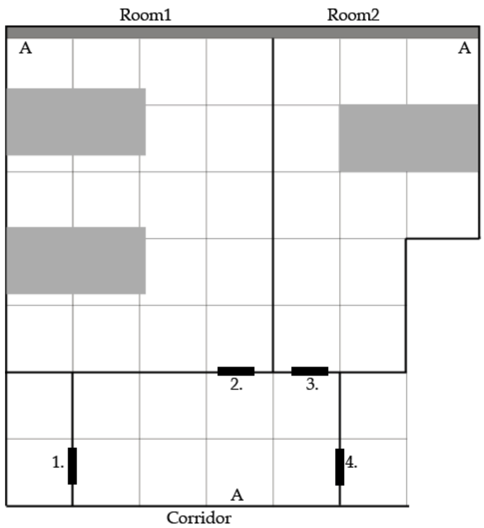


Figure 5.27: SS-NSEP: Reverse test route

The testing categories and the classification as an approved sample is the same as the ones in the existing infrastructure test as described in section 5.5.1.

In figures 5.28 and 5.29 the test results can be observed. Since the test route is limited, only the relevant part of the test will be shown.

In tables 5.20 and 5.21 the results from the test and classifications in the categories can be seen.

In this test it can observed that the average percentage of approved samples are 37.5%. This result is disappointing, still it is better than in the existing test. However, the reason for this is what is interesting. All the samples satisfy **C1**, it is the requirement **C2** that fails every single time. The average error margin of 0.5 and 0.33 metre is far lower than the error margins from the exisiting infrastructure test.

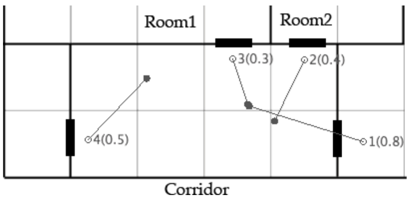


Figure 5.28: SS-NSEP: Test

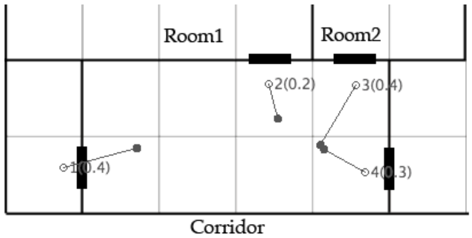


Figure 5.29: SS-NSEP: Reverse test

| Sample | Error | **C1** | **C2** | **A** |
|---|---|---|---|---|
| 1 | 0.8 | √ | - | - |
| 2 | 0.4 | √ | - | - |
| 3 | 0.3 | √ | √ | √ |
| 4 | 0.5 | √ | - | - |
| Result | 0.5 | 100% | 25% | 25% |

Table 5.20: SS-NSEP: Test results

| Sample | Error | **C1** | **C2** | **A** |
|---|---|---|---|---|
| 1 | 0.4 | √ | - | - |
| 2 | 0.2 | √ | √ | √ |
| 3 | 0.4 | √ | - | - |
| 4 | 0.3 | √ | √ | √ |
| Result | 0.33 | 100% | 50% | 50% |

Table 5.21: SS-NSEP: Reverse test results

Part of the problem here could be that it is a very limited space that is calibrated with SiteCalibration as shown in figure A.1 in the figure appendix.

### 5.5.3 Applying logic to improve the result

In accordance with **T3** as specified in section 5.3.6 logic will be applied to the scenario to see if the raw location information from the system can be enhanced. In this particular scenario it is interesting to use an algorithm to estimate an average position based on several raw estimates. Not only can this test see if it is possible to detect if a user is standing still at a point, it can also be used to see if the average estimation is drastically better than the first raw estimation. This test is done with the same test setup as that in the improved infrastructure test in section 5.5.2.

The algorithm used will record a number of samples and then calculate an average estimated position from all of the valid samples. A sample will be classified as valid if it is withing 1 metre of the sample point.

In this test the device starts out at a distance away from the sample point and then moves there and starts recording a sample. The device then remains stationary at the same point while the technology records the desired number of samples.

There were 12 tests done in the experiment. 4 inside room1 and the corridor, 2 inside room2 and one outside both the left and right door in the corridor. The figures of

| Test | 10 samples First | Average | Time | 5 Samples First | Average | Time |
|---|---|---|---|---|---|---|
| Corridor1 | 0.5 | 0.3 | 17 | 0.4 | 0.3 | 6 |
| Corridor2 | 1.3 | NA | 18 | 1.2 | 1.0 | 8 |
| Corridor3 | 0.4 | 0.5 | 28 | 0.4 | 0.5 | 7 |
| Corridor4 | 0.5 | 0.5 | 27 | 0.4 | 0.3 | 6 |
| Room1-1 | 2.1 | 0.5 | 18 | 1.7 | 0.7 | 16 |
| Room1-2 | 1.1 | 0.7 | 20 | 1.6 | 0.7 | 11 |
| Room1-3 | 1.9 | 1.1 | 17 | 1.5 | NA | 8 |
| Room1-4 | 1.4 | 0.9 | 24 | 1.9 | 0.6 | 10 |
| Room2-1 | 1.2 | 0.4 | 24 | 1.1 | 0.2 | 7 |
| Room2-2 | 1.3 | 1.0 | 27 | 1.4 | NA | 7 |
| Left Door | 1.5 | 0.8 | 22 | 0.9 | 0.7 | 13 |
| Right Door | 0.7 | 0.5 | 21 | 0.5 | 0.5 | 8 |

Table 5.22: SS-LOGIC: Test results

the tests can be observed in the figure appendix A in figures A.20 - A.43.

Each of these 12 tests was done twice, fist with 10 samples and then with 5.

The tests Cooridor1, Corridor3, Corridor4, Room1-2, Left Door and Right Door showed good results. The pattern of the estimations was similar in the 10 and 5 sample tests and the average algorithm improved the results. In all of these samples the 5 sample algorithm showed equal or better improvement than in the 10 sample algorithm.

Two of the tests, Corridor2 and Room2-2, had the same good pattern of estimation points between the tests as in the good tests, however in these tests the results of the average algorithm are not good. The estimations are in general too far away from the sample point in these tests.

The remaining four tests Room1-1, Room1-3, Room1-4 and Room2-1 show strange results. In all of these tests the pattern of the estimations are different in the 10 and 5 sample tests. These results are strange and there is no explanation why the technology behaves like this.

The results from this algorithm test are all in all disappointing. Some of the tests show great promise but then again some are just strange. Since only half of the tests can be viewed upon as good it can be concluded that the test is not usable to detect if somebody is standing outside a door.

### 5.5.4 Discussion

In accordance with **T4** specified in section 5.3.6 the results of the testing will be discussed to see if the requirements can be modified.

The testing done in both the existing and the improved infrastructure shows poor results compared to what is needed for this scenario.

It is therefore interesting to look at the requirements for the test and observe how the percentage of approved samples develop as the requirements are changed.

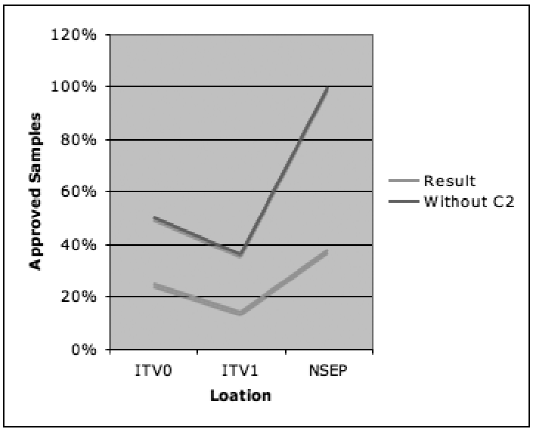


Figure 5.30: SS: Requirements modification

In figure 5.30 a graph showing the different degree of approved samples for various requirements modifications can be seen. The graph shows that the degree of approved samples rise considerably if the requirement for the sample to be considered outside a door as described in **C2** is removed.

### 5.5.5 Summary

In this section the scenario *Standing still* has been elaborated and tested in both the existing infrastructure, in an improved infrastructure and with logic. According to the results with the ordinary set of requirements neither setup was acceptable. An experiment was done in the improved infrastructure to try to remove the **C2** requirement and solve this problem with logic. Since the logic test did not show good results it can be concluded that the requirements cannot be modified.

According to the tests done in this section the EPE technology is not suitable to be used in a scenario like Standing Still.

## 5.6 Scenario Discussion

In this section the results found in the testing will be analyzed against the need for location information in the other suggested scenarios.

In section 5.2.1 the various scenarios where compared to each other before two of them where selected for testing. As mentioned two of the scenarios The Guide and Room Status are very similar to the two chosen scenarios Standing Still and Locator. From a pure positioning system point of view the conclusion for these scenarios should be the same as for their comparable scenario. The Guide would therefore not be feasible and Room Status should be feasible in both the improved infrastructure and in part of the existing infrastructure.

The last scenario Proximity is based around finding out if two users are standing in close proximity. The accuracy of Proximity is the same as the one need in Standing Still so the conclusions from that scenario are the ones that come closes to apply. In addition to this the poor results from section 5.5.3 makes this scenario even more unlikely.

## 5.7 Summary

The purpose of this chapter has been to answer the second and third research questions presented in section 1.1. *What kind of LBS scenarios are interesting in a campus-like environment and what location information do the scenarios need?* and *How can location information be obtained in a campus-like environment in order to support an LBS?*

In order to satisfy the second research questions several scenarios were suggested and their need for location information were researched. Some of them where then selected for testing and tested with Ekahau WLAN technology to satisfy the third and final research question. The results from the testing was then applied to the other scenarios to see if they are feasible as well.

The results show that scenarios that require a room-level accuracy of location information with a medium level of probability are feasible.

# Chapter 6

# Discussion and Further Work

In this chapter the results from the two main chapters 4 and 5 will be analyzed and discussed. Then advice and experiences on experimenting with the EPE technology from Ekahau will be given. Finally it will be discussed what further work that must be done to enable an LBS in a campus environment.

## 6.1 Analyzing the research

In this section the results found in this thesis will be compared to the research presented in chapter 3.

### 6.1.1 Location Modeling

Using a hybrid approach in the location modeling process was decided at an early stage. The decision was made based upon the fact that both symbolic as well as geometric information should be represented in the LM. The first LM was created using a *tree* structure. However, it was soon discovered that a tree could not model a building according to all possible relationships between its different constructs. Because of this, the LM where redefined as a lattice.

The syntax of the location modeling also posed a challenge. At first the syntax proposed by Dürr and Rothermel was used to create the hybrid LM [17]. This syntax, however, could not model locations well enough for range-queries. It also lead to extremely complicated models when the building to be modeled consisted of many floors, wings and rooms. To cope with these shortcomings, a UML based syntax was used in the creation of our suggestion.

The proposed LM is an enhancement to the suggested model made by Dürr and Rothermel in [17] to allow the LM to support *nearest-neightbor-queries* and allow the LM to be modeled in UML.

The process of modeling an old fashioned office building in the UML based syntax proved to be easy and straightforward once the syntax was in place.

The method used to select and create the suggestions to model a hybrid LM makes the results of the research trustworthy. Relevant research has been considered and enhanced to create the modeling guidelines.

### 6.1.2 Obtaining Location Information

When this thesis was first suggested the Ekahau technology was tested in a demo version with an iPAQ with an Avayo WLAN card as the testing device. The initial results looked good and both myself and my supervisors had high hopes for it. Earlier there have been done some experiments with Cordis RadioEye (section 3.5.2) positioning technology and proximity based solutions based on RFID for the institute. Compared to them the initial results from the EPE looked good.

However, as it turned out, the solution did not give us quite the expected results. On the ground floor of the testing location ITV, the T101 tags did not receive as strong a signal as the iPAQ with Avayo WLAN card did. As it has been discussed in section 5.7 the results are sometimes confusing and other times not as good as expected.

In section 3.5.2 an existing product that uses the Ekahau technology is presented. The model in [4] that shows the map of the library at the University of Oulu has no scale, it is therefore difficult to compare it to the results found in this thesis.

In the article [28] the Ekahau company presents their solution and claims it has an accuracy of up to 1 metre. As can be seen in the testing done in this thesis this is an accurate claim. In the improved infrastructure the average accuracy was of well under 1 metre in the three tests that used three WLAN base stations to enhance the infrastructure.

What is strange and disappointing is that the directions of the errors are varying as can be seen in section 5.5.3. In this test it can clearly be seen how the technology estimates the position in different positions even if the user is standing completely still.

Since the results from the technology was disappointing other general analytical techniques where applied to the raw data. Experiments where done to compute the estimated position from the average of several raw data sample points. This technique is promising but the results from the technology are too unstable to make it of any practical use.

The specification of the LM was also applied to results to remove estimations that the LM invalidated. This technique proved to work very well and the practical results from it was of great value.

The results in this part of the thesis were not as good as expected. The testing method used in order to obtain them has been closely followed so the results are trustworthy. In the domain that the technology was tested in, it was simply not good enough for some of the scenarios.

## 6.2 Experience and Advice on Ekahau

Using the Ekahau Manager application was complicated. Calibrating a positioning model is time consuming and requires precision and concentration. The process as explained in section 5.3.2 is prone to some complications. A T101 tag was used as the calibration client. The tag was turned on calibration mode in the telnet interface and then selected as the calibration client in the Ekahau Manager application. However during the calibration at ITV the WLAN signal got weak and the Tag dropped out of calibration mode. Before each sample the mode of the tag and the calibration client in the manager program had to be double checked.

In addition to this there is the process of the recording of the signal itself, turning around 360 degrees with the tag as the pivot point. Doing this accurately to record a good sample is important, and on many occasions a point had to be re-calibrated. Learning this process took some trial and error but after a while it became a routine.

When calibrating the model and moving through doors, samples where recorded on both sides of the door. However the Ekahau Manager is very sensitive to where you actually click the mouse when you record a sample. If the two sample points are too close together and you click just a bit inaccurately, the second sample will not be recorded. It took a while to get the hang of this and place the points at the doors correctly.

As concluded in section 5.7 the EPE positioning technology is a good technology for finding the approximate position of a user within a calibrated space. The solution is according to the same results not usable to detect if somebody is standing still outside a door. From a pure location information perspective it looks like the solution will work great as an overall positioning solution in an LBS. However a more accurate and perhaps proximity based solution would be needed to detect if you are standing in an important area or close to another user.

## 6.3 Further work to enable an LBS

In order to enable a fully functional LBS at a campus environment like Gløshaugen there are several pieces that are missing. This section will elaborate these and include the work done in this thesis where it applies.

### 6.3.1 Obtaining location information

The LBS needs one or several ways to find location information and somehow map that information to a model. This thesis has suggested an syntax to create an LM to do the mapping and it has researched how EPE WLAN based positioning technology can find location information.

However, as concluded in chapter 5 the technology tested does not yield results that can be used to give location information that enable all kinds of scenarios (for a list of possible scenarios see section 5.2.1).

As mentioned in section 3.4 there are several techniques that can be used in a positioning technology to find location information. Some sort of technology that uses proximity based positioning (as mentioned in 3.4) could be used to acquire the location information that the EPE is not good at.

### 6.3.2 Storing the location information

An LBS needs some sort of technology to store the information obtained and structure it so that it can easily be queried and presented as needed.

An interesting solution for this is the use of Spatio-Temporal databases. These databases integrate time and space into one storage solution as mentioned in [38]. One approach to this can be seen in the work done by Reza S. Mirazei in his thesis [44].

### 6.3.3 Presenting the information

The information in an LBS needs to be presented to the user so that it can be of value to the community. Ekahau has its Application Suite as mentioned in section 5.3.1 that has some examples on how this has to be done.

The task here is to create a view for the location information that is both usable for the user and has rich features that can give new possibilities to the users of the LBS.

The design of such views are an entire field of its own and it can be very challenging to present location information on a small device in a usable way.

### 6.3.4 Privacy

Privacy is another aspect of an LBS that must be taken into consideration before an LBS is deployed. Some users are sceptical to how an LBS can violate their privacy and show information about them that they do not want to be revealed. It should be possible for users to customize how they want to use the LBS and inform them on what kind of information they will give away if they enable certain features.

There are several examples on existing LBS and planned LBS that break the privacy of the user. Wall-mart in the United States had a test project where they tagged all their products with RFID tags and scanned them as the cart left the store. The problem was that the tags was not disabled after they left the store so a person with a RFID scanner could check out all the products you bought after you left the store.

Brittan Elementary School in California have also tried a RFID based service in their school. They teamed up with InCom and created an LBS where they tracked all the kids movements in and out of school. This service was recently dropped because of privacy concerns.

### 6.3.5 Security

Securing location information is very important. What if somebody can see if a professor is in his office or not, and they want to steal something from him. If they then can find out that he is not there it is not good. It is therefore necessary to have security in mind when designing an LBS.

The EPE technology used in this thesis has a great advantage when it comes to security. The solution does not need to know the physical position of the base stations, thus a potential security risk is removed.

### 6.3.6 Economy

While an LBS certainly can give you advantages and nice services you have to look at the economical aspects of it when you create them. A very nice LBS that is too costly will simply not be feasible.

In this thesis EPE positioning technology was used for the testing. As mentioned in section 6.2 the process of SiteCalibration is time consuming and it requires a more dense setup of base stations than a setup that would only consider coverage of WLAN to the entire campus.

In order to get the usable results, as concluded in section 5.7, several more based stations must be put up in the campus environment. Then accurate maps of the entire campus must be provided. Preferably with the same scale so that setting the scale in the Ekahau Manager will be easier. The next step is to draw tracking rails in the entire campus and then to calibrate the model. The problem emerge as soon as some base stations are moved or added. Then the entire LM surrounding those parts must be recalibrated. This work will obviously take several hours and the cost of setting up and supporting more base stations are also substantial.

Part of the advantage of using Ekahau is that you do not need to know the position of the base stations. This can be very good since it is harder to find the base stations and steal them. However these solutions needs so many extra base stations that hiding all of them will be very difficult and hence part of the advantage of the solution is gone.

A solution that uses an exact geographical map and the exact position of the base stations and then triangulates to find the position (like RADAR) would then be much cheaper to set up.

## 6.4 Summary

In this chapter the research done in this thesis has been discussed, advice on further work to enable an LBS and how to use the EPE technology from Ekahau has been given.

# Chapter 7

# Final Conclusion

This thesis has discussed two LBS related topics: suggesting a syntax and method of designing an LM and how to obtain location information, in a campus environment, to support different LBS scenarios.

## 7.1 Location Modeling

Different aspects of location modeling were discussed, among them symbolic, geometric and hybrid location models. Only the hybrid form is suited to accurately position objects within a domain and relay this information to users in an understandable way.

The proposed modeling technique is a solution using basic constructs of UML with added extensions to model an LM using a lattice. A domain model with objects and relationships to suit indoor location aware system where created. This supports both the geometric extent of locations and transitions.

## 7.2 Obtainining Location Information

Several interesting LBS scenarios where elaborated and the requirements for location requirements where determined. Some scenarios where then tested and the results obtained were applied to the other scenarios.

The results show that the technology used in the experiments, EPE from Ekahau Inc., is usable as a positioning system in scenarios that requires room level awareness. The technology is not usable to support scenarios that require a more fine grained estimation.

# Bibliography


[1] Lauri Aalto, Nicklas Göthlin, Jani Korhonen, and Timo Ojala. Bluetooth and WAP push based location-aware mobile advertising system. In *MobiSys*. USENIX, 2004.

[2] Northstream AB. Location based services: Considerations and challanges. http://www.northstream.se/page/custom/northnews/get_news_file.asp?id=77 - Last Visited November 30, 2005.

[3] Tamas Abraham and John F. Roddick. Survey of spatio-temporal databases. *GeoInformatica*, 3(1):61–99, 1999.

[4] Markus Aittola, Tapio Ryhänen, and Timo Ojala. *SmartLibrary - Location-Aware Mobile Library Service*, volume 2795. SpringerLink, January 2003.

[5] G. Anastasi, R. Bandelloni, M. Conti, F. Delmastro, E. Gregori, and G. Mainetto. Experimenting an indoor bluetooth-based positioning service. In *ICDCSW '03: Proceedings of the 23rd International Conference on Distributed Computing Systems*, page 480, Washington, DC, USA, 2003. IEEE Computer Society.

[6] GSM Association. Gsm world. http://www.gsmworld.com - Last Visited November 30, 2005.

[7] Paramvir Bahl and Venkata N. Padmanabhan. RADAR: An in-building RF-based user location and tracking system. In *INFOCOM*, pages 775–784, 2000.

[8] Christian Becker and Frank Dürr. On location models for ubiquitous computing. Article in journal, Universität Stuttgart : Sonderforschungsbereich SFB 627 (Nexus: Umgebungsmodelle für mobile kontextbezogene Systeme), January 1, 2004.

[9] Michael Beigl, Tobias Zimmer, and Christian Decker. A location model for communicating and processing of context. *Personal Ubiquitous Comput.*, 6(5-6):341–357, 2002.

[10] Gaetano Borriello and Jerey Hightower. A survey and taxonomy of location systems for ubiquitous computing, August 27 2001.

[11] Barry Brumitt and Steven Shafer. Topological world modeling using semantic spaces, December 08 2001.

[12] Radionor Communications. Cordis radioeye. http://www.radionor.no/Downloads/radionor_white_paper.pdf - Last Visited November 30, 2005.

[13] Tony Cornford and Steve Smithson. Project research in information system - a student's guide. Palgrave New York, USA, 1996.

[14] Mike Dempsey. Indoor positioning systems in healthcare. Radianse Inc, 2003.

[15] Svetlana Domnitcheva. Location modeling: State of the art and challenges. Workshop on Location Modeling for Ubiquitous Computing, 2001.

[16] Elizabeth Douglas. Indoor positioning systems can track equipment and people. In *Anesthesiology News*, pages 26–28, October 2004.

[17] Frank Dürr and Kurt Rothermel. On a location model for fine-grained geocast. In *Proceedings of the Fifth International Conference on Ubiquitous Computing (UbiComp 2003)*, Artikel in Tagungsband, pages 0–0. Seattle: Springer-Verlag, October 12, 2003.

[18] ESRI. Arcinfo. http://www.esri.com/software/arcgis/arcinfo/ - Last Visited November 30, 2005.

[19] ESRI. Arcview. http://www.esri.com/software/arcview/ - Last Visited November 30, 2005.

[20] ESRI. What is gis? http://www.gis.com/whatisgis/ - Last Visited November 30, 2005.

[21] Hans Gellersen and Michael Beigl. Smart-its: An embedded platform for smart objects, May 16 2003.

[22] Kamil A. Grajski and Ellen Kirk. Towards a mobile multimedia age? location-based services: A case study. *Wirel. Pers. Commun.*, 26(2-3):105–116, 2003.

[23] Object Management Group. Unified modeling language. http://www.uml.org/ - Last Visited November 30, 2005.

[24] Ralf Hartmut Güting. An introduction to spatial database systems. *The VLDB Journal*, 3(4):357–399, October 1994.

[25] Andy Harter and Andy Hopper. A distributed location system for the active office. *IEEE Network*, 8(1), / 1994.

[26] Jeffrey Hightower and Gaetano Borriello. Location systems for ubiquitous computing. *IEEE Computer*, 34(8):57–66, 2001.

[27] Ekahau Inc. Ekahau. http://www.ekahau.com - Last Visited November 30, 2005.

[28] Ekahau Inc. Ekahau epe 3.1. http://www.ekahau.com/file.php?id=129 - Last Visited November 30, 2005.

[29] Ekahau Inc. Ekahau rtls brochure. http://www.ekahau.com/file.php?id=14 - Last Visited November 30, 2005.

[30] Ekahau Inc. Ekahau: Technology and products. Ekahau Inc., 2003.

[31] Ekahau Inc. Ekahau developer guide epe 3.0. Ekahau Inc., 2004.

[32] Ekahau Inc. Ekahau user guide epe 3.0. Ekahau Inc., 2004.

[33] Ekahau Inc. T101 user guide. Ekahau Inc., 2004.

[34] Ekahau Inc. T201 user guide. Ekahau Inc., 2005.

[35] Changhao Jiang and Peter Steenkiste. A hybrid location model with a computable location identifier for ubiquitous computing. In Gaetano Borriello and Lars Erik Holmquist, editors, *Ubicomp*, volume 2498 of *Lecture Notes in Computer Science*, pages 246–263. Springer, 2002.

[36] Chris Rizos Joel Barnes and Junling Wang. Locatanet: A new positioning technology for high presiscion indoor and outdoor postioning. In *Proceedings of the 16th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GPS/GNSS 2003)*, pages 1119–11128, September 2003.

[37] Mari Korkea-aho, Haitao Tang, and Reijo Sulonen. Expressing location information for applications in the internet. *Personal and Ubiquitous Computing*, 6(5/6):329–333, 2002.

[38] Manolis Koubarakis and Timos K. Sellis. Introduction. In Manolis Koubarakis, Timos K. Sellis, Andrew U. Frank, Stéphane Grumbach, Ralf Hartmut Güting, Christian S. Jensen, Nikos A. Lorentzos, Yannis Manolopoulos, Enrico Nardelli, Barbara Pernici, Hans-Jörg Schek, Michel Scholl, Babis Theodoulidis, and Nectaria Tryfona, editors, *Spatio-Temporal Databases: The CHOROCHRONOS Approach*, volume 2520 of *Lecture Notes in Computer Science*, pages 1–8. Springer, 2003.

[39] Thomas Kuhn. *The Structure of Scientific Revolutions*. The University of Chicago Press, Chicago, IL, 1970.

[40] Ulf Leonhardt. Supporting location-awareness in open distributed systems, May 18 1998.

[41] Hubert Ka Yau Leung, Ioana Burcea, and Hans-Arno Jacobsen. Modeling location-based services with subject spaces. In *CASCON*, pages 171–181. IBM, 2003.

[42] Bluepulse Pty LTD. Bluepulse. http://www.bluepulse.com.au -Last Visited November 30, 2005.

[43] Christopher A. Miller and Harry B. Funk. Location modeling for ubiquitous computing: Is this any better?, September 24 2001.

[44] Reza S. Mirzaei. Spatio-temporal databases for indoor positioning system. Technical report, NTNU - IDI, 2005.

[45] Nissanka B. Priyantha, Anit Chakraborty, and Hari Balakrishnan. The cricket location-support system. In *MOBICOM*, pages 32–43, 2000.

[46] Nissanka B. Priyantha, Allen K. L. Miu, Hari Balakrishnan, and Seth J. Teller. The cricket compass for context-aware mobile applications. In *MOBICOM*, pages 1–14, 2001.

[47] Bharat Rao and Louis Minakakis. Evolution of mobile location-based services. *Commun. ACM*, 46(12):61–65, 2003.

[48] Colin Robson. *Real World Research: A Resource for Social Scientists and Practinoer-Researchers*. Blackwell Publishers, Univeristy of Huddersfield, 2002.

[49] Hege Servold and Sigurd Gimre. Lokasjonsbasert guiding. Technical report, NTNU - IDI, 2003.

[50] Clint Smith and Daniel Collins. 3 g wireless networks. McGraw-Hill New York, USA, 2002.

[51] Buddy Space. Buddy space. http://buddyspace.sourceforge.net/ - Last Visited November 30, 2005.

[52] Hideaki Takeda, Paul Veerkamp, Tetsuo Tomiyama, and Hiroyuki Yoshikawa. Modeling design processes. *AI Magazine*, 11(4):37–48, Winter 1990.

[53] Ping Tao, Algis Rudys, Andrew M. Ladd, and Dan S. Wallach. Wireless lan location-sensing for security applications. In *WiSe '03: Proceedings of the 2003 ACM workshop on Wireless security*, pages 11–20, New York, NY, USA, 2003. ACM Press.

[54] Sonitor technologies. Sonitor ips. http://www.sonitor.com/news/article.asp?id=10 -Last Visited November 30, 2005.

[55] Sonitor technologies. Sonitor ips. http://www.sonitor.com -Last Visited November 30, 2005.

[56] Versus Technology. Versus. http://www.versustech.com/index.html -Last Visited November 30, 2005.

[57] Versus Technology. Versus - success stories. http://www.versustech.com/mainpage/ss.aspx -Last Visited November 30, 2005.

[58] Kiran Thapa and Steven Case. An indoor positioning service for bluetooth ad hoc networks. In *MISC 2003: The 36th Annual Midwest Instruction and Computing Symposium, Duluth, MN, USA, 11-12 April - 2003*, 2003.

[59] Roy Want, Andy Hopper, Veronica Falcao, and Jonathan Gibbons. The active badge location system. *ACM Transactions on Information Systems*, 10(1):91–102, January 1992.

[60] GPS World. Gps world. http://www.gpsworld.com/gpsworld/ - Last Visited November 30, 2005.

[61] Vasileios Zeimpekis, George M. Giaglis, and George Lekakos. A taxonomy of indoor and outdoor positioning techniques for mobile location services. *SIGecom Exch.*, 3(4):19–27, 2003.

# Index

# Appendix A

# Figures

In this Appendix figures from the testing done in chapter 5 will be presented.

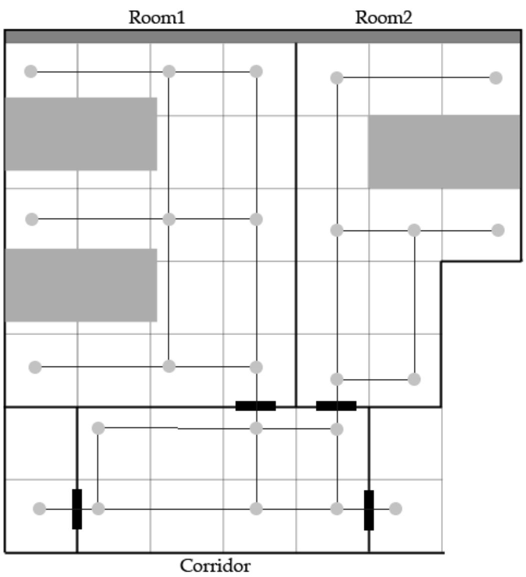


Figure A.1: NSEP: Tracking rails

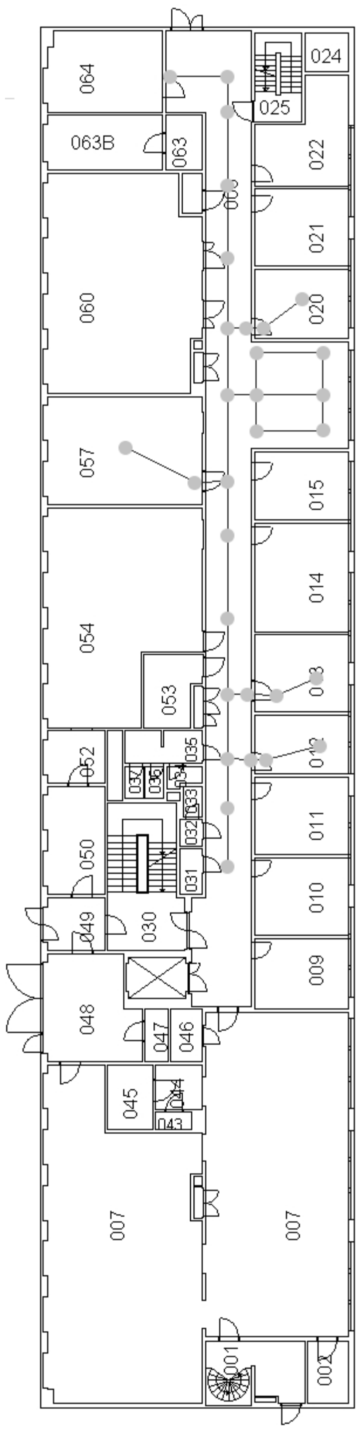

Figure A.2: ITV: Ground floor tracking rails

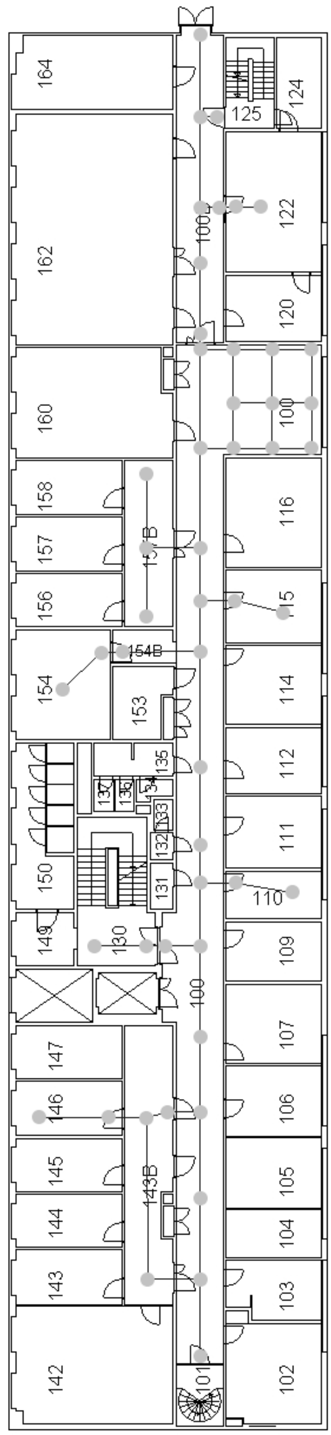

Figure A.3: ITV: First floor tracking rails

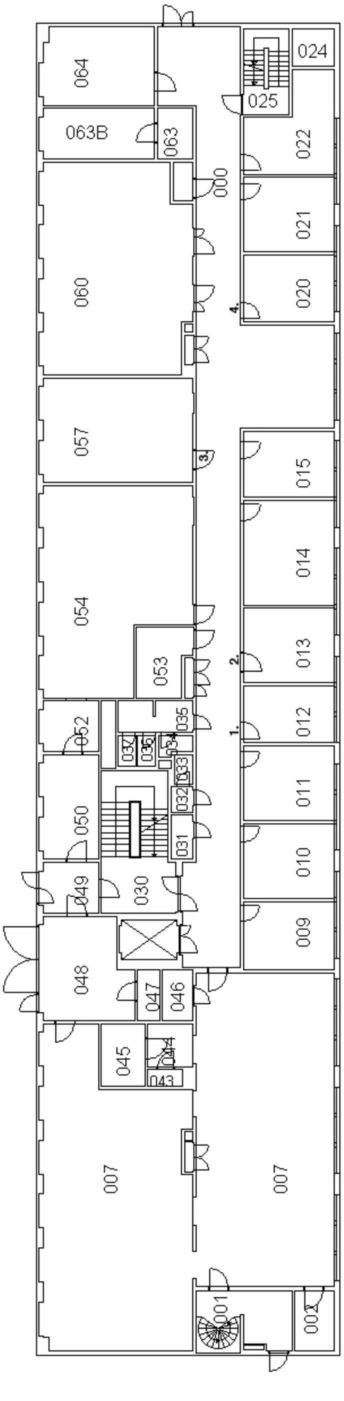


Figure A.4: SS-ITV: Ground floor test route

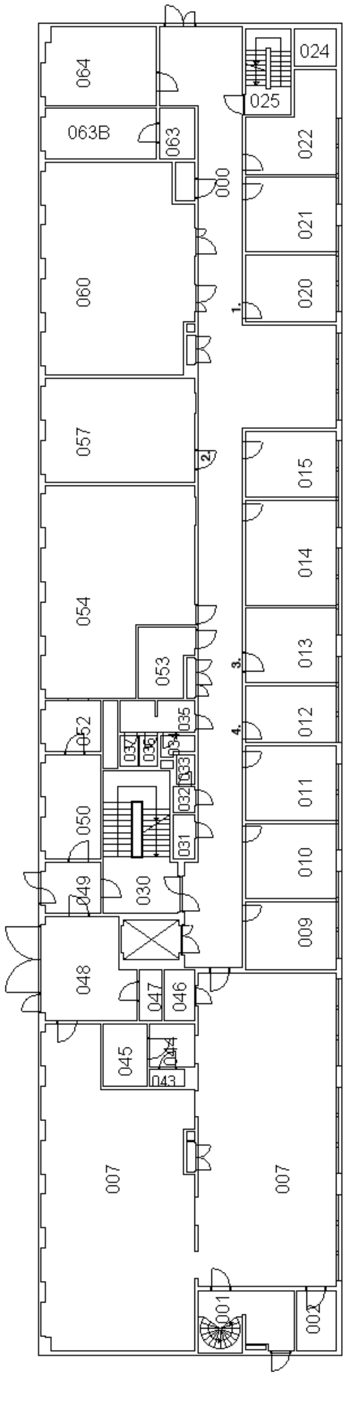


Figure A.5: SS-ITV: Ground floor reverse test route

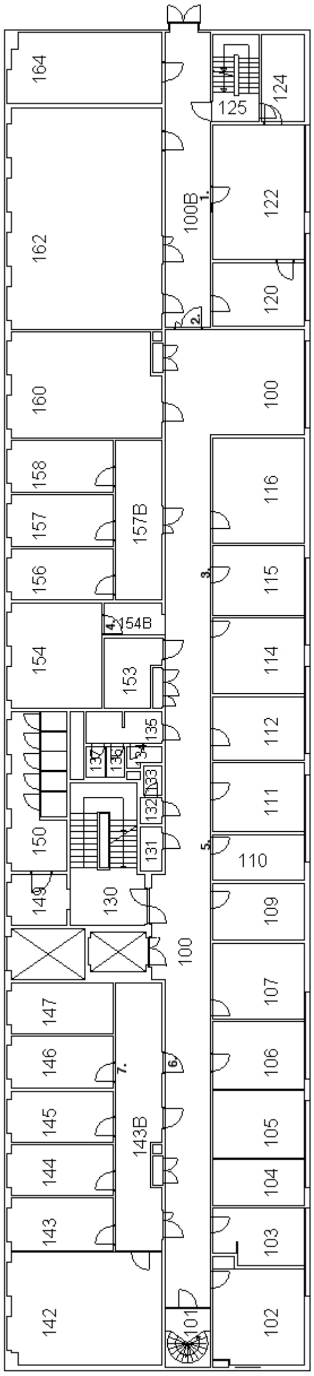


Figure A.6: SS-ITV: First floor test route

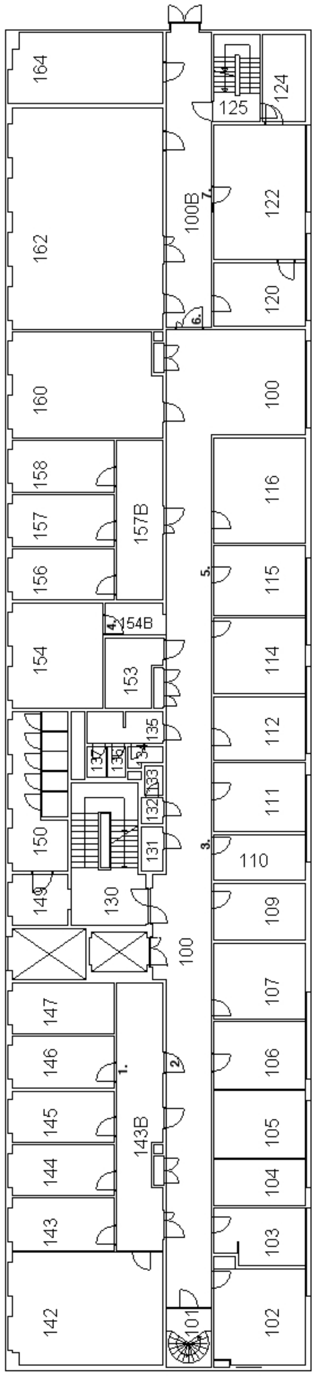


Figure A.7: SS-ITV: First floor reverse test route

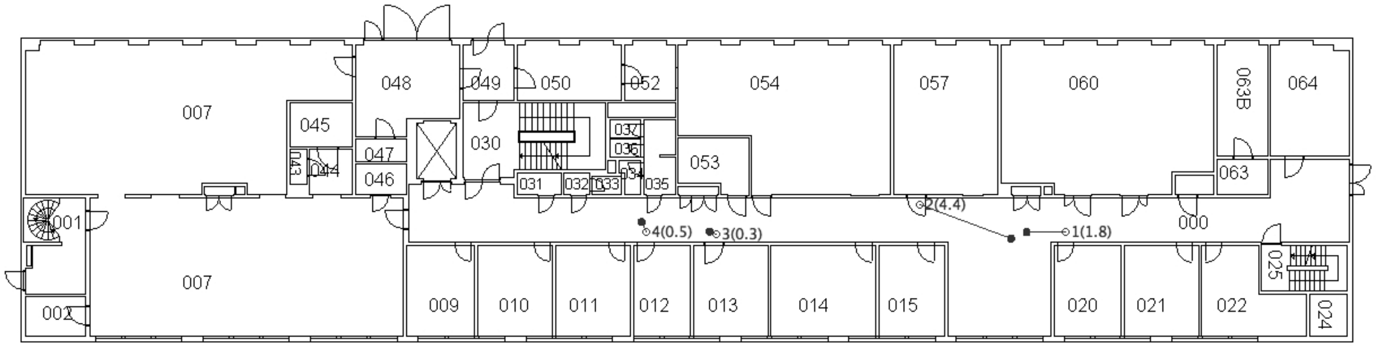


Figure A.8: SS-ITV: Ground floor Test

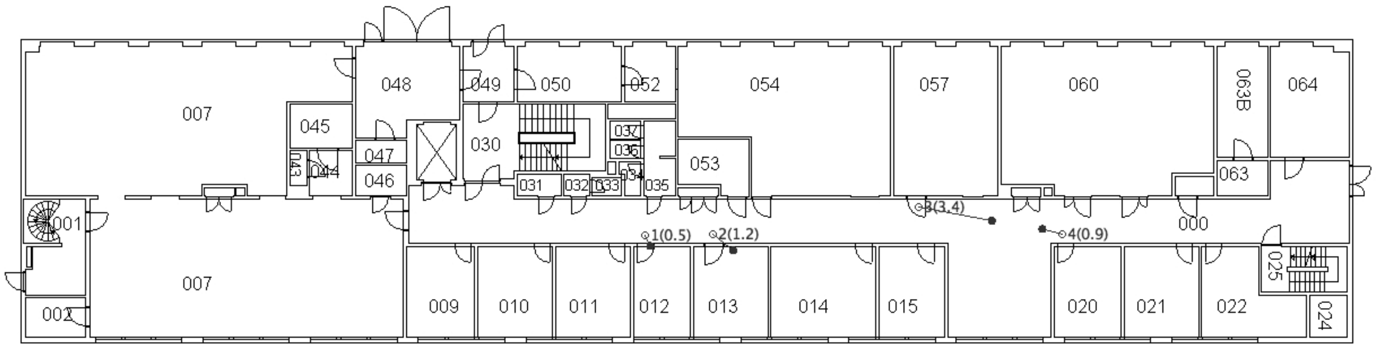


Figure A.9: SS:ITV: Ground floor Reverse Test

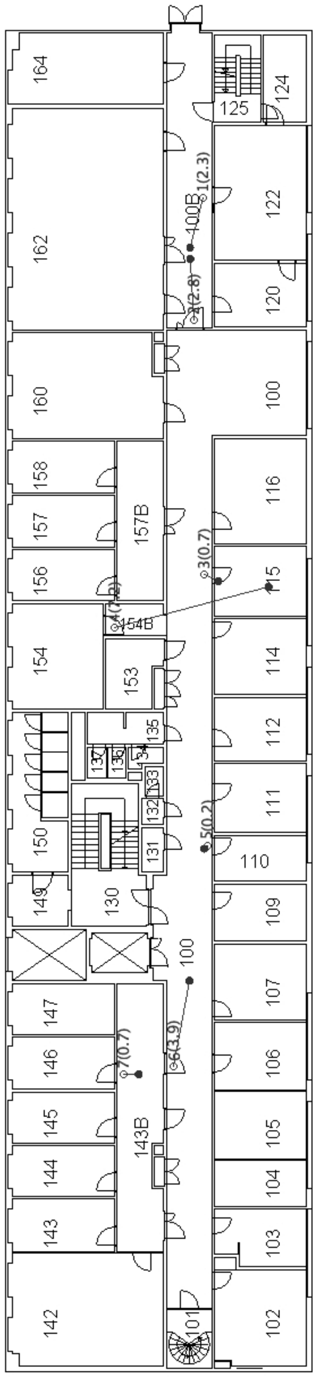


Figure A.10: SS-ITV: First floor Test

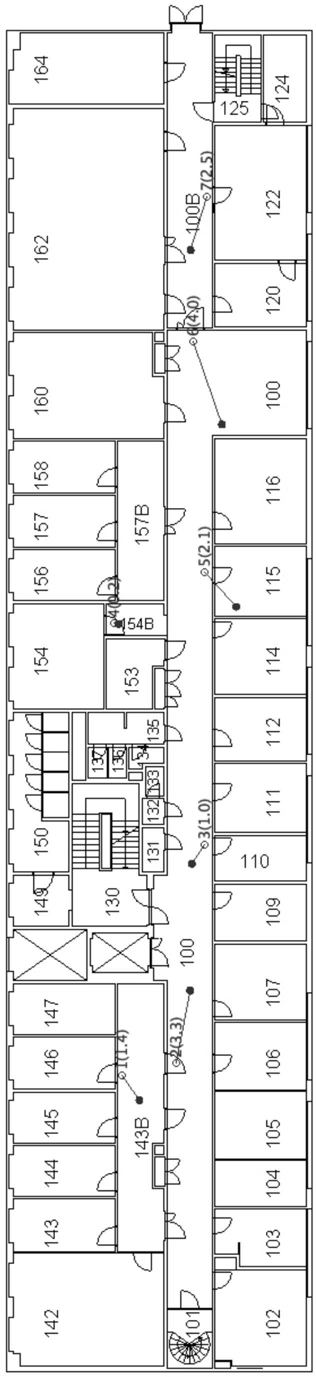


Figure A.11: SS-ITV: First floor reverse Test

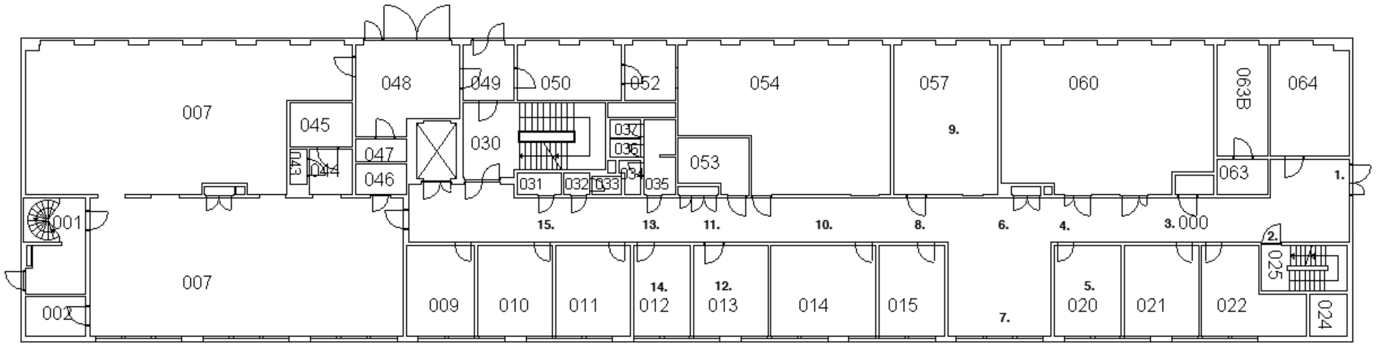


Figure A.12: L-ITV: Ground floor test route

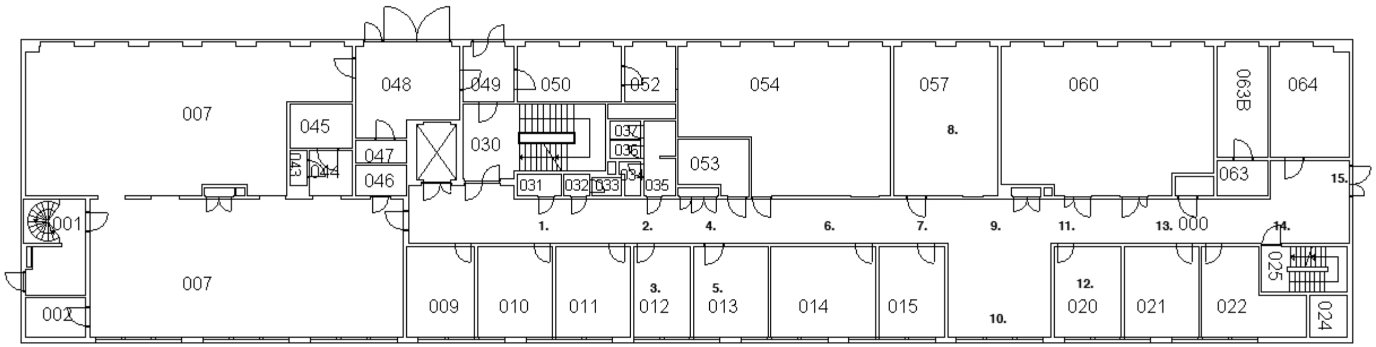


Figure A.13: L-ITV: Ground floor reverse test route

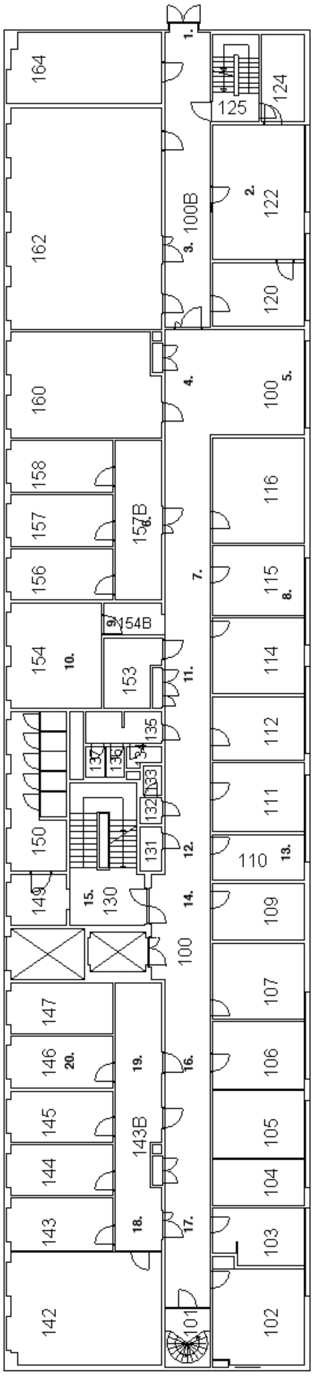


Figure A.14: L-ITV: First floor test route

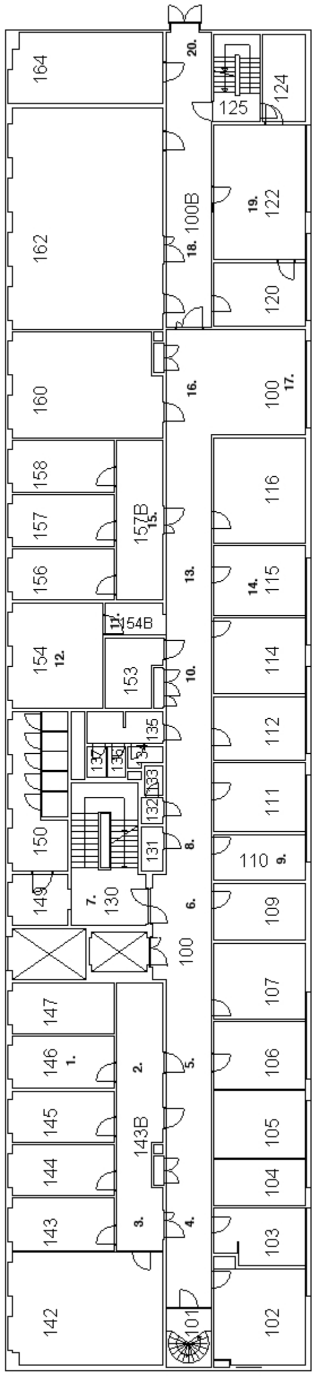


Figure A.15: L-ITV: First floor reverse test route

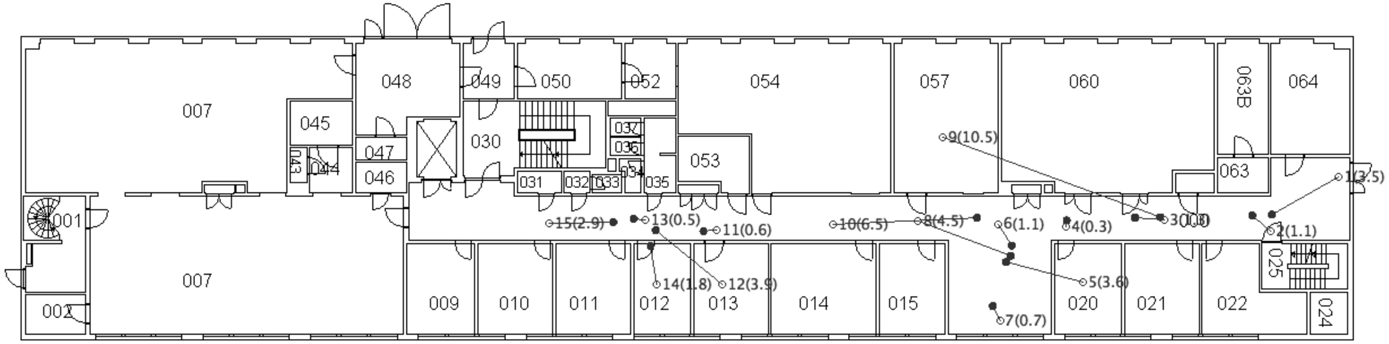


Figure A.16: L-ITV: Ground floor Test

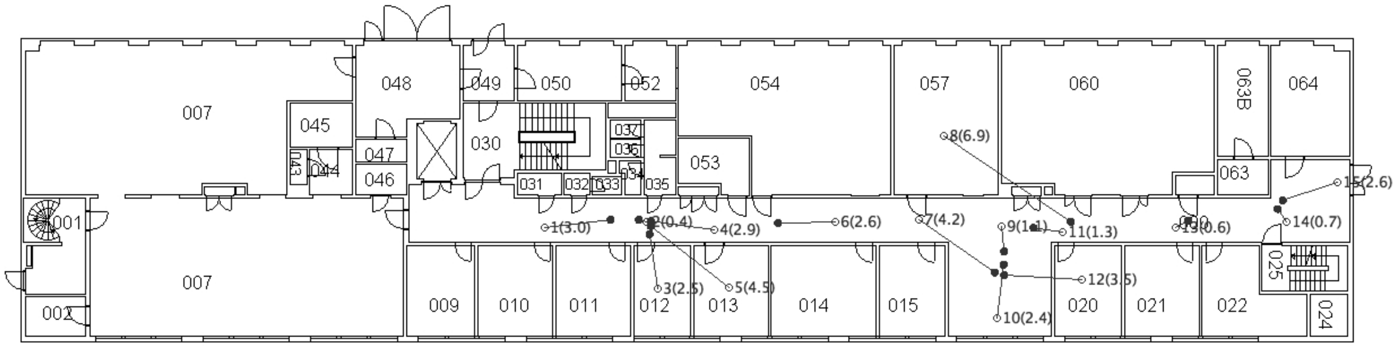


Figure A.17: L-ITV: Ground floor Reverse Test

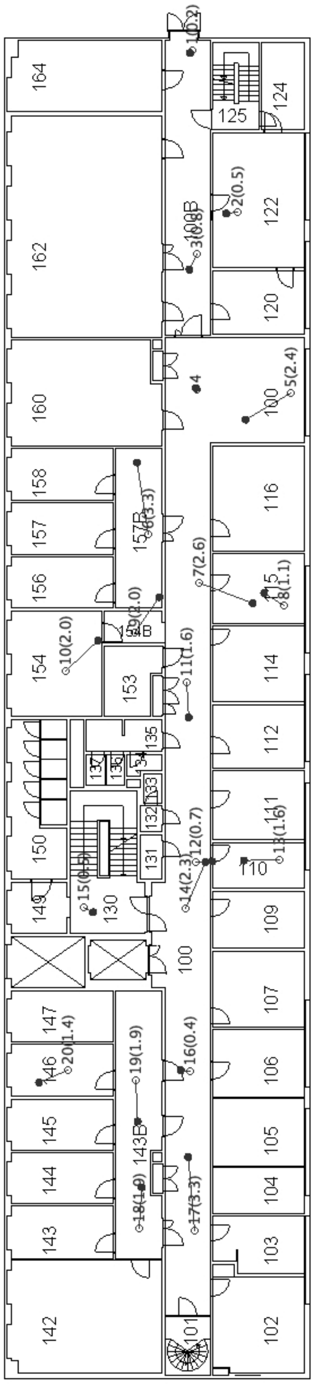

Figure A.18: L-ITV: First floor Test

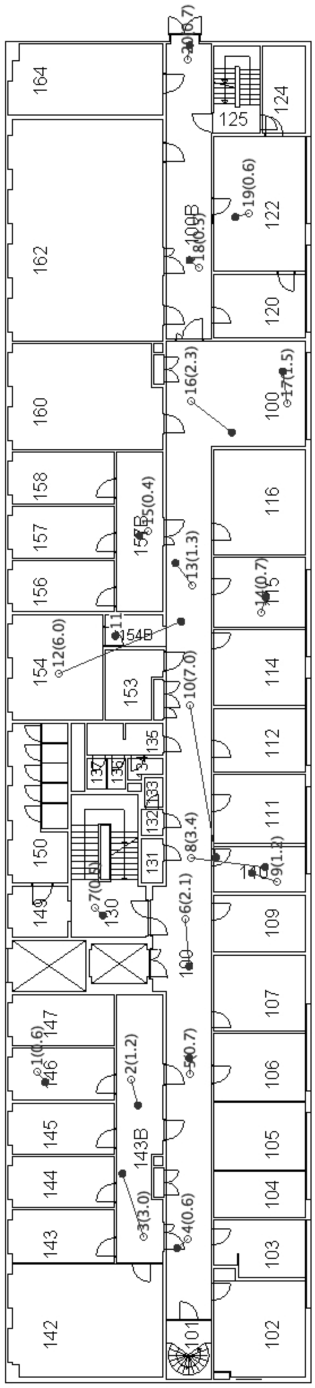

Figure A.19: L-ITV: First floor Reverse Test

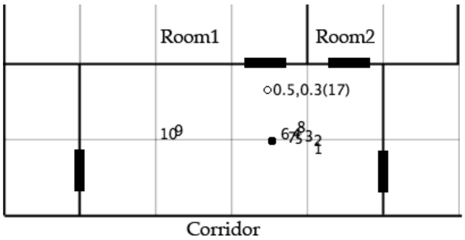


Figure A.20: SS-LOGIC: Corridor1 with 10 samples

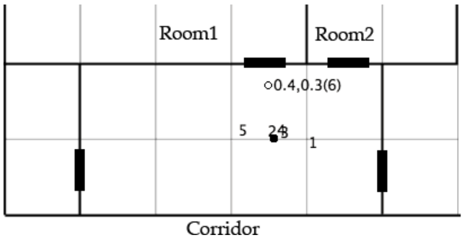


Figure A.21: SS-LOGIC: Corridor1 with 5 samples

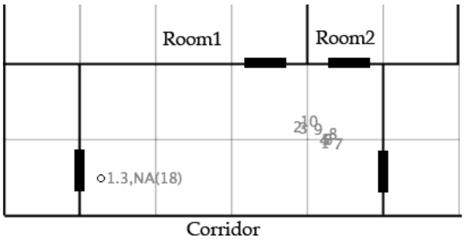


Figure A.22: SS-LOGIC: Corridor2 with 10 samples

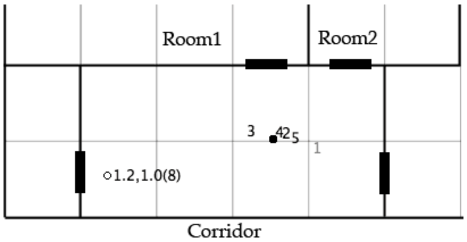


Figure A.23: SS-LOGIC: Corridor2 with 5 samples

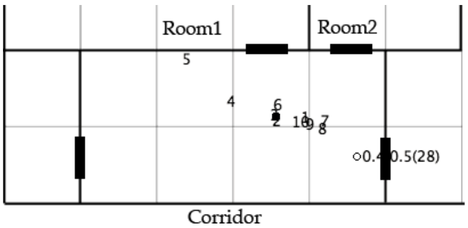


Figure A.24: SS-LOGIC: Corridor3 with 10 samples

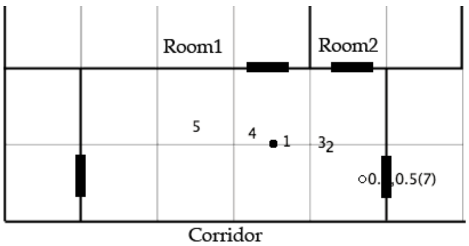


Figure A.25: SS-LOGIC: Corridor with 5 samples

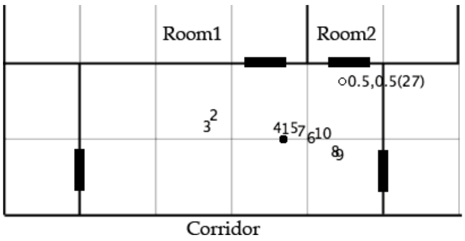


Figure A.26: SS-LOGIC: Corridor4 with 10 samples

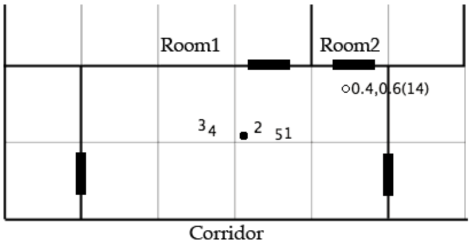


Figure A.27: SS-LOGIC: Corridor4 with 5 samples

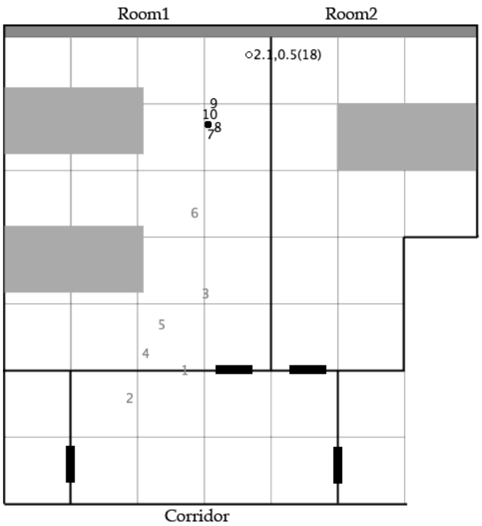


Figure A.28: SS-LOGIC: Room1-1 with 10 samples

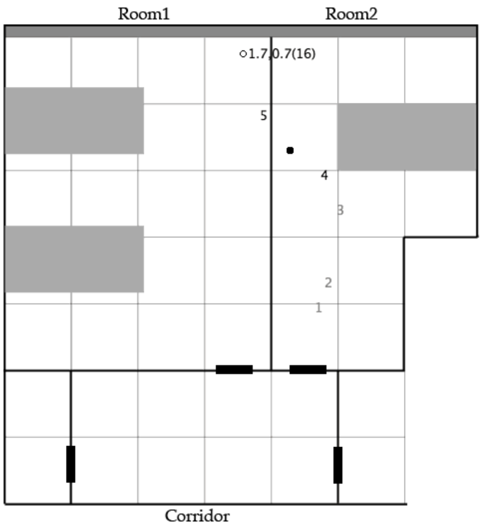


Figure A.29: SS-LOGIC: Room1-1 with 5 samples

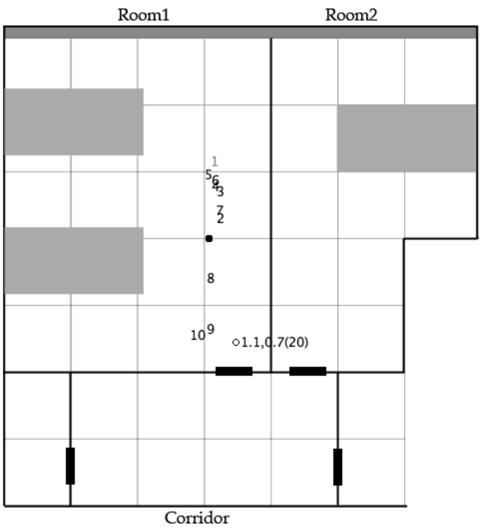


Figure A.30: SS-LOGIC: Room1-2 with 10 samples

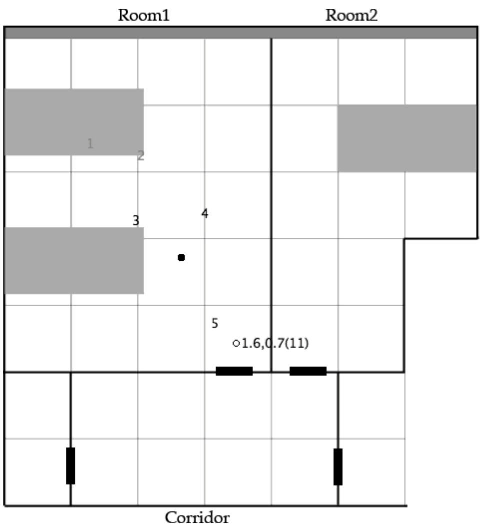


Figure A.31: SS-LOGIC: Room1-2 with 5 samples

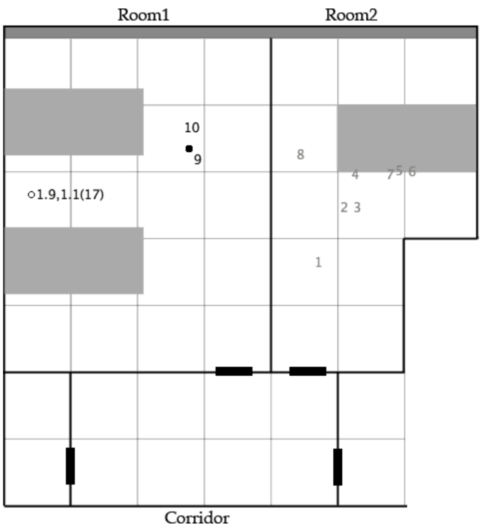


Figure A.32: SS-LOGIC: Room1-3 with 10 samples

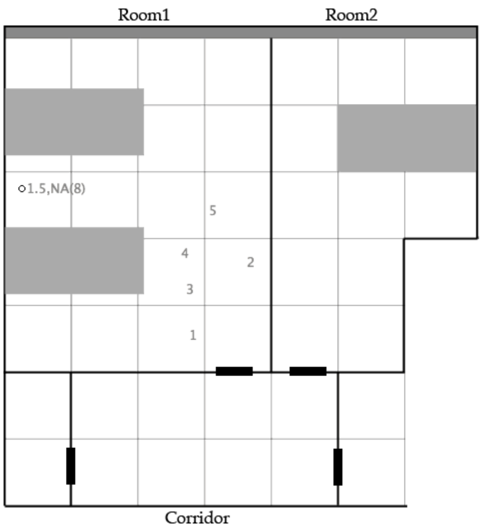


Figure A.33: SS-LOGIC: Room1-3 with 5 samples

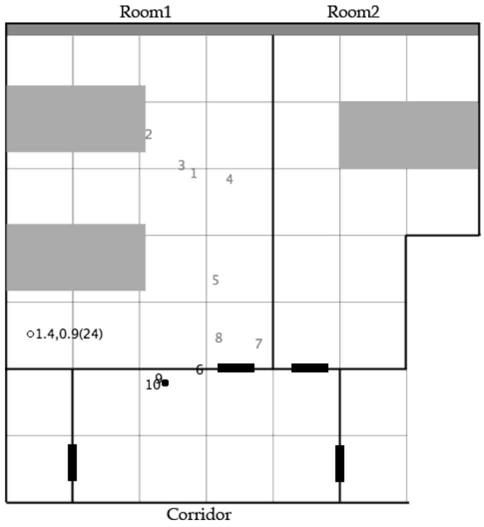


Figure A.34: SS-LOGIC: Room1-4 with 10 samples

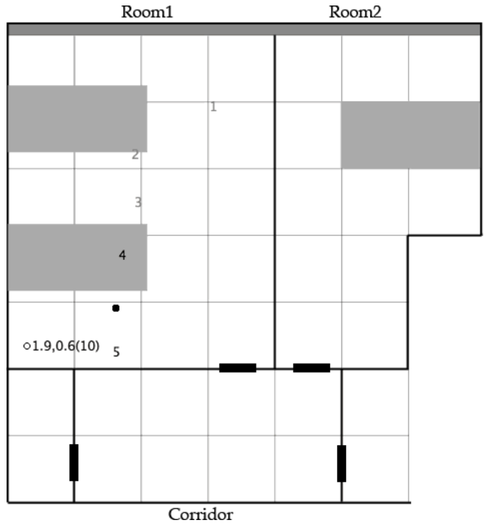


Figure A.35: SS-LOGIC: Room1-4 with 5 samples

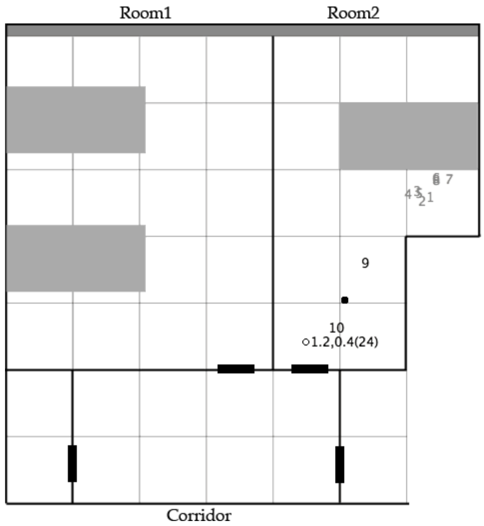


Figure A.36: SS-LOGIC: Room2-1 with 10 samples

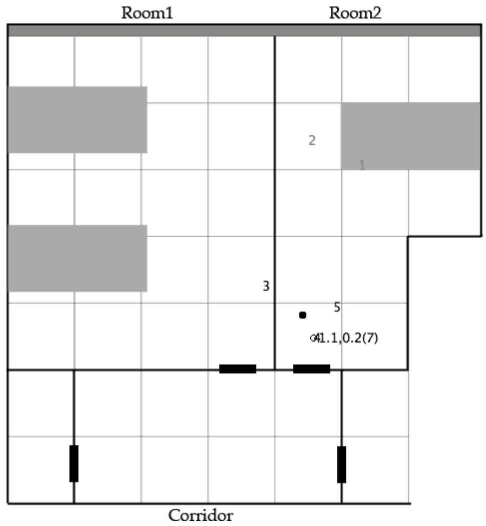


Figure A.37: SS-LOGIC: Room2-1 with 5 samples

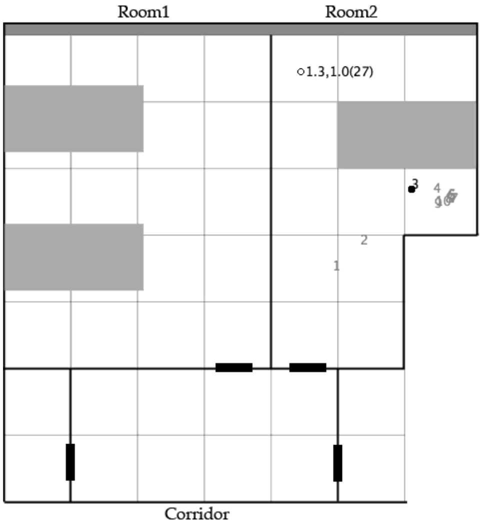


Figure A.38: SS-LOGIC: Room2-2 with 10 samples

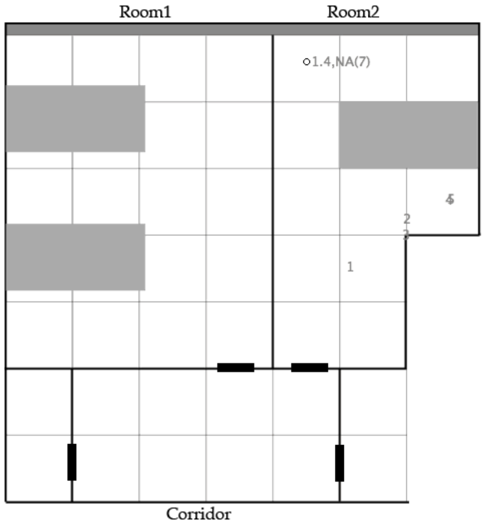


Figure A.39: SS-LOGIC: Room2-2 with 5 samples

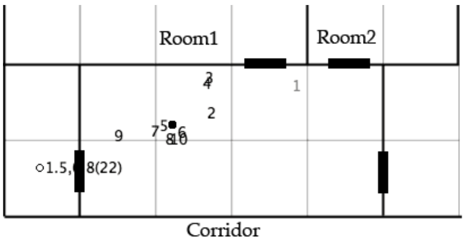


Figure A.40: SS-LOGIC: Left door with 10 samples

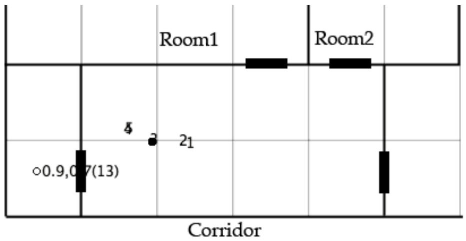


Figure A.41: SS-LOGIC: Left door with 5 samples

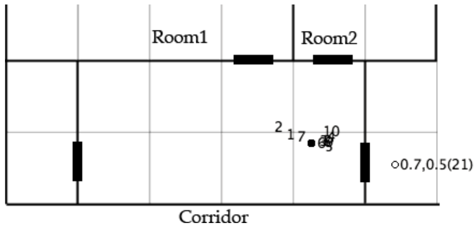


Figure A.42: SS-LOGIC: Right door with 10 samples

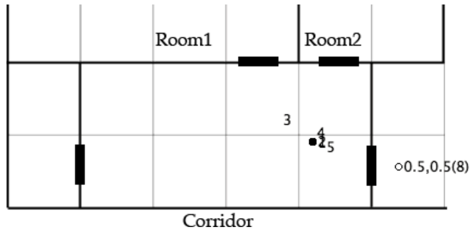


Figure A.43: SS-LOGIC: Right door with 5 samples

# Appendix B

# Java testing applications

In this appendix the Java testing application will be explained from a more technical point of view.

The application is an extension to an existing application *TrackingView* that shipped with the EPE 3.0.

## B.1 Original application

The *Tracking View* is a small Java example that show how to use the features of the Java API. The application show a JFrame with the map of the floor the selected device is in. It will then show all the devices in this floor with the selected device marked in a different color. If the selected device is inside a logical area this area will be highlighted on the map. The active device can be changed in a right click menu.

## B.2 Creating the test application

In order to produce a testing application that would give graphical results of the tests done, some modifications to the existing application is needed.

First the no longer needed parts of the original application is stripped. The logic that handles logical areas and the painting of several devices is stripped out.

A JToolbar is then created and populated with a save button, a text field to input the name of the saved file, two radio buttons to select mode and two radio buttons to select the testing location. An ActionListener is added to the GUI elements to make the inner workings respond to their commands.

When the GUI of the application is in place the internal workings of the application must be changed to support recording of sample points. This process is slightly different for the normal and extended mode. A basic SamplePoint class was created to handle this in the normal mode while an ExtendedSamplePoint class that extends the SamplePoint class was added to modify the logic where needed. In figure B.1 the simplified class diagram for the application can be seen.

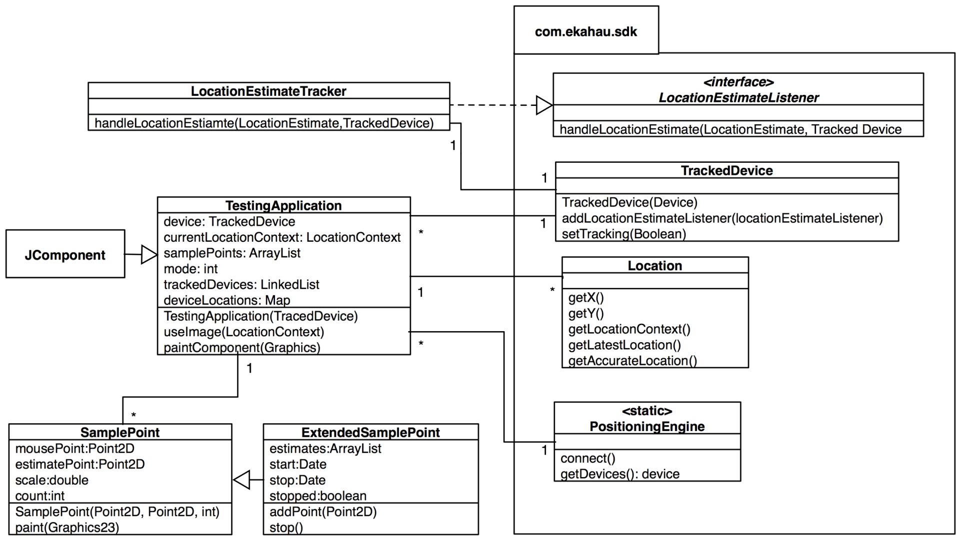


Figure B.1: UML Class diagram of the testing application

### B.2.1 Normal Mode

The logic of the Normal mode in the testing application can be seen in the simplified sequence diagram B.2. The diagram show logically how the application works when different calls from the user are made.

### B.2.2 Extended Mode

In the extended mode there are some additional features. The simplified sequence diagram showing the logic can be seen in figure B.3.

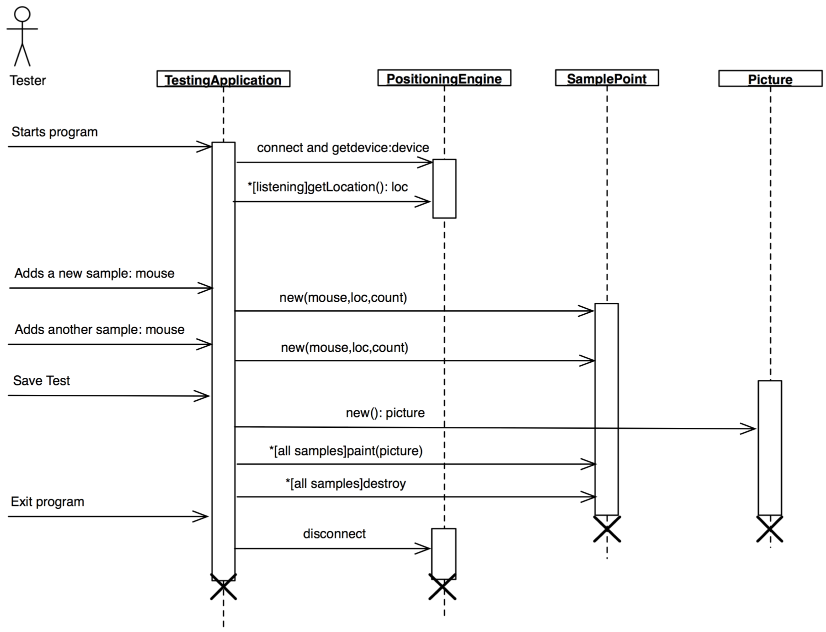


Figure B.2: Sequence Diagram for the normal mode

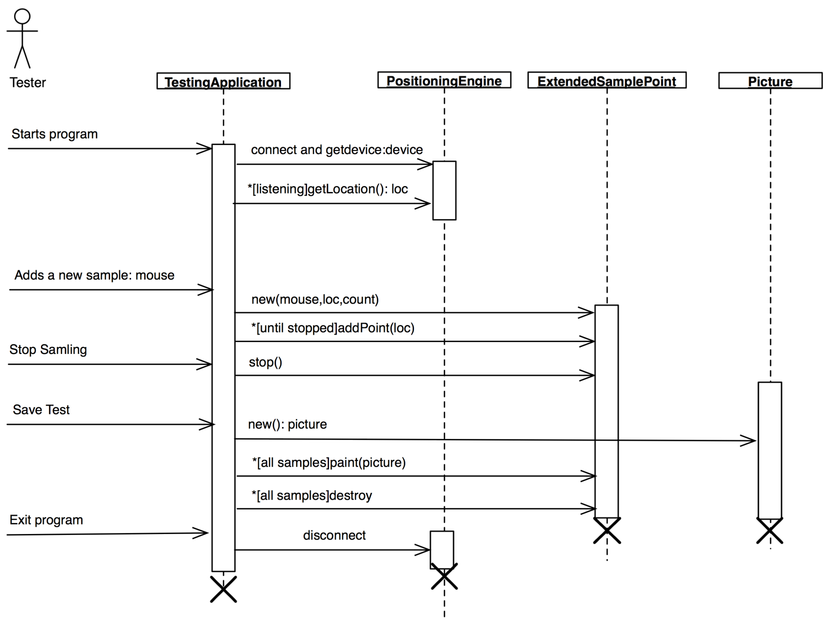


Figure B.3: Sequence Diagram for the Extended mode