Location in Context Aware Service Discovery

by

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Abstract

Context Aware Service Discovery is an extension to Service Discovery that uses context information to offer the best service to the user. Context Aware Service Discovery can for example use the location information of devices and services connected to the network as a context information to find nearest service. For the System in this report, there has been designed an interface between a Context Aware Service Discovery System, and a general Location Platform, which has been implemented using a Position System based on Bluetooth Signal Strength technique. For the design there has been carried out a study about the accuracy in the major wireless localization techniques and it has been defined an accuracy of the location, in order enable the Context Aware Service Discovery to efficiently use this additional information to the location itself. Finally there has been carried out measurements with the implementation of the designed interface, regarding the generated delay and traffic in the System and the service's selections of the Context Aware Service Discovery. Results shows that the discovery time and the generated traffic increase linearly by a factor of 1400 and 72 respectively with the number of devices in the cluster and the wrong selections at cluster level are less than 25%.

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Preface

This report is written during the project period of the 10th semester as members of the Networking and Security Group at the Department of Communication Technology, Institute of Electronic Systems, Aalborg University.

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Quiero agredecerselo especialmente a Carlos y Dimas por lo mucho que me han ayudado en este trabajo y tambien se lo quiero agredecer a Rafa, por haber estado ahi siempre, a Amanda, a Adri, a Matas, a Jose, a Raul, a Nacho, a Oriol, a Gaby, a Javi, a Anna, a Laurent, a Pier, al Gitan... y a todas las grandes personas y amigos que he conocido durante el tiempo que ha durado este proyecto y este erasmus, y que seguro siempre recordare, y por ultimo tambien se lo quiero agredecer a las "petter grifit" y a "las reno" por habernos hecho pasar tantos inolvidables momentos juntos en las intensas noches de Aalborg.

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Table of Contents

I Introduction **xi**

1 Motivation **1**

1.1 Example of User Cases 1

1.2 Problem Definition 3

II Background **5**

2 Context Aware Service Discovery **6**

2.1 General description 6

2.1.1 Context Definition 7

2.1.2 General Steps of the CASD Procedure 7

2.2 High Level Architecture of the CASD 8

2.2.1 Structure of CASD network 8

2.2.2 Internal Structure of the CASD 8

2.2.2.1 Service Discovery Module 9

2.2.2.2 Context Management Module 9

2.2.2.3 Service Ranker 9

2.2.2.4 Diagram Flow of Service Discovery High Level Internal Messages 10

2.3 Discovery Protocols 11

2.3.1 UPnP 11

2.3.1.1 Step 0 Addressing 11

2.3.1.2 Step 1 Discovery 12

2.3.1.3 Step 2 Description 13

2.3.1.4 Step 3 Control 13

2.3.1.5 Step 4 Eventing 14

2.3.1.6 Step 5 Presentation 14

2.3.2 INS/Twine 15
2.3.2.1 Resolver Layer 16
2.3.2.2 StrandMapper Layer 17
2.3.2.3 KeyRouter Layer 17
2.3.3 Bluetooth Service Discovery Protocol 17
2.4 Sumary 19

3 Localization Techniques for Wireless Devices 21
3.1 Introduction 21
3.2 Radiolocation 22
3.2.1 Angle of Arrival 22
3.2.2 Signal Strength 23
3.2.3 Time of Arrival 24
3.2.4 Time Difference of Arrival 25
3.2.5 Radiolocation Systems 26
3.2.5.1 GPS 26
3.3 Proximity systems 27
3.3.1 Cell ID 27
3.4 Environment analysis 28
3.4.1 Fingerprinting 28
3.5 Hybrid Techniques 29
3.5.1 GPS + Cell ID 29
3.5.2 Cell ID + Cell Sector + TA 29
3.6 Summary 30

III Design 31

4 Redefinition of the problem 32

5 Design of the interface 36
5.1 Requirements to the interface 36
5.1.1 Location platform 36
5.1.2 Context Aware Service Discovery 36
5.1.3 Requirements 37
5.2 Structure of the Location Interface Block 38
5.2.1 Interface Management Module 40
5.2.1.1 Case 1: There is no location information available 40
5.2.1.2 Case 2: There is location information available 40

5.2.2 Accuracy Estimation Module 42
5.2.3 Angle of Arrival Accuracy Estimation Module 43
5.2.3.1 Urban Environment 45
5.2.3.2 Rural Environment 46
5.2.4 Signal Strength Accuracy Estimation Module 47
5.2.4.1 Urban Environment 48
5.2.4.2 Rural Environment 50
5.2.5 Time of Arrival and Time Difference of Arrival Accuracy Estimation Module 50
5.2.5.1 Urban Environment 51
5.2.5.2 Rural Environment 51
5.2.6 Cell ID Accuracy Estimation Module 51
5.2.6.1 Urban Environment 51
5.2.6.2 Rural Environment 52
5.2.7 Accuracy Weighting Factor Transformation Module . . 52
5.3 Summary of setup information 53
5.4 Communication Messages Diagram 53

6 Design of Service Ranker **59**
6.1 Service Ranker considering Uniform Distribution 59
6.1.1 Taking the worst case Ranker 60
6.1.2 Taking the best case Ranker 60
6.2 Service Ranker considering Normal Distribution 61

IV Analysis **63**

7 Implementation Issues **64**
7.1 Location Interface Implementation 64
7.2 Service Rankers Implementation 66

8 Measurements of the Implementation **68**
8.1 Selected Service Measurements 68
8.1.1 Comparison of the Measurements 75
8.2 Time Measurements 76
8.3 Network Traffic Measurement 78

V Conclusions **79**

9 Conclusions **80**

10 Future work **82**

A Angle of Arrival estimated location's region area **84**

List of Figures

1.1 Hospital Network . . . 2
1.2 Problem Definition . . . 3

2.1 Personal Network of the user case 4 in section 1.1 . . . 6
2.2 High level CASD Network . . . 8
2.3 Service Management internal structure . . . 9
2.4 High level internal message diagram [3] . . . 10
2.5 Discovery step of UPnP architecture . . . 12
2.6 Description step of UPnP architeture . . . 13
2.7 Control step of UPnP architecture . . . 14
2.8 Presentation step of UPnP architecture . . . 15
2.9 INS/Twine network . . . 16
2.10 Resource Description example of INS/twine [8] . . . 16
2.11 INR Layers [8] . . . 17
2.12 Example of piconet network . . . 18
2.13 SDP requests responses model [12] . . . 18

3.1 Device location with Angle of Arrival Technique [1] . . . 22
3.2 Angle of arrival Accuracy . . . 23
3.3 Location estimation using Signal Strength . . . 24
3.4 Signal Strenght . . . 25
3.5 TDOA device location . . . 26
3.6 Cell ID [1] . . . 27
3.7 Fingerprinting [1] . . . 28
3.8 cell ID + Cell Sector + TA . . . 29

4.1 Scenario of cluster level . . . 33
4.2 Problem definition diagram . . . 34

5.1 Location Interface Structure 39
5.2 There is not responds from the Location Platform 40
5.3 There is location information available without accuracy information 42
5.4 There is location information available with accuracy information 42
5.5 Area of the location's region using AoA technique 44
5.6 Area variation with the azimuth spread 45
5.7 The location accuracy worst case 46
5.8 Path loss line 48
5.9 $\log(x)$-Standard Deviation 48
5.10 RSSI Location's Region [2] 49
5.11 Weighting Factor Transformation Function 53
5.12 Step 1 of the communications message diagram requesting . . 54
5.13 Step 1 of the communications message diagram responding . . 55
5.14 Step 2 of the communication messages diagram 56
5.15 Step 3 and first case of the communications messages diagram 56
5.16 Step 2 second case of the communication messages diagram . . 57
5.17 Step 4 of the communications messages diagram 58

6.1 Uniform distribution assumption in the location's region . . . 60
6.2 Service Ranker considering Normal Distribution and the user setting the distance 62

7.1 Class Diagram 65

8.1 Measurement scenario path of the mobile devices 69
8.2 Real distance between the user and services in the measurements 69
8.3 Distance between the user and services estimated coordinates in the measurement 70
8.4 Estimation error of the Device 1 70
8.5 Estimation error of the Device 2 71
8.6 Estimation error of the Device 3 71
8.7 Estimation error of the Device 4 71
8.8 Selected Service with Service Ranker 1 taking the worst case and the Position System providing the accuracy information . 73
8.9 Selected Service with Service Ranker 1 taking the best case and the Position System providing the accuracy information . 73
8.10 Selected Service with Service Ranker 1 taking the worst case and the accuracy estimations by the Location Interface 74

8.11 Selected Service with Service Ranker 1 taking the best case and the accuracy estimation by the Location Interface 74
8.12 Selected Service with Service Ranker 2 74
8.13 Comparison of error selection ratio for SR1 (uniform distribution) of different cases. 75
8.14 Comparison of error selection ratio for SR2 (Normal distribution) for different user's set up distance. 76
8.15 Discovery Time-number of services 77
8.16 Discovery Time with location/ Discovery Time without, location increasing with the number of devices 77
8.17 Number of packets-number of services 78

A.1 Area of the location's region AoA 84
A.2 Angles of the location's region 85
A.3 Sides of the locatio's region 85
A.4 Location's region split in two triangles 86
A.5 Area when $\alpha > 0$, $\beta > 0$, $\phi = \alpha + \beta$ 87
A.6 Area when $\alpha > 0$, $\beta > 0$, $\phi > \alpha + \beta$ 88
A.7 Area when $\alpha = 0$, $\beta = 0$, $\forall\phi$ 88

Part I

Introduction

Chapter 1

Motivation

Location information is a information which makes possible to develop new applications in the network. When the geographical location of the user's device and the geographical location of the services are known in the network, it is possible provides to the user the nearest service. In this situation new applications may appear which could offer the best nearest service that the user needs.

In the other hand Context Aware Service Discovery (CASD) is a technique that makes possible choose among all network connected services. Basically this technique makes possible to choose the best connected service in the network for the user, basing its choice on the context information. The context information is the rules that service discovery uses to select the best service for the user. The location of the user's device and the location of services could be the context information of the service discovery. In this case the CASD could choose the nearest service for the user in the network.

1.1 Example of User Cases

The following examples are some user cases where the context aware service discovery with the location information could be useful.

User case 1: One user is in a new city or in an urban area that he does not know, he has a mobile device and he is connected to a mobile phone network, if he would like to know where is nearest Chinese restaurant where he wants to lunch, the network could give him this address. Knowing the user's location and this kind of service's location, the network could rank all these kind of service and choose nearest service to the user, and then inform her.

User Case 2: Other example of scenario where it is clear how the context information makes possible to service discovery filter all connected services and choose the best, is described in [4]. In case of natural disaster the field hospital have to be flexible and to be able to cope with high mobility. As we can see in 1.1, in this scenario could be three networks, Patients network, Nurses network and Doctors network. The patient has logging device with different sensors and nurses have PDA to assist them. The doctors also have theirs own PDA. In the doctors networks there would be several doctors from the different speciality.

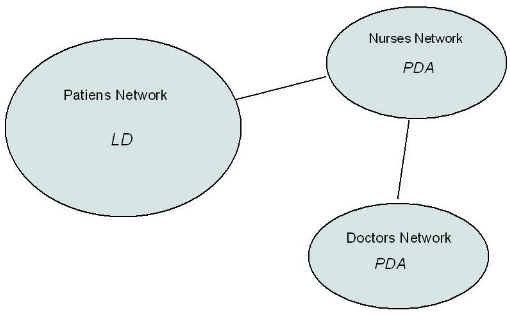

Figure 1.1: Hospital Network

Initially one nurse can see the data from one patient, and if is necessary that the patient be looked, she triggers CASD in her PDA. Then Service discovery would find the nearest doctor who is available and which speciality is that the patient needs. Therefore in this case the context information will be: speciality of the doctor, activity of doctor and the location of doctor. This information would make possible to find quickly the needed doctor.

User case 3: One user with a mobile device which is connected to the mobile phone network and it is driving one car in open area. The car has not enough gas that why he wants to know the kilometer that there are to the next gas station that it is open near to his position. Then CASD knowing the estimated position of the driver and the positions of the gas stations that there are opened, it could provide the information to the user.

User case 4: Nowadays one user could have too much services distributed in different geographical place like the office building, home, car..in this situation the user could need to know which is best service in all the the interconnected network, for example if he is using his personal computer connected internet an he needs to send something to print, the CASD could be useful to the user providing the best service.

1.2 Problem Definition

As it has been said before CASD is a technique that makes possible to filter all network connected services using context information. Therefore if the user wants to use the nearest services, the location information has to be included on the context information. Then the Service Discovery could choose the nearest service. However this situation requires that Service discovery has to know the user's location information and the service's location information

There are already implemented a CASD and Location Platforms, however there is not implemented yet the interface which could communicate this two parts. Therefore the goal of this master thesis is to design and implement the communication between the location platforms, and the CASD. This communication should makes possible to CASD knows the locations of the users and services, and then it could makes possible to choose, the nearest service for the user that is present in the network.

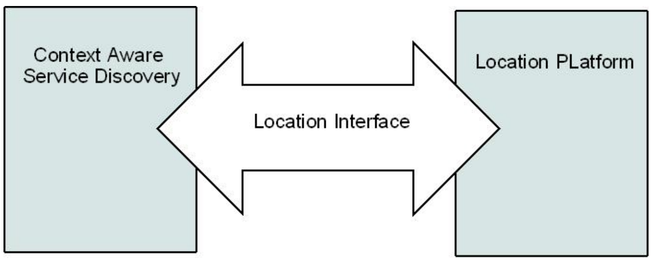

Figure 1.2: Problem Definition

In order to design and to implement correctly this interface the first part of this thesis is a study about CASD and the Wireless Devices Localization Techniques. The aim of this part is to understand the specifications of Service Discovery and which is the information that it needs, and afterward the problems in the localization techniques which have an impact in CASD.

The second part of the thesis is a design of the interface between the Service Discovery and Location Platform, considering all the exceptions or problems that may appear when these different parts begin working together. Moreover, this part includes results about the implementation of design choice while all system working.

Finally in the third part there are the conclusions and the future works which could continue the advances of this area.

Part II

Background

Chapter 2

Context Aware Service Discovery

Nowadays the number of the personal devices or services a user requires in different geographical places is increasing. Depending on the user location or on his needs, only the best service is connected to the network. The Context Aware Service Discovery (CASD) is a technique that becomes the network more intelligent always providing the best service to the user.

2.1 General description

Personal devices can be interconnected forming networks in different geographical places such as home, office, car, etc. These networks might be connected using infrastructures, such as the Internet or GSM, what is known as a Personal Network [7]. Its architecture consist of different clusters of personal devices situated in different places, as for example Figure 2.1 shows.

A Personal Network may include many services so as it can be difficult

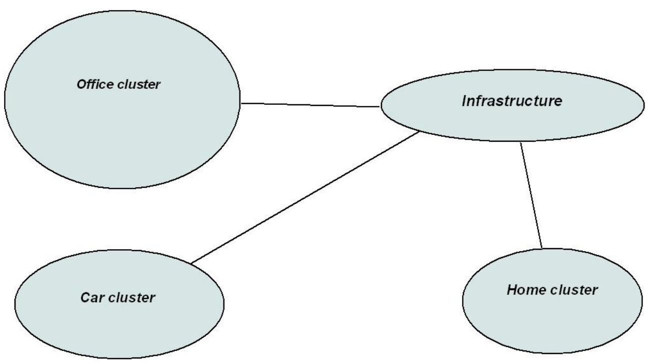

Figure 2.1: Personal Network of the user case 4 in section 1.1

for the user to find or select the most suitable service. For instance, if a user wants to print any document, each printer in all clusters will eventually be listed to the user. However if the location of the user and printers is taken into account, only the ones nearby the user will be chosen. The CASD is an important technique for a user to locate services in a network. The context information is used in this technique to assist the user in finding the most relevant service.

2.1.1 Context Definition

The context is a kind of information that makes it possible to the Service Discovery filter all the connected services and choose the best. The context could be classify in a lot of different ways. For example in [7], the context is classify in three different groups:

- **User context**: related to user information, user profile, devices and activity.
- **Network context**: related to the network state, delay, bandwidth and network load.
- **Environment context**: this context contains location information, time and physical conditions, noise level, temperature, etc.

2.1.2 General Steps of the CASD Procedure

The procedure to obtain the best service of the CASD using the context information can be explained in five general steps:

1. The context information is continuously stored and updated in the cluster continuously with a certain frequency.
2. If a user requests a service to the Service Discovery, the system decides which context is important to this type of request.
3. The system looks for the services that are going to be matched.
4. The context information of each service is matched by a rule system.
5. The service discovery replies with the service that has been found.

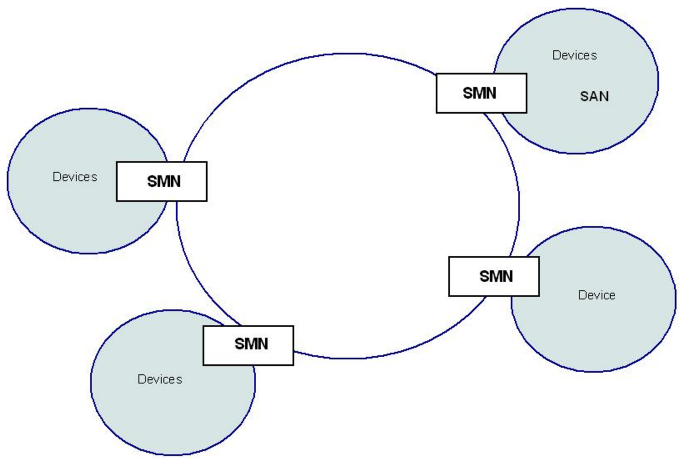

Figure 2.2: High level CASD Network

2.2 High Level Architecture of the CASD

2.2.1 Structure of CASD network

The architecture of CASD external network is split into two layers 2.2. One for local discovery in network of device clusters, and the other one for global discovery which covers all interconnected networks. There are two important entities:

- **Service Management Node (SMN)**: this node is responsible for the interaction with other SMN and maintains a repository of context data within a cluster of nodes.

- **Service Assistant Node (SAN)**: it is a potential SMN, which can take over the role as an SMN and it may also act as proxy between SMN and no IP devices.

2.2.2 Internal Structure of the CASD

The SMN is possible to be split into two different parts 2.3. One part is the lower layers which are grouped in an entity called **Service Management Module**. This entity is responsible of interacting with the external clients devices and services devices, by using legacy Service Discovery protocols such as UPnP. The other one is the Service Discovery Adaptation Layer which is the interface between these protocols and the upper components. The upper layers contain the main modules, which make it possible to filter the

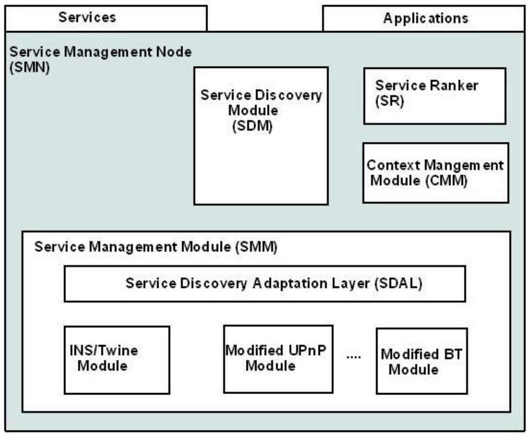

Figure 2.3: Service Management internal structure

best service: **Context Management Module (CMM)**, **Service Ranker (SR)** and **Service Discovery Module (SDM)**.

2.2.2.1 Service Discovery Module

The Service Discovery Module (SDM) is the module responsible for the interaction between the upper layers components of the SMN. It means the SDM gets the context information from CMM sending it to the SR and finally giving the information of the best service to the user using Service Adaptation Layer (SAL).

2.2.2.2 Context Management Module

The Context Management Module (CMM) is responsible for two important tasks in the CASD. The first task is to discover sources of context information which are connected to the network, and the second task is to update this context information in a database. In both cases, the CMM requires a SAL in order to use discovery protocols which can get the context information from the context sources.

2.2.2.3 Service Ranker

The Service Ranker (SR) is the part of the service discovery which chooses the best service according the services and the user context. In order to select this service, it implements a rank algorithm following the next equation, in which w is a weight factor, f is some predefined function, s is a type of service and x is the context value for the user and service.

$$S = \sum_{n=1}^{m} w_n * f_n(s, x_{s,n}, x_{u,n}) \tag{2.1}$$

2.2.2.4 Diagram Flow of Service Discovery High Level Internal Messages

When a user triggers the CASD in order to find the best service, an internal message transaction happens between the main internal parts of the CASD. In Figue 2.4 we can see a messages flow diagram between the main modules of the upper layers, when there is a new request in the system:

1. The SMM initially receives a service discovery request from a user or a SAN.

2. By the Service Discovery Adaptation Layer (SDAL), the SMN triggers the SDM to get a context parameter data, which is going to be used in the ranking process.

3. The context parameters are provided by CMM to SDM.

4. Then, the SDM provides this information to the SR. Finally, the SR finds the best service and communicates it to the SDM.

5. In the last step, the SDM provides the best service to the user by the SDAL.

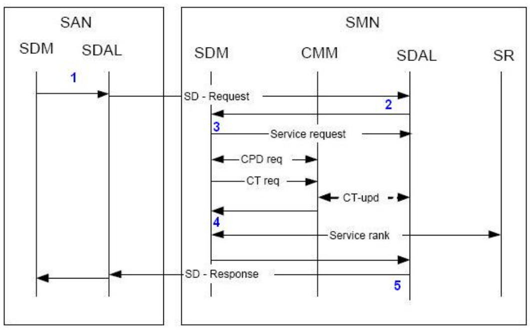

Figure 2.4: High level internal message diagram [3]

2.3 Discovery Protocols

The context aware service discovery makes use of legacy discovery protocols. The service management layer uses different discovery protocols to discover the services provided by the devices, and to communicate with other devices and services. In Figure 2.3 we can see that in the lower layers of the CMN there are three different discovery protocols which have been considered to be included in the CASD structure: **Modified UPnP**, **INS/twine** and **Modified BT**. In the following subsections these discovery protocols are described.

2.3.1 UPnP

Universal Plug and Play (UPnP) is an open standard service discovery protocol and it is used by the CASD to discover devices and services residing at the cluster level. Such standard is divided into three important entities: **Control Point**, **Device** and **Service**. The Control Point is the component which registers the devices and services and handles all the requests services. The UPnP discovery protocol consists of the six following steps:

- Step 0 Addressing
- Step 1 Discovery
- Step 2 Device description
- Step 3 Control
- Step 4 Eventing
- Step 5 Presentation

2.3.1.1 Step 0 Addressing

The UPnP networking basics is the IP addressing. When a new device is connected to the network there are two possibilities. If the network is managed, the network assigns one IP to the device. But if the network is unmanaged, the device has to choose itself one IP. Then it has to test the selected IP, if it is already in use in the network by other device. The device has to periodically check if the network assigns it a new IP.

2.3.1.2 Step 1 Discovery

Through this step the control points can find new devices connected in the network. When a new device is added to the network, it multicasts a number of discovery messages advertising its embedded devices and services to a standard address port. Then, any control point can list these messages and discover that new capabilities are available in the network. The device which wants to advertise its capabilities has to multicast a number of discovery messages corresponding to each of its embedded devices and services. It has to send three discovery messages for the root devices, two discovery messages for each embedded device, and one for each service. These messages have to include duration until the advertisements expire. When a device wants to disconnect from network, it should multicast a number of discovery messages revoking its advertisements. If not, the advertisements will expire on their own. The discovery messages have four main component or information:

- The device or service UPnP type.
- The device's identifier for the advertisement.
- URL to the device's UPnP description.
- Duration for which advertisement is valid.

When a new control point is added to the network, it multicasts a discovery message searching for interesting devices, services or both. All devices have to be listening to the standard multicast address for these messages. If any of their services match to the search criteria they have to respond.

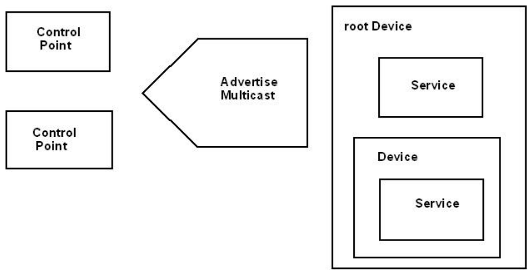

Figure 2.5: Discovery step of UPnP architecture

2.3.1.3 Step 2 Description

After a discovery step, the control point knows very little about the device. If the control point wants to know more about the devices and their services, the control point has to retrieve a description of the device and its capabilities, from the URL provided in the discovery message. The UPnP device description is partitioned into two parts: a device description and service description. These two descriptions are in XML syntax.

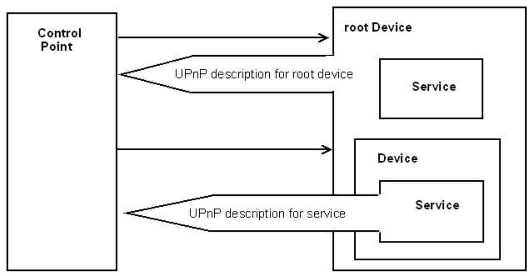

Figure 2.6: Description step of UPnP architeture

A UPnP device description includes manufacturer information, like the model name and serial number. For each service the device description is also included, which lists the service type, name, a URL for a service description, and a URL for eventing. Finally, a description of all embedded devices is added.

A UPnP service description includes a list of commands, or actions, the service responds to, and parameters, or arguments, for each action. A service description also includes a list of variables which model the state of the service at run time.

2.3.1.4 Step 3 Control

After the addressing, discovery, and description, the next step is the control. In this step, the control point can invoke actions to the device and poll for the value of state variables.

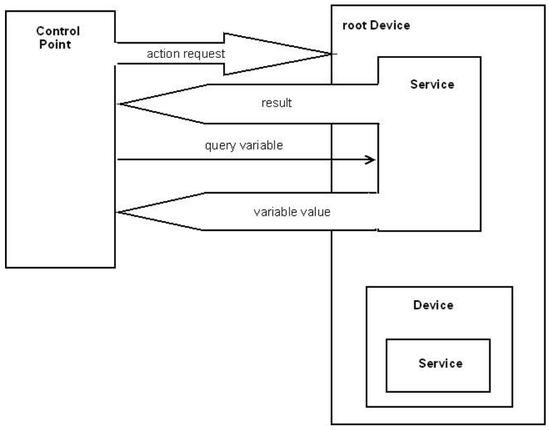

Figure 2.7: Control step of UPnP architecture

When the control point wants to invoke an action, a control message is sent to the control URL for the service, and the service returns any results or errors from the action in response. Furthermore, the control point may also poll the service for the value of a state variable by sending a query message.

2.3.1.5 Step 4 Eventing

In the description step, a UPnP service description includes a list of actions the service responds to and a list of variables that model the state of the service at run time. These state variables are evented, then the service publishes updates when this variables change, and a control point may subscribe to receive this information.

If a control point wants to know about events it has to subscribe by sending a subscription message. If the device accepts the subscription then it sends a response with enough time length for the subscription. When the device (publisher) notes the state changes, it will send an event message to subscriber control point. Event messages contain the names of one of more state variables and the current value, expressed in XML.

If the subscriber wants to keep the subscription active it has to renew its subscription before it expires. If the subscriber do not need more eventing for a publisher, it has to cancel its subscription sending a new message.

2.3.1.6 Step 5 Presentation

Presentation is the last step in UPnP architecture showing an HTML-based user interface for controlling and or viewing device status. If a device has a URL for presentation, the control point can get a page from this URL allowing a user to control the device or view the status. The capabilities for the user in this state depend on the specific capabilities of the presentation page and device.

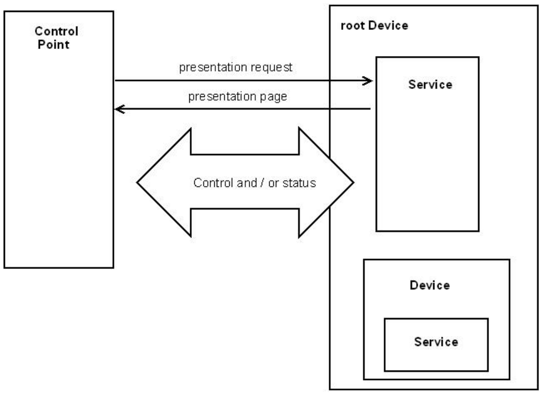

Figure 2.8: Presentation step of UPnP architecture

2.3.2 INS/Twine

INS/twine is an architecture for peer to peer network. In INS/twine there are two important parts: **resources** and **resolvers**. Resources are any service which is connected to the network. Resolvers are nodes which are organized themselves expanding the network and they are responsible for routing the resource descriptions to other nodes. Also they are responsible for store the resource descriptions and to solve the clients query.

When one service is connected to the network, it sends a resource description to the nearest resolver. This resolver interprets and stores this information, and then it route to the other resolvers. When one client queries about one kind of resource, it asks the nearest resolver and then the network provides the issues. So, in this architecture the results are independent from the location of the client and the resource.

The main feature of INS/twine is that it achieves the scalability using a hash based partitioning of the resource description. In INS/twine the resources are composed of three different layers:

- Resolver Layer
- StrandMapper Layer

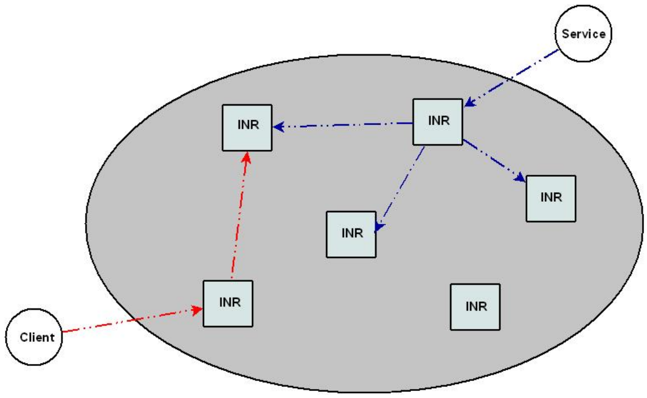

Figure 2.9: INS/Twine network

- KeyRouter Layer

2.3.2.1 Resolver Layer

The Resolver Layer (RL) is the top-most layer. In this layer, the client applications messages are received. It is also the interface between the client applications and the query engine where the messages are stored locally. The messages that RL receive from the client are composed of three parts. The first part is the type of message T, and it says if the message is an advertisement or a query. The second part of a message is a name record NR, which contains information about the network location of the resource, IP address, transport protocol and port number. The third part is the resource description. This description is a hierarchy of the attributes that the resource contains. The description is presented in a proper language such as XML.

```
<res>camera
    <man>ACompany</man>
    <model>AModel</model>
</res>
<subject>traffic</subject>
```

Figure 2.10: Resource Description example of INS/twine [8]

When the RL receives the resource description it executes one algorithm called strand-splitting algorithm. By this algorithm, the service layer breaks the description in meaningful pieces called strands. These pieces have to preserve the resource description but at the same time they have to support partial queries.

2.3.2.2 StrandMapper Layer

When the RL has split the description into strands, then it sends the complete message but with the resource description split into strands to the StrandMapper Layer. The goal of this layer is to use a hash function which associates one numeric m-bits Key to each strand.

2.3.2.3 KeyRouter Layer

When the upper layer has obtained the Key number then it is sent with the rest of the message to the KeyRouter Layer. This layer has to think about which is the best resolver in the network to which it has to forward the message in order to store it or participate in solving the query.

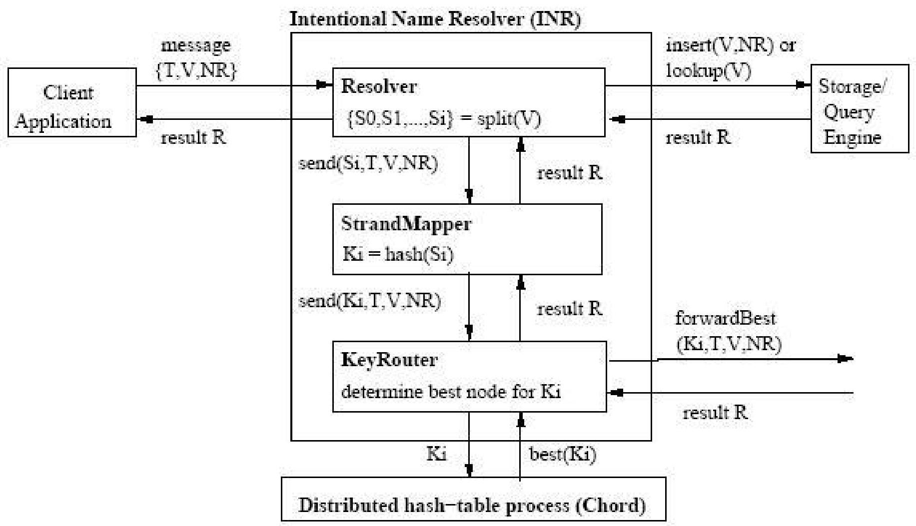

Figure 2.11: INR Layers [8]

2.3.3 Bluetooth Service Discovery Protocol

Bluetooth is a wireless architecture where there are two main entities: the **master radio** and the **slave**. The Bluetooth based network it is formed by interconnecting different small networks called piconets. A piconets requires one master and more than one slaves, which are in the same radio channel.

The master radio provides the clock reference to synchronize the piconet and the slaves can not communicate directly, they have to use the master radio. The communication between the slaves and master is a full duplex communication using a time division multiplexing. In each piconet different Frequency hoping sequence are used .

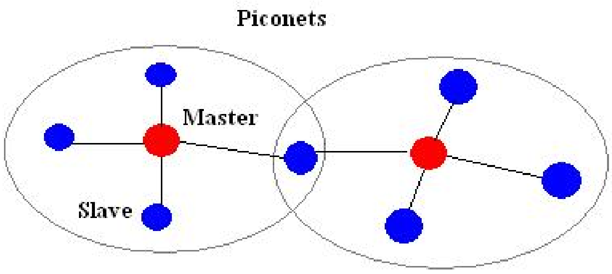

Figure 2.12: Example of piconet network

The Bluetooth Service Discovery Protocol (SDP) is the protocol that defines how the user can search for a service based on specific attributes without knowing anything of the available services on this Bluetooth environment. This protocol is optimized for the highly dynamic nature of the Bluetooth communications and it is used by the context aware service discovery to discover Bluetooth supported devices and services. Bluetooth Service Discovery Protocol works using a request/responds model. Each request or respond transaction uses one Protocol Data Unit.

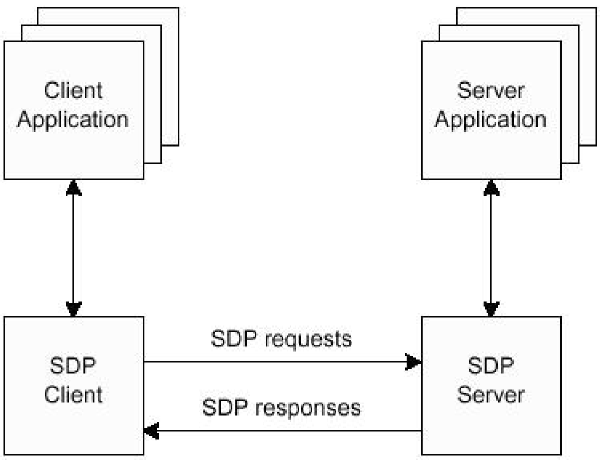

Figure 2.13: SDP requests responses model [12]

The Protocol Data Unit format consist of PDU header and PDU specific parameters. The PDU header consists of three fields:

- PDU ID: identifies the type of PDU.

- TransactionID: identifies the request PDUs.

- ParameterLegnth: specifies the lengths of all the parameters which are contained in the PDU.

In Service Discovery Protocol, each type of request PDU usually obtains a PDU responds. In case that the format of the request PDU is erroneous or the server can not respond with appropriate PDU answer, then the server will respond with an error PDU called SDPErrorResponse.

In the Bluetooth network, all the information about each service is described by service record in the SDP server. The service record consists of a list of all service attributes. The service attributes are defined by two components:

- An attribute ID: this field identifies each service attribute from other service attributes.

- The attribute value: the meaning of this filed depends on the associated ID attribute or on its content.

All services that available in the Bluetooth SDP, are defined such an instance of service class. The service Class defines which attributes are contained in the service record of the services. Each service class is assigned a unique identifier called UUID. This identifier is used when there is a one service search in the system, matching in a list of the requested UUID.

2.4 Sumary

The CASD is a service discovery that can automatically provide the best available service in the network to the user by means of the context information. Context Management Module is the part of CASD responsible for storing and updating the context information such as the location information and the Service Ranker is the part that is responsible for executing a ranking algorithms in order to choose the best service using this context information. Furthermore CASD can uses different legacy discovery protocol with different features such as INS/twine, UPnP and Bluetooth SDP. The UPnP can be used by the CASD to discover the IP devices in the network and it uses XML descriptions for the services, the main problem that it can involve, is that it could generate too much overhead in big network due to the broadcasting messages. On the other hand the Bluetooth SDP can be used by the CASD to discover no IP services in Bluetooth environments using a responds request model. Moreover the INS/twine is a good choice when it is necessary to achieve a good scalability in the network, for example it can be used by the CASD in order to create a global network interconnecting Service Management Nodes.

Chapter 3

Localization Techniques for Wireless Devices

3.1 Introduction

There are several location techniques, and depending on which technique is used, the accuracy of the location information that the Context Aware Service Discovery can use varies. The accuracy of the technique also depends on the scenario where device is situated.

The different localization techniques can be classified into three main groups:

- Radiolocation: This group of techniques uses measurements of the radio signal to calculate the position of the device. Inside of this group there are **Signal Strength** and **Time of Arrival** techniques. These techniques are also called Triangulation techniques because they use triangulation methods to locate the device. Other techniques in this group are **Angle of Arrival** and **Time Difference of Arrival** techniques.

- Proximity systems: In this group of techniques, the position of device is calculated considering the access points of the device to the network. Inside this group of techniques, the most representative is the **Cell-ID** technique.

- Environment analysis: This kind of techniques predicts the position of the device by analyzing its environment. They require a previous study of the covered area, storing the result into a database. Once this study has been performed, it will be possible to predict the position of the device analyzing the environment and comparing with the database. The most common techniques in this group are **Fingerprinting** and **Location Pattern Matching**.

3.2 Radiolocation

3.2.1 Angle of Arrival

For the implementation of this technique it is necessary to use two directional antennas. With this kind of antenna is possible to know the angle of arrival of the signal that is sent by the device. As illustrated in figure 3.1, if we draw a line with these angles from two Base Stations (BS), the area of intersection determines the possible location of the device.

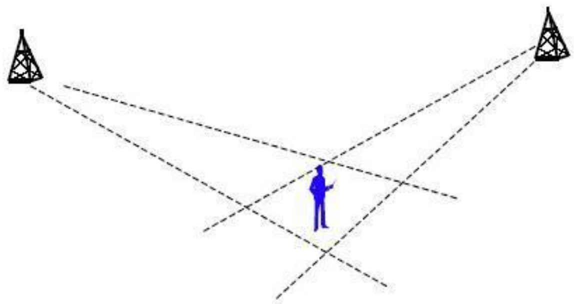

Figure 3.1: Device location with Angle of Arrival Technique [1]

In this technique, the accuracy of location depends on distance between device and the BSs. When device is near to a BS the accuracy is higher than when it is far from the BS. When device is near to a BS the area of intersection is smaller because the beam of the antennas is narrower.

It is possible to demonstrate mathematically that the accuracy of the location depends on the distance between the mobile device and the BSs. Figure A.1 depicts two antennas with the same azimuth spread ϕ, the signal's arrival angle of the antenna on the left is α, the signal's arrival angle to the antenna on the right is β and the distance between the BSs is D.

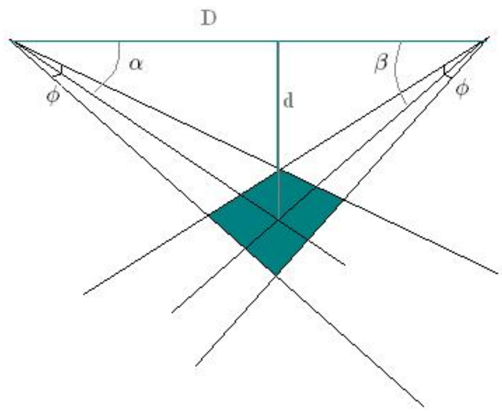

Figure 3.2: Angle of arrival Accuracy

Using geometry laws it is possible to find an expression that relates the area where device could be with the angles of arrival, the azimuth spread of the antennas and the distance between the BSs. Equation (3.2.1) determines the area of location of the device as a function of these variables. The mathematical development required to obtain it can be found in Appendix 1.

$$
A = \begin{cases}
\left(\frac{D^2 sin^2(\phi) sin(\beta+\phi/2) sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi) sin^2(\alpha+\beta)}\right) + \left(\frac{D^2 sin^2(\phi)}{sin^2(\alpha+\beta-\phi)}\right) & \\
* \left(\frac{sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi)} - \frac{sin(\beta+\phi/2) sin(\phi)}{sin(180-\alpha)-\beta-\phi) sin(\phi+\beta)}\right) & \\
* \left(\frac{sin(\beta+\phi/2)}{sin(180-\alpha-\beta-\phi)} - \frac{sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi)} \frac{sin(\phi)}{sin(\alpha+\beta)}\right) & \\
*(sin(180-\alpha-\beta+\phi)) & \alpha > 0 \ , \ \beta > 0, \ \phi < \alpha+\beta \\
\frac{D^2 sin(\beta+\phi/2) sin(\alpha+\phi/2)}{2 sin(180-\alpha-\beta-\phi)} & \alpha > 0, \ \beta > 0, \ \phi = \alpha+\beta \\
\frac{D^2 sin(\beta+\phi/2) sin(\alpha+\phi/2)}{2 sin(180-\alpha-\beta-\phi)} + \frac{D^2 sin(\phi/2-\alpha) sin(\phi/2-\beta)}{2 sin(180+\alpha+\beta-\phi)} & \alpha > 0, \ \beta > 0, \ \phi > \alpha+\beta \\
\frac{D^2 \tan(\phi/2)}{2} & \alpha = 0 \ , \ \beta = 0 \ , \ \forall\phi
\end{cases}
$$

3.2.2 Signal Strength

This technique is based on power level measurements from different BSs. With signal level measurements it is possible to estimate the distance between the device and BS and draw a circle where device could be located. With three different measurements from three BSs, it is possible to perform the estimation by drawing three circles. As it is illustrated in figure 3.3, the intersection of the three circles determines the possible location of the device. This kind of technique is also known as triangulation technique.

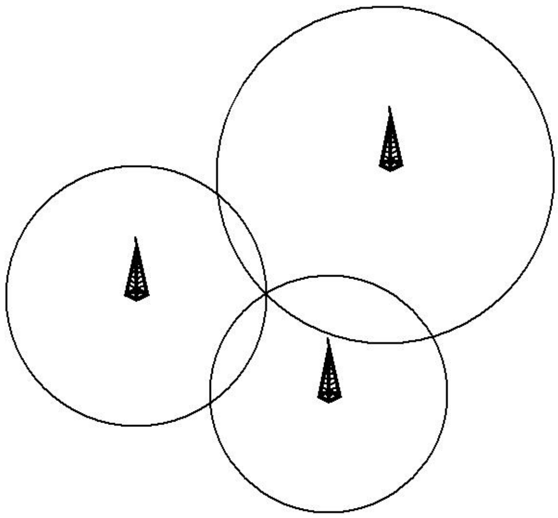

Figure 3.3: Location estimation using Signal Strength

The main problem of this technique is the variations in the received signal power due to obstacles between the device and the BSs. This variations are known as Shadowing and are produced by absorption, reflection, diffraction and scattering effects. The variation in the power of the received signal caused by obstacles is a random variable and can be modeled by a log-normal distribution [13].

The standard deviation of this distribution changes from one environment to another. In urban areas there are a lot of buildings or obstacles between the device and BS and then the standard deviation of shadowing is larger than in rural areas. Therefore, in this scenario the accuracy of the location is worse than in open areas.

3.2.3 Time of Arrival

This technique is based on time measurements. The principle of this method is similar to the triangulation and Signal Strength techniques. Knowing the time that the signal needs to arrive from the device to BS it is possible to estimate the distance between the device and BS using the propagation velocity and multiplying this by the time. Then, with three different BS it is possible to draw three circles and the intersection will denote the location of device.

The main problem of this technique is the multipath effect. In urban areas or in indoor scenarios where there are a lot of reflectors, due to multipath, the received signal consists of many impulses with different delays (see figure 3.4). In this kind of channel, the delay of the impulses is a random variable. The first impulse corresponds to a line of sight impulse and the rest of impulses correspond to multipath. The delay spread is defined as the time difference between the first impulse and the last received impulse and it is also a random variable that depends on the scenario.

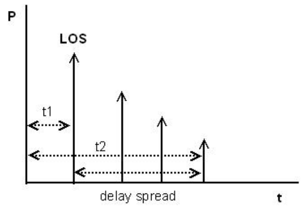

Figure 3.4: Signal Strenght

The accuracy of this technique depends on which is the delay spread of the channel. In dense urban areas this value is larger than in open rural areas due to the obstacles.

3.2.4 Time Difference of Arrival

This technique is also based in time measurements and it is similar to the Time of Arrival method. When the device and BS are not synchronized it is possible to use the difference in the time of arrival of two different BSs to estimate the location of the device. The estimation requires the difference between the times of arrival and the location coordinates of the two BSs. Supposing that there are two BS, BS1 with (x_1,y_1) coordinates, BS2 with (x_2,y_2) coordinates and that the coordinates of the device are (x,y) and the difference in time of arrival is Δt, it is possible to draw an hyperbola where device could be located. The Hyperbola equation can be found in (3.1).

$$C * \Delta t = \sqrt{(x - x_1)^2 + (y - y_1)^2} - \sqrt{(x - x_2)^2 + (y - y_2)^2} \qquad (3.1)$$

At least three BSs are required to perform this method as it is illustrated in figure 3.5. The area of intersection is again the possible location of device.

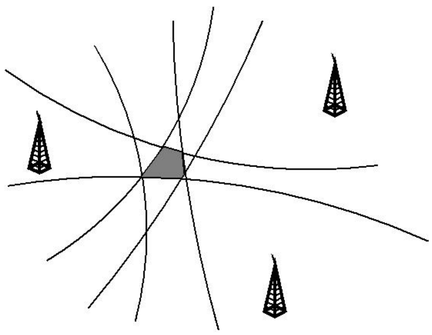

Figure 3.5: TDOA device location

The accuracy of this technique also depends on the multipath. As it has been explained before, in dense urban areas the delay spread is larger than in open areas, and hence the accuracy is worse. The estimated area where the device is located is larger in this case. The accuracy also depends on the number of BSs around the device. The higher the number of BSs, the better the accuracy. The more the measurements the smaller the location area.

3.2.5 Radiolocation Systems

3.2.5.1 GPS

Global Positioning System (GPS) is not exactly a technique but it is the most famous location system that uses a radiolocation techniques. GPS was created by US department of defence. Currently, it consists of 24 satellites (NAVSTAR constellation) that send two kinds of signals. The first signal is very precise and is only available for military applications. Second signal is less precise but is available for all world users equipped with a GPS hardware receiver able to decoded the GPS signal. The principle of this system is similar to the Signal strength technique. In this case, a GPS receiver, regardless of its position, can always find at least 4 satellites. The exactly position of these satellites is known by the receiver because the signal sent by the satellite has this information. The receiver measures the time that radio signal needs to arrive to the GPS receiver from the satellite. With this time it is able to calculate the distance from satellite to the receiver. With three satellites it is possible to draw 3 spheres and the intersection will be the exactly position of receiver. The forth satellite is required because the receiver clock and the Satellite clock, are not synchronized. With the fourth satellite the receiver can recalculate the position and solve the difference of times between receiver and satellite.

In the case of the civil user, the accuracy on the location is around 10m and it is worse than for military users. This system, like the Signal Strength technique, needs line-of-sight conditions. In dense urban areas where there are a lot of big buildings the GPS receiver can not see the satellites and it can not calculate the location of the device.

3.3 Proximity systems

3.3.1 Cell ID

This technique is the simplest of all the described in this master thesis. It is only available on cellular systems and it is the simplest because it does not need additional equipment or software in the network. The principle of this technique is to know which is BS to which the user is connected. With this technique, the information is reduced to the BS coordinates (x,y) and no calculation is required.

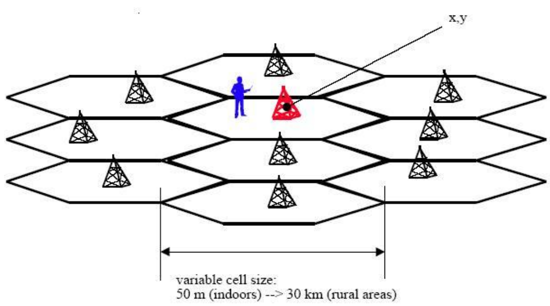

Figure 3.6: Cell ID [1]

Figure 3.6 shows that the main disadvantage of this technique is that its accuracy will depend on the sice of the cell. In rural areas, cells are larger than in urban areas, thus the accuracy will be worse than in urban areas. However, even in urban areas where the cells are smaller, the accuracy of the location is low.

3.4 Environment analysis

3.4.1 Fingerprinting

This technique is based a database that contains information about all the area covered by the BSs. This information is available through a server of the network. When there is a multipath propagation condition, there many signals are received with different power levels and delays. These group of signals are called fingerprint and they depend on the place where device is. Figure 3.7 describes the process. When a device wants to know its position, it needs to perform measurements of received signal that are sent to the BS. This information is sent to server where it is compared to the stored fingerprints. The server will then predict location of the device.

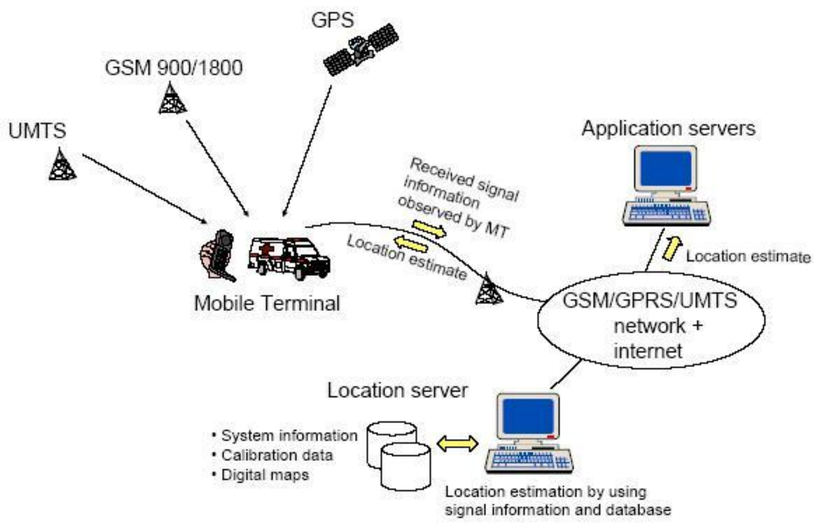

Figure 3.7: Fingerprinting [1]

This technique has good accuracy in urban areas. The accuracy of location depends directly on the database. In dynamic networks, the database has to be updated often since in urban areas, if the scenario changes, the fingerprints will be different and then the system will not be able to estimate the location of the device properly. To create the database it is necessary to take measurements in the whole covered area. The speed of the server to estimate the location is also critical because if it can not do it fast, the device could have changed its location.

3.5 Hybrid Techniques

There are some techniques that are combinations of other techniques that have been explained in previous sections. Combining these major techniques, it is possible to improve the accuracy of the methods.

3.5.1 GPS + Cell ID

GPS system using Time of Arrival technique can be used to calculate the location of device in open areas improving the accuracy. However, when device is in very dense areas where is not a line of sight it is difficult to calculate the location using only a GPS device. In this case the cells are smaller than in open areas and then Cell ID technique is more accurate than GPS. As a consequence, combining these two techniques it is possible to have good accuracy in open areas and in urban areas.

3.5.2 Cell ID + Cell Sector + TA

These three methods can also be combined to improve the accuracy. Firstly, with Cell ID technique it is possible to know which is the cell where the device is. Secondly, which directional antenna it is possible to know which is the sector of the cell. Finally, with TA technique we can draw a ring around the BS which will circle the location of the device.

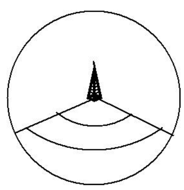

Figure 3.8: cell ID + Cell Sector + TA

3.6 Summary

Several location techniques exist, depending their accuracy on the scenario in all of them. In open areas as the user case 3 described in section 1.1, Radiolocation techniques such as triangulation are very accurate. However, in urban areas as the user case 1 in section 1.1, it is more difficult to accurately calculate the location with these techniques.

In the rest of cases, environment analysis techniques are very accurate in urban areas while they need a good database and a frequent update of it. When it is required a high accuracy in both urban and open areas, the hybrid techniques are a good choice. However their implementation may be more expensive.

All things considered, the best choice from the different location techniques depends on the required accuracy and the scenario where device is situated.

Part III

Design

Chapter 4

Redefinition of the problem

As it has been explained before in chapter 2, the Context Aware Service Discovery (CASD) is a technique that can find the best service for the user in the network. In the CASD there are two important modules: the Service Ranker (SR) and the Context Management Module (CMM). The SR is the part of the Service Discovery (SD) which executes the algorithms to find the best service. The CMM is the part of the SD responsible for getting the context information such as location of the device and updating it.

Several localization techniques exist, and depending on which one is used by the Location Platform (LP) and which is the scenario of the device, the accuracy of location may differ. The aim of this project is to design and implement the communication interface block between the LP and the CASD considering the exact information the service discovery needs, and the information the different localization techniques can obtain. According to this, if the CMM of the CASD, using the designed location interface block, can get the location information correctly, the SR would be able to sort all the services and then make the right choice.

As mentioned in chapter 2, the CASD can use different legacy discovery protocols to communicate with external devices and services. Three of them are described in chapter 2: Modified UPnP, INS/twine and Modified BT. The implementation of the interface will use Modified UPnP to communicate with the CASD. The main reason is that the UPnP discovery protocol can be used by the CASD to communicate with the IP devices that there are at cluster level. Assuming that the LP is situated in each cluster of the Network and it is an IP device, the UPnP is the best choice to communicate with the CASD. Furthermore this is the architecture the university has been working with before in this area.

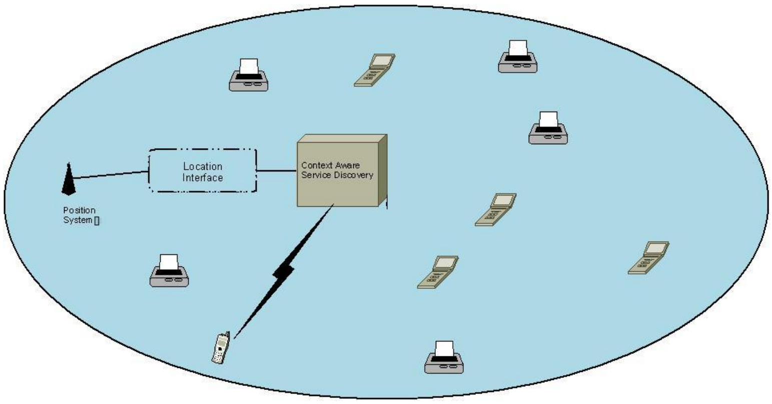

Figure 4.1: Scenario of cluster level

The analysis of the Location Interface Block (LIB) is going to be performed considering the case the CASD chooses the nearest service to the user that has triggered the CASD. In the latest version of the CASD, the algorithm for the selection does not use the location context information from the SR yet. So it is going to be necessary also to design and to implement the SR rules in order to choose the nearest service with the received location information from the LIB.

Furthermore the scenario that is going to be considered for the design and the implementations of the interface is a discovery cluster level. In the picture 4.1 there a local discovery is represented. There are different devices or services in the same cluster and one user can request for one of the services that are available in the cluster and then the service discovery has to be able to offer him the nearest service.

Figure 4.2 shows a messages diagram that explains the communication steps between the CASD and LP using the LIB:

1. Assuming that the CMM is subscribed to the location platform in its cluster, every time that the CMM needs to store or update the location context information of one device, it sends location request messages in the UPnP control step messages.

2. The LIB sends the request to the LP. The location platform uses the localization techniques to estimate the location of the device and then

it sends the location information to the LIB.

3. The LIB process the location information and evaluate the additional information that the CASD needs.

4. The LIB sends the responds messages with the right necessary information to the CASD.

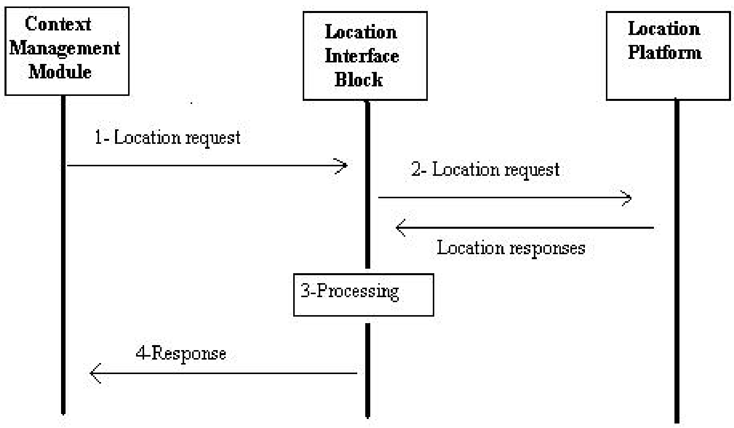

Figure 4.2: Problem definition diagram

The main task of the Location Interface Block is the third step, the processing. The Location Platform could be any position system using any of the localization techniques that are described in chapter 3. The position system could provide information about the location accuracy. Therefore, it is necessary to consider two cases that the Interface has to solve in the design of the processing step:

- The Position System provides information about the accuracy of the location estimations. Each Position System provides different types of information about the accuracy. The Location Interface Block should define the accuracy information format for the Context Aware Service Discovery always receive the same kind of information regardless of the Position System that is used in the cluster.

- The Position System does not provide any information about the accuracy of the location estimations. In this case, the Location Interface should estimate the accuracy of the estimation taking into account which is the localization technique the Position System is based on and which is the environment type of the cluster.

Once the system has been designed and implemented, other important task would consist on analyzing all the system performance. In this task the first measurement will be the number of correct selections for the local discovery by the CASD in a scenario like the depicted in figure 4.1 at cluster level. Two other important and necessary measurements of the system performance are the generated delay and the generated traffic due to use the location context in the Service Discovery.

Chapter 5

Design of the interface

5.1 Requirements to the interface

In order to analyze the requirements for the design of the Location Interface Block (LIB), the first step is to understand the information that the Location Platform (LP) provides and which information the Context Aware Service Discovery (CASD) needs.

5.1.1 Location platform

There are several localization techniques able to get the location of the device with different grades of accuracy depending also on which is the scenario of the device. The definition of the location accuracy is how close to the real location the estimate of the localization technique is. All the localization techniques estimate the location of the device with a spatial coordinates of one point (x,y) with a range of meters around it where device could be. The localization techniques actually estimates a region or area of the space where the device could be. Depending how the size of this area is, the accuracy changes. The smaller the area is, the better the accuracy. However, some Position Systems might not provide the accuracy of the coordinates that they have estimated.

5.1.2 Context Aware Service Discovery

The CASD needs to store the location information of the device every time the Context Management Module (CMM) requests it. In the scenario that has been described before, the location information basically could be the spatial coordinates (x, y) of the devices or services considering a two dimensional space. However, the accuracy of every estimated location coordinates is also a valuable information in order to choose the nearest service with the highest probability. For example if there is one service at 100 meters distance form the user and ±50 metres accuracy, and there is other service at 110 metres with ±10 metres accuracy, the best service with higher probability would be the second one. This means the accuracy information should also be received by the CASD.

Other information that has to be considered is the axes reference of the location coordinates. In a global discovery in all clusters of the interconnected network it is necessary to know if the coordinates are global or local coordinates, and in the case of local coordinates, which is the axes reference of each coordinate. However, in the scenario described in figure 4.1 of section 4, the location coordinates are going to be considered local coordinates. Furthermore, it will be assumed that the Position System is always using the same axes coordinates, so that all the location estimations have with the same axes reference. This means it will not be necessary to specify where the location axes reference is to calculate the nearest service at the cluster level.

5.1.3 Requirements

After analyzing each part separately, there are some requirements that the design of the Location Interface Block has to fulfill for the system to work correctly:

- **R1 Response time:** The first requirement of the Location Interface Block is that the CASD has to receive always one answer. In the case the LP can not estimate the location of the device or in the case that it spends too much time, the interface has to reply to the CASD notifying that there is no location information available for the requested device in this moment.

- **R2 Accuracy Information has to be provided:** The Context Aware Service Discovery should always know the accuracy of the location coordinates that it receives in the replies and it has to be received always in the same format in order to be understandable by the CASD.

- **R2.1:** *Accuracy estimation.* In the case the LP can not provide the accuracy of the location coordinates, the LIB has to estimate this accuracy and append it in the responds message taking into account the localization technique that is being used by the LP and the information about the cluster's environment.

- **R2.2:** *Accuracy information format transformation.* In the case the LP can provide information on the accuracy of the estimated coordinates, the Location Interface has to transform the format of the accuracy to a standard format, in order to make it understandable by the CASD and make it the same for all the Position Systems.

- **R3 Identification of the location information:** The location coordinates have to be related to the device that has this location information. In all the messages that contain the location information it is necessary to add the device identification. This is necessary in the case there are more than one service in the cluster and the Context management module requests at the same time for the location of context information of all the services that are available in the cluster, the Service Discovery is going to receive a location message per service.

- **R4 Coordinates axes information:** The CASD has to know if the received location coordinates are local coordinates corresponding to the cluster area or are global coordinates. As it is has been explained earlier, this project focuses at the cluster level, so the service discovery is local. However, this requirement is proposed for a future implementation for global discovery at SMN (Service Management Node) network level.

5.2 Structure of the Location Interface Block

As we can see in figure 5.1 the Location Interface Block has been designed split in different important modules. The **Context Aware Service Discovery Interface Module** and the **Location Platform Interface Module** are the parts of the interface that take care of receiving and sending messages between the two systems: the Context Aware Service Discovery and the Location Platform.

There are three important modules: the **Interface Management Module**, the **Accuracy Estimation Module**, and the **Accuracy Weighting Factor Transformation Module**. The Interface Management Module is responsible for the management of the Location Interface. The Accuracy Weighting Factor Transformation Module is responsible for the calculations of the Accuracy Weighting Factor variable and the Accuracy Estimation Module is responsible for the estimations the Accuracy Weighting Factor. The **Accuracy Weighting Factor** is a variable that is going to be described clearly in the next sections and it is used to define the location accuracy with the same terms regardless which is the position system that is used in the cluster. It is defined to make understandable for the CASD the location accuracy information.

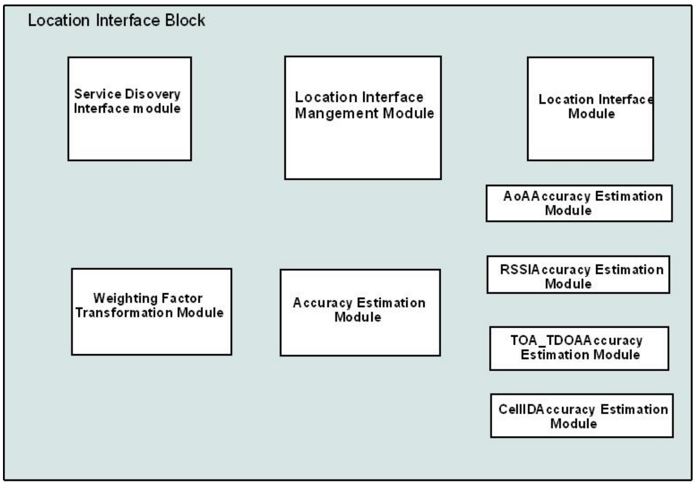

Figure 5.1: Location Interface Structure

There are four more modules that are responsible for the calculations required to obtain each estimation for each localization technique: the **Signal Strength Accuracy Estimation Module**, the **Angle of Arrival Accuracy Estimation Module**, the **Time Of Arrival and Time Different Of Arrival Accuracy Estimation Module**, and the **Cell ID Accuracy Estimation Module**. The Fingerprinting localization technique has not been considered for the estimations of the accuracy due to its very strongly dependence on the environment where the database has been obtained. The Hybrid techniques has not been considered either since there is a combination of this basic localization techniques. In the following sections all these modules are explained, inside of these different modules, there are also defined different setup variables in the Location Interface for the good working of the system. These variables define information that is necessary for the system and that have to be initialized in the configuration of the system. They are described in the description section of each module where there are situated in and in section 5.2.7.

5.2.1 Interface Management Module

The Interface Management Module (IMM) is the main part of the interface and it is responsible for the management of the communications between the CASD and the LP.

5.2.1.1 Case 1: There is no location information available

When the CASD requests the location of a service, the request is received by the CASD interface module and then the IMM sends this request to the LP Interface. After this, it waits for the response from the LP Interface. In case there is no response from the LP Interface, the IMM creates the message to signal the CASD that there is no information available regarding the location of the requested service.

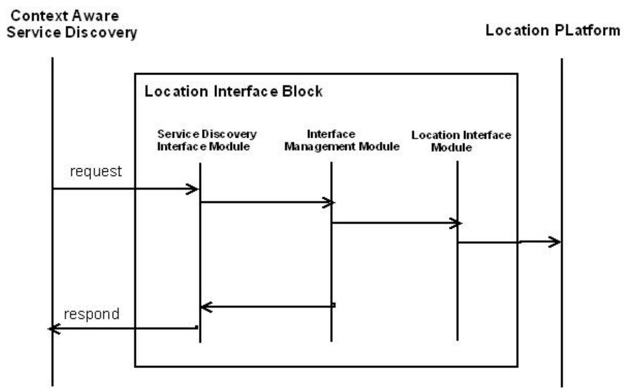

Figure 5.2: There is not responds from the Location Platform

5.2.1.2 Case 2: There is location information available

In the other hand when the location information is available and it is received in the LP Interface, it is analyzed by the IMM. This module looks which is the information that has been received, i.e. the spatial coordinates (x,y) of the position of the device and potentially the information about the accuracy of the estimated coordinates. Depending which is the Position System or the localization technique that has been used, the accuracy information that the Location Platform sends could be different. In order to send always the same information to the CASD, the IMM defines the accuracy of the position coordinates with one variable that is going to be the same for all the position systems regardless of the localization technique that is used.

In equation (5.1) the **Accuracy Weighting Factor** is defined as the inverse of the area of the region where the device could be located. The accuracy weighting factor is always in the range of [0, 1]. When the estimated accuracy of the coordinates is very good the weighting factor is close to 1 and when the accuracy is very poor the value of the weighting factor is near to 0. The γ is the decay exponent and it is a setup variable whose value depends on the cluster scenario.

$$WeightingFactor = \frac{1}{(Area+1)^{\gamma}} \ \forall \text{ A } \epsilon \ [0, \infty] \tag{5.1}$$

- **Decay Exponent:** This setup variable specifies the decay of the weighting factor variable function and depends on the area covered by the cluster. The CASD could not consider services with an accuracy below a threshold, for instance 0.5. In this case, the value for the Decay Exponent defines the area that makes the Accuracy Weighting Factor equal to 0.5. In the following equation (5.2) the the Decay Exponent is defined.

$$\gamma = \frac{\log(\frac{1}{w})}{\log(A+1)} \tag{5.2}$$

  As a practical example, if a cluster covers an area of $45m^2$ and if the CASD does not consider the services with an estimated location's area lower than $15m^2$, the decay exponent is equal to 1/4. This area is known as the *Acceptance Area*.

When in the location information, there is information on the accuracy sent by the LP, such information is sent by the IMM to the **Accuracy Weighting Factor Transformation Module** as it is illustrated in figure 5.4. The latter will calculate the Accuracy Weighting Factor variable with this information. In case the LP does not provide any information on the accuracy (see figure 5.4), the IMM asks for the accuracy of the coordinates to the **Accuracy Estimation Module** which has to estimate this accuracy taking into account the localization technique that the position system uses and the setup information of the environment. Once the Accuracy Weighting Factor has been calculated or estimated, the IMM sends the location response to the CASD interface that communicates with it.

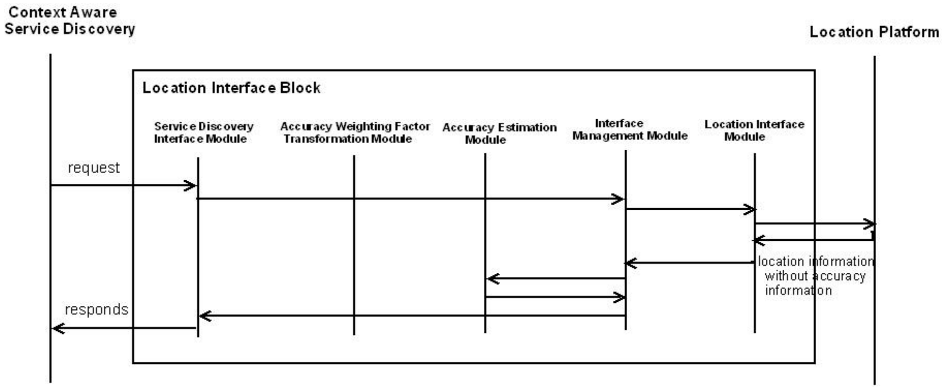

Figure 5.3: There is location information available without accuracy information

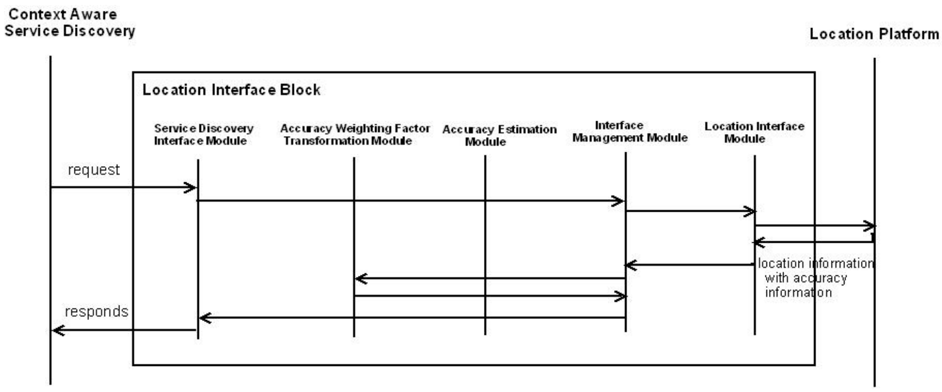

Figure 5.4: There is location information available with accuracy information

5.2.2 Accuracy Estimation Module

As it has been explained earlier, when the LP cannot provide the accuracy of the coordinates, it is necessary to estimate it. The IMM requests the Accuracy Estimation Module the Weighting Factor of the estimated coordinates by sending the setup value of the Decay Exponent. The accuracy of the coordinates depends on which is the localization technique that is used by the LP and which are the propagation conditions of the current cluster environment. There is an estimation module for each localization technique. The Accuracy Estimation Module is the responsible to query these modules considering some setup information of the system that it is necessary to be initialized beforehand. The setup variables required by the Accuracy Estimation Module listed below.

- **Localization Technique:** This setup value specifies the localization technique that is used by the LP to estimate the coordinates.

- **Scenario Type:** This setup value specifies the kind of cluster environment. For the estimation of the accuracy, the types of environments have been split into two different scenarios considering the propagation conditions, Urban scenario and Rural scenario.

Once the Accuracy Estimation Module knows the Localization Technique it is able to chose between the different modules that determine the Accuracy Weighting Factor. To do so, it sends the Scenario Type and the Decay Exponent values. Due to the strongly dependence of the accuracy on the scenario, each estimation module could have its own setup information that will be described in the description section of each module. If it is not possible to define the value of these variables because there is no information about them, all the estimation modules are able to estimate the Accuracy Weighting Factor of the coordinates with the defined setup values in the Accuracy Estimation Module. In this case, each estimation module uses a general accuracy studio that has been made in the two scenario environments, urban or indoor environment and rural or open environment.

5.2.3 Angle of Arrival Accuracy Estimation Module

The accuracy of the location in this technique is calculated using (3.2.1), described in chapter 3. This equation provides the area of the region where the device is situated using the angles of arrival, the distance between the antennas and the azimuth spread of the two antennas. The azimuth spread is the error in the angles of arrival in the two directional antennas.

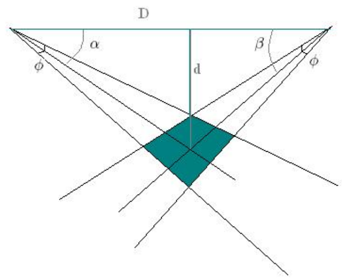

Figure 5.5: Area of the location's region using AoA technique

$$A = \begin{cases} \left(\frac{D^2 sin^2(\phi) sin(\beta+\phi/2) sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi) sin^2(\alpha+\beta)}\right) + \left(\frac{D^2 sin^2(\phi)}{sin^2(\alpha+\beta-\phi)}\right) & \\ * \left(\frac{sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi)} - \frac{sin(\beta+\phi/2) sin(\phi)}{sin(180-\alpha)-\beta-\phi) sin(\phi+\beta)}\right) & \\ * \left(\frac{sin(\beta+\phi/2)}{sin(180-\alpha-\beta-\phi)} - \frac{sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi)} \frac{sin(\phi)}{sin(\alpha+\beta)}\right) & \\ *(sin(180 - \alpha - \beta + \phi)) & \alpha > 0 \ , \ \beta > 0, \ \phi < \alpha + \beta \\ \frac{D^2 sin(\beta+\phi/2) sin(\alpha+\phi/2)}{2 sin(180-\alpha-\beta-\phi)} & \alpha > 0, \ \beta > 0, \ \phi = \alpha + \beta \\ \frac{D^2 sin(\beta+\phi/2) sin(\alpha+\phi/2)}{2 sin(180-\alpha-\beta-\phi)} + \frac{D^2 sin(\phi/2-\alpha) sin(\phi/2-\beta)}{2 sin(180+\alpha+\beta-\phi)} & \alpha > 0, \ \beta > 0, \ \phi > \alpha + \beta \\ \frac{D^2 \tan(\phi/2)}{2} & \alpha = 0 \ , \ \beta = 0 \ , \ \forall\phi \end{cases}$$

As depicted in figure 5.5, the area of the region where the device is located depends on the values of α and β, the distance d between the antennas and the azimuth spread ϕ of the two antennas. Figure 5.6 represents the variation of this area (in m^2) with the azimuth spread for different values of α and β. The azimuth spread is a random variable with different distribution function depending on which is the propagation environment. In [11] and [12] empirical distribution function studies of the azimuth spread can be found for urban and rural environments.

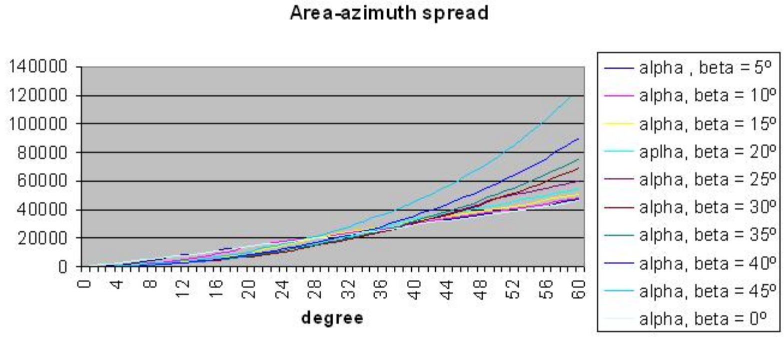

Figure 5.6: Area variation with the azimuth spread

5.2.3.1 Urban Environment

Since the area of the location's region strongly depends on the distance between the antennas, and due to this, also on which is the position of the device inside the covered area, the coordinates of the two antennas have been defined as two new setup variables: $BScoordinates_1$ and $BScoordinates_2$. Once these coordinates are known, by using the estimated coordinates of the device it is possible to determine the distance d between the antennas (5.3) and the angles of arrival α and β (5.6).

$$D = \sqrt{(x_{BS2} - x_{BS1})^2 + (y_{BS2} - y_{BS1})^2} \tag{5.3}$$

$$v_1 = (x_{BS2} - x_{BS1}, y_{BS2} - y_{BS1}) \tag{5.4}$$

$$v_2 = (\hat{x}_{Device} - x_{BS1}, \hat{y}_{Device} - y_{BS1}) \tag{5.5}$$

$$\alpha = \arccos(\frac{x_{v1} * x_{v2} + y_{v1} * y_{v2}}{|v_1|\,|v_2|}) \tag{5.6}$$

The typical value for the azimuth spread in urban environment is around 10, while in rural environment is around 1,8 [11],[12]. With the calculated angles, the distance between antennas and with the typical value for the current scenario, equation (5.2.3) can be used to calculate the area of the location region, and hence, the Accuracy Weighting Factor.

In case that the interface does not know the value of $BScoordinates_1$ and $BScoordinates_2$ configuration parameters, it can calculate the Accuracy Weighting Factor by knowing the Scenario Type setup parameter that defined in the Accuracy Estimation Module and using the results of a general study made in urban environment.

The angles of arrival of the two antennas depend on the situation of the device in the area covered by the two antennas. The general estimation is calculated considering the worst case in this environment, when the area of the location region is the largest, considering that the device is using a cellular network and it uses the nearest two antennas to estimate the location. As it is illustrated in figure 5.7, the area of the location region will be the largest when the angles of arrival are equal to 0. In urban areas, the size of the cells is small, being the cell radius around 200m [14]. Therefore, the distance between the two antennas is the 400m.

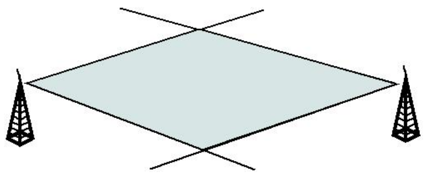

Figure 5.7: The location accuracy worst case

Considering these assumptions and the worst case, the general estimated area of the location region for a general case in urban environment is around $7000m^2$ using equation (3.2.1).

5.2.3.2 Rural Environment

The typical value of the azimuth spread in a rural environment is around 1.8. By calculating the angles of arrival and the distance between the antennas at the same way as in the urban environment, it is possible to estimate the area of the location's region using equation (5.2.3).

In case the Location Interface does not know the setup values of the coordinates of the antennas then it estimates the area using the results of a general study made in a rural environment.

In a rural environment, the general accuracy estimation of the location is calculated in the same way as in a urban environment, i.e. considering the worst case. However, in this environment the cell size is larger than in urban areas. The cell radius is around $15km$ in this case, so the distance between the antennas is $30km$. In this environment the worst case also corresponds to the case in which the angles of arrival are 0. With these assumptions the estimated area for a general case in rural environment is around $7069165m^2$ using equation (3.2.1). The Accuracy Weight Factor can be calculated using this area as it has been defined.

5.2.4 Signal Strength Accuracy Estimation Module

As it has been explained in chapter 3, the accuracy of this technique depends on the variations of the received signal power due to shadowing. As it is explained in [13], the shadowing can be modeled as a random variable with a log-normal distribution with different standard deviations depending on which is the environment of the device. The variations in the signal level makes the estimated distance between the device and the BS vary. To calculate such variations it is necessary to calculate the Path-Loss with the simplified Path-Loss model. In equation (5.7), P_r is the power of the received signal, and P_t is the power of the transmitted signal.

$$P_r[\mathrm{dBm}] = P_t[\mathrm{dBm}] + K[\mathrm{dB}] + 10 * \gamma * \log(\frac{d_0}{d}) \tag{5.7}$$

$$K[\mathrm{dB}] = 20log_{10}(\frac{\lambda}{4\pi d_0}) \tag{5.8}$$

Figure 5.8 depicts the path loss line and the variations in the Pr/Pt due to the effects that shadowing produces in the estimated distance. Such variations are defined inside the interval $[\log x - \Delta log(x), \log x + \Delta log(x)]$. In equation (5.7), γ is the path loss exponent and its values depends on which is the environment, while d_0 is the reference distance to the far field antenna and also depends on the type of environment. As it has been explained before, Pr/Pt is a random variable with a log normal distribution. With the decay (5.9) of the path loss line and the standard deviation of the Pr/Pt variable, it is possible to calculate $\Delta log(x)$ (5.10) of the estimations error interval.

$$\frac{\Delta \frac{Pr}{Pt}}{\Delta log(x)} = -10 * \gamma \tag{5.9}$$

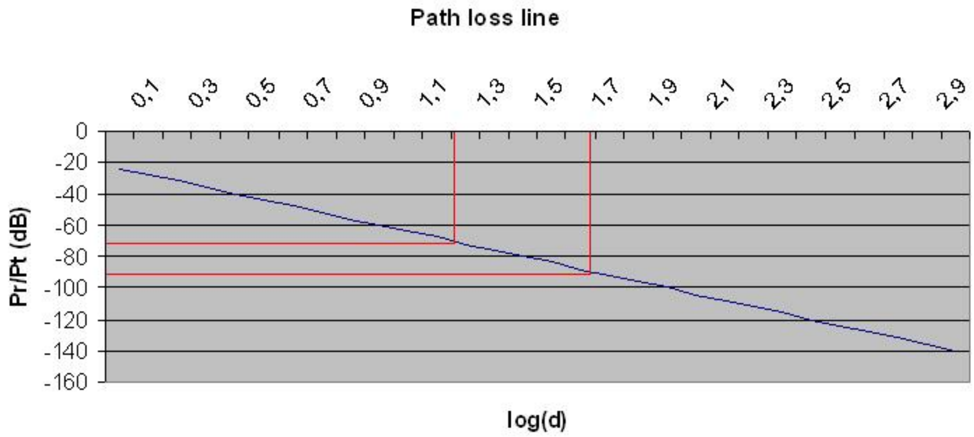

Figure 5.8: Path loss line

$$-10 * \gamma * Estandarddeviation = \Delta log(x) \tag{5.10}$$

The value of the path-loss exponent in an open environment is near to 2, while in a urban environment it is near to 4 [13]. The standard deviation values can be in the range of 4dB to 13 dB depending on the kind of environment [13]. Figure 5.6 represents the variations in the estimated $\Delta \log(x)$ for different values of the standard deviation with the path-loss value for a urban environment and for a rural one.

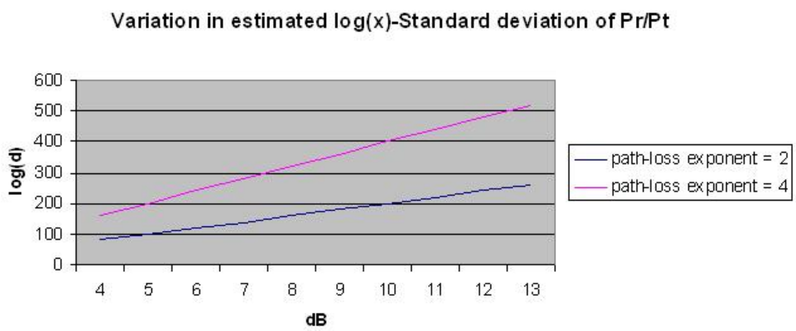

Figure 5.9: $\log(x)$-Standard Deviation

5.2.4.1 Urban Environment

Equation (5.9) depends on which is the path loss exponent. This variable is near to 4 in urban environments. Since the standard deviation of the Pr/Pt random variable is around 13dB in urban environment [13], it is possible to calculate $\Delta log(x)$ as

$$\frac{1}{-40} * 13 = \Delta log(x) \tag{5.11}$$

However, in order to know the estimation error interval $[X-\Delta X, X+\Delta X]$ it is also necessary to know, in each coordinates estimation, the estimated distance between the antennas and the device. A new setup variable is therefore added to the module with the coordinates of the antennas that are used by the LP to estimate the device's position: *BScoordinates*. Knowing the coordinates of one of the antennas and the estimated coordinates of the position of the device it is possible to obtain the estimated distance between the device and the antenna (5.12).

$$estimateddistance = \sqrt{(\hat{x}_{device} - x_{BS})^2 + (\hat{y}_{device} - y_{BS})^2} \tag{5.12}$$

To estimate the Accuracy Weighting Factor we need to calculate the area defended by the estimation error due to the shadowing effect. As it is illustrated in the figure, the location region is one ellipse. Nevertheless, it is going to be considered as a circle with the estimation's error equal to the diameter ΔX. In case the coordinates of all the antennas that are used are known in the position estimation, the interface uses the estimated distance form the nearest antenna due to the fact the estimation's error is going to be smaller and hence the location region is smaller too.

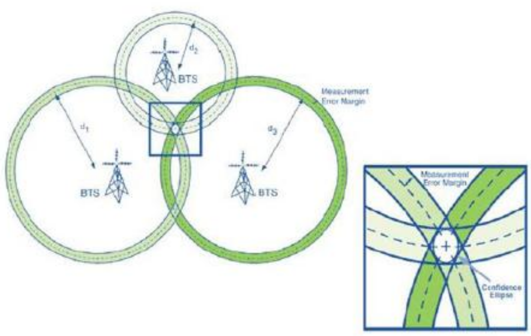

Figure 5.10: RSSI Location's Region [2]

To calculate the estimation's error ΔX, knowing the estimations error interval in log scale, it is necessary to perform a transformation (5.14).

$$EstimationError = [10^{\log(x)-\Delta log(x)}; 10^{\log(x)+\Delta\log(x)}] \tag{5.13}$$

$$\Delta X = 10^{\log(x)+\Delta log(x)} - 10^{\log(x)-\Delta\log(x)} \tag{5.14}$$

With this last step it is possible to calculate the area of the location region the using the diameter (5.14) and then calculate the Accuracy Weighting Factor as it has been defined in the Accuracy Estimation Module.

In case the interface does not know the *BScoordinates* setup parameter, it could consider that the reference of coordinates in the cluster are the coordinates of the antennas that are used to estimate the position of the device.

5.2.4.2 Rural Environment

In the case of rural environment the path loss exponent typically value is around 2 and the standard deviation of the Pr/Pt random variable is around 4dB. So with these values it is possible to calculate $\Delta logx$ in rural environments.

As in the urban environment case, it is necessary to know the estimated distance between one of the antennas and the device using the setup value *BScoodirnates*. In case the interface does not know this value it can also consider that the reference of coordinates is one of the antennas. To calculate the estimations error due to shadowing it is also necessary to make again the transformation like in the equation (5.14). Finally with this calculation it is possible to estimate the area and then the Accuracy Weighting Factor as it has been defined.

5.2.5 Time of Arrival and Time Difference of Arrival Accuracy Estimation Module

These two techniques use time measurements to estimate the location of the device. The accuracy of the location estimations depends on the multipath effects. As it has been explained in chapter 3, due to multipath, there is a delay in the received signal. This delay is a random variable and it depends on which is the environment of the device. Due to the delay there is a variation in the estimated distance between the device and the BS. Estimating the distance variations the area of the location region has been calculated.

5.2.5.1 Urban Environment

The *delay spread* is the time difference between the line of sight signal, and the next received signal due to multipath effects. Using the delay spread time it is possible to calculate the variation in the distance estimation (Δt)c. The value of the delay spread in urban areas is around 15 microseconds [13], so the distance variation is around 4500m. The location region has been approximated to one circle with a diammeter of 4500m. Therefore, the estimated area of the location region is around $15904312m^2$.

5.2.5.2 Rural Environment

The *delay spread* in rural environments is smaller than in urban environments, being around 200 nanoseconds. This means the variations of the estimated distance due to the multipath is around 60 m. In this case, the location region has also been approximated to a circle with a diameter of 60m. The estimated area of the location region in rural environment is around $2827m^2$.

5.2.6 Cell ID Accuracy Estimation Module

In this technique, the estimation of the accuracy is based on calculating the area of the kind of cell the device is situated in and then estimating the Accuracy Weight Factor. So the accuracy of this technique strongly depends on the size of the cell that is used by the device. A setup parameter is defined with the value of the cell radius in the cluster: *Cellradio*. In case the interface does not know this value it can consider the typical cell sizes for the two types of environments.

5.2.6.1 Urban Environment

In a urban environment the size of the cells are smaller than in a rural environment. In [14], the urban micro cell radius is around 200m. Assuming hexagonal cells, their area is around $103923m^2$.

5.2.6.2 Rural Environment

In a rural environment, the cell radius of the macro cell is around 15 km [14]. The area of the cell with this radio is around $584567147m^2$.

5.2.7 Accuracy Weighting Factor Transformation Module

When the LP sends information about the accuracy of the estimated coordinates it is necessary to modify it and make it understandable for the CASD. This means that, with this information, it is necessary to calculate the Accuracy Weighting Factor as it has been defined in the Interface Management Module (5.1).

The only problem is that the information about the accuracy that each position systems provides is different and specific to the position system that is used. For this reason, a setup function is defined inside this module called Weighting Factor Transformation Function. This function has to be defined in the system configuration step according to the accuracy information that the Position System can provide in order to successfully calculate the Accuracy Weighting Factor. The algorithm of this function is specific to the positioning system that is used by the CASD and to the available information to calculate the Weighting Factor. The Weighting factor is always defined in the same way, the value of the Decay Exponent setup variable is the only thing that changes, so the Weighting Factor Transformation Function always uses the Decay Exponent (γ) argument among other arguments that will depend on the position system type. Therefore, the algorithm for the Accuracy Weighting Factor Transformation Module consists of an equation with the decay exponent variable and the accuracy parameters ($\alpha, \beta, ...$) the different position system can provide.

$$AccurcyWeightingFacto = f(\gamma, \alpha...) \tag{5.15}$$

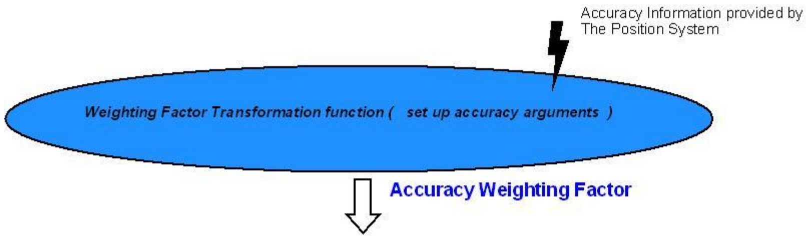

Figure 5.11: Weighting Factor Transformation Function

5.3 Summary of setup information

As it has been explained inside of the different modules of the Location Interface structure, there the different methods and modules require the introduction of setup variables and parameters in order to work properly. In the table below includes all the previously mentioned setup parameters. The blue setup variables are essential since the Location Interface can not work without them. The rest of the variables are not completely necessary but they represent additional information that can improve the accuracy of the estimation of each location coordinates.

Interface Management Module	Decay Exponent
Accuracy Estimation Module	Scenario Type, Localization Technique
AoAAccuracy Estimation Module	$BScoordinates_1$, $BScoordinates_2$
RSSIAccuracy Estimation Module	BScoordinates
TOA_TDOAAccuracy Estimation Module	-
CellIDAccuracy Estimation Module	Cell radio
AWeightingFactorTransformation Module	AWeightingFactorTransformationFunction

Set up information table of the Location Interface

5.4 Communication Messages Diagram

When the CASD requests the location information of one device or service to the Location Interface Block, the following steps occur during the communication procedure:

- **Step1:** The Context Aware Service Discovery sends the request in the control step of the UPnP architecture. In this request it sends the identification of the device which it wants to know the location information. The variable that stores the identification of the device is: IDdevice. This message is received by the CASD Interface Module and it is sent by the Interface Management Module to the Location Platform Interface in for the Location Platform to receive the request with the IDdevice variable. (Figure 5.12)

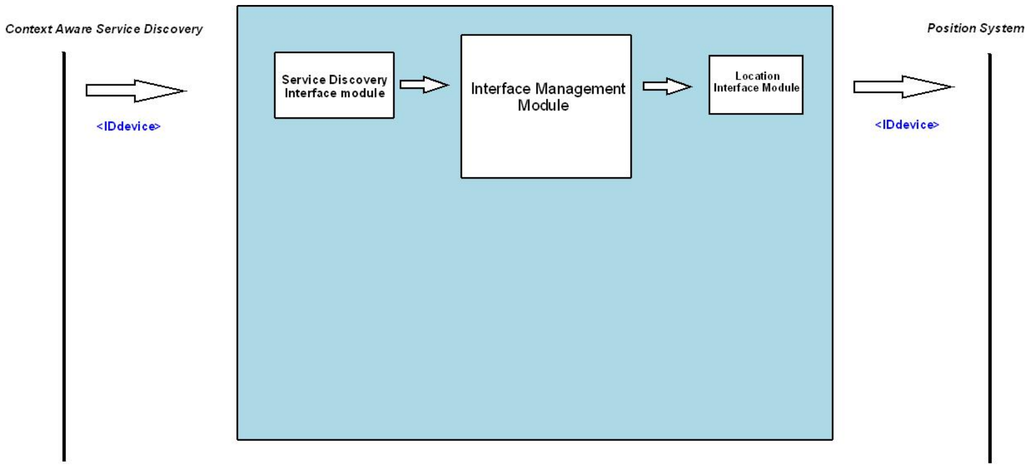

Figure 5.12: Step 1 of the communications message diagram requesting

When the request has been sent, the Interface Management Module waits for the response from the Location Platform. If there is no response or the location information is not available, the Interface Management Module sends a message to the CASD signaling that the information is not available. The response messages (Figure 5.13) include the following variables:

IDdevice: This variable represents the identification number of the device that has been requested and whose location information is not available.

Validity: This variable is equal to 0 when the location is not available or the location context information can not be calculated due to an error in the system. It is equal to 1 when the location information has been successfully calculated.

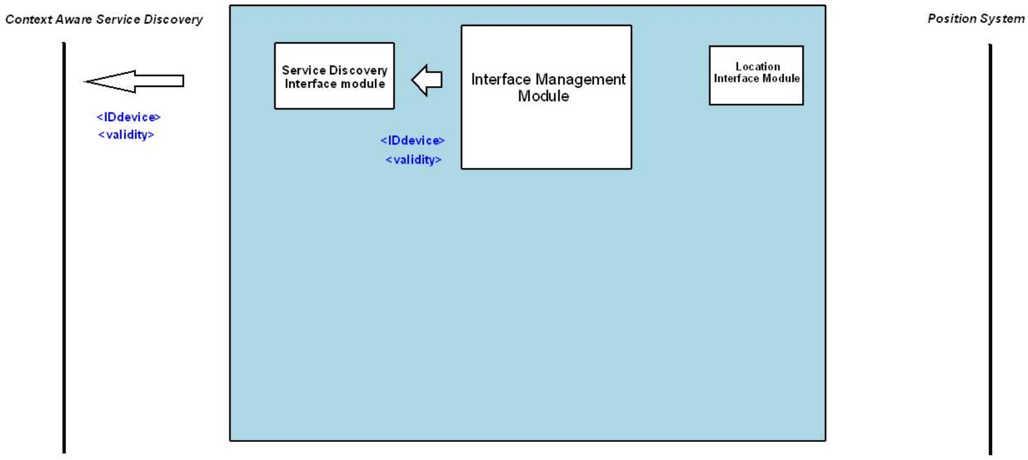

Figure 5.13: Step 1 of the communications message diagram responding

- **Step2:** The Location Platform estimates the position of the device that has been requested, and then it sends a message with the location information. The Location Platform Interface receives the message and then it sends to the Interface Management Module which is going to analyze the information. The responds message (Figure 5.14) of the Location Platform has the following variables:

  (x,y): The spatial coordinates of the estimated position.

  AccuracyInformation: The accuracy variable of the position's estimation, this variable depends on which is the position system and depends on if it has any accuracy information about the estimation. So in the case that there is not information about that then this variable is not going to be in the message.

  IDdevice: This variable as it has been explained in the request is the identification of the device.

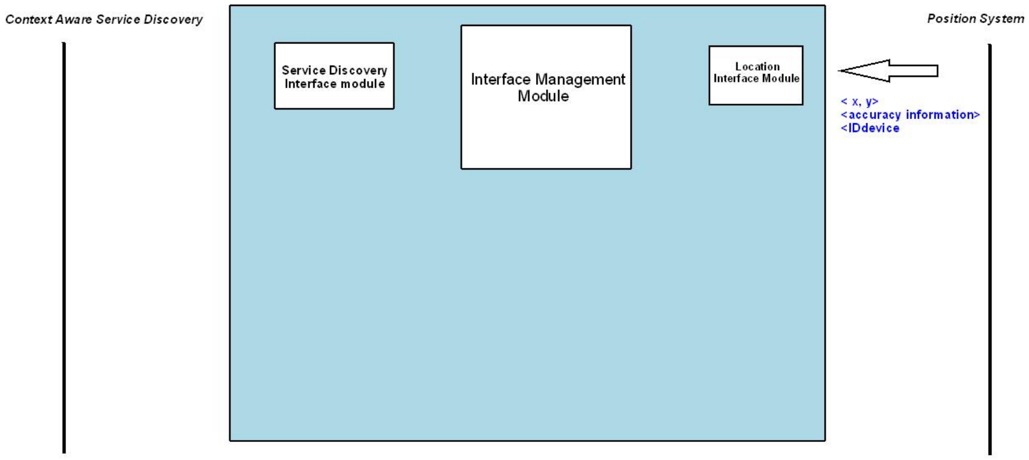

Figure 5.14: Step 2 of the communication messages diagram

- **Step3:** In this step there are two possibilities and they depend on whether the response message that Location Platform has sent includes information regarding the accuracy or not:

  Case 1: If there is accuracy information in the response message, the Interface Management Module sends this information to the Weighting Factor Transformation Module with the Decay Exponent set up value, in order to calculate the Accuracy Weighting Factor variable. This module will then calculate it and answer with the Weighting Factor (see figure 5.15).

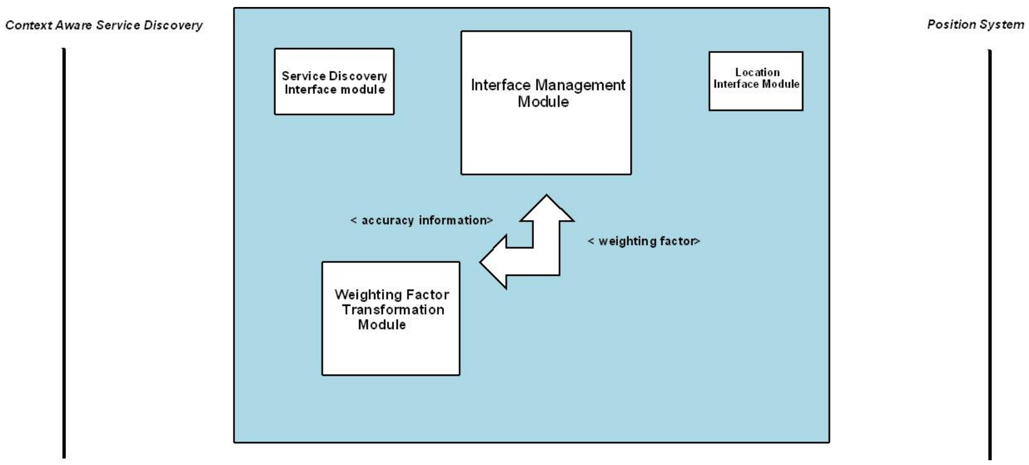

Figure 5.15: Step 3 and first case of the communications messages diagram

Case 2: If there is no information available regarding accuracy, the

Interface Management Module requests an estimation of the Accuracy Weighting Factor to the Accuracy Estimation Module sending the estimated coordinates of the device and the Decay Exponent setup value. The Accuracy Estimation Module will request the estimation to the Estimation Module that corresponds with the value of the localization technique. In the request it sends the kind of scenario, the Decay exponent and the estimated coordinates of the device.

When the Accuracy Weighting Factor is calculated, it is sent to the Accuracy Estimation Module and then it sent to the Interface Management Module (see figure 5.16).

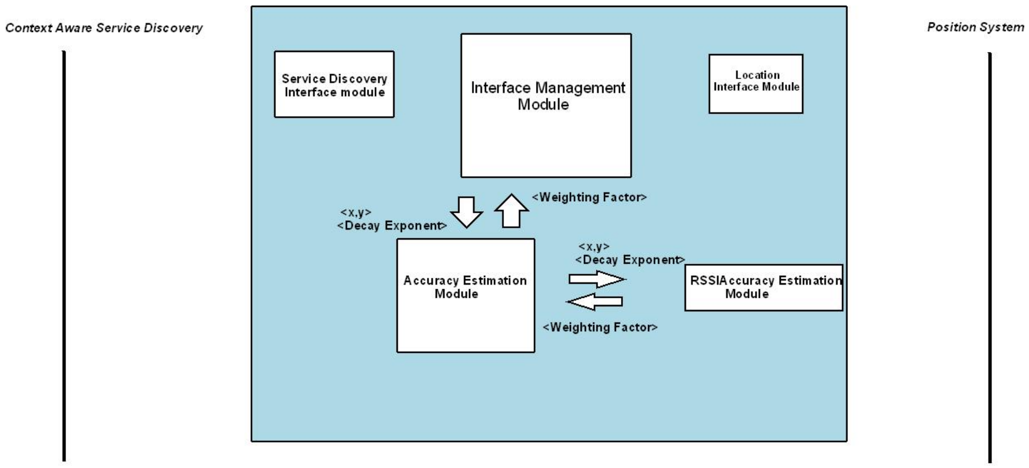

Figure 5.16: Step 2 second case of the communication messages diagram

- **Step4:** Finally, when all the location information has been calculated and processed by the Location Interface, the Location Management Module creates the response and to be sent to the CASD. The message (see figure 5.17) includes the following information:

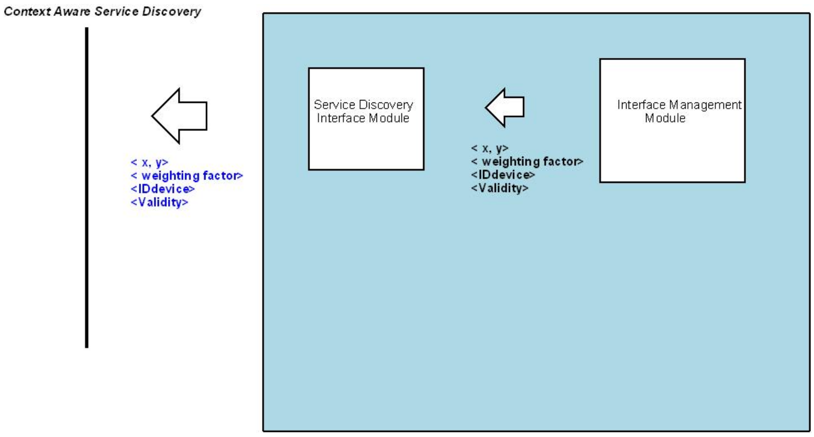

Figure 5.17: Step 4 of the communications messages diagram

(x,y): The spatial coordinates of the estimated position.

Weigthing Factor: The Accuracy Weighting Factor of the estimated coordinates.

IDdevice: The identification of the Device.

Validity: The validity variable, whose value is 1 if all the information has been successfully calculated and there is no error in the system. It will be equal to 0 otherwise

Chapter 6

Design of Service Ranker

As it has been explained before it is necessary also to design and to implement the rules for the Service Ranker (SR) in the CASD in order to choose the nearest service in the cluster with the received location information from the Location Interface Block.

Two different SRs have been designed. The simple version with simple rank laws has been implemented in the latest available CASD version considering that the error in the estimated coordinates has a uniform distribution. The other SR is more complex and is going to be implemented considering that the user could set how distant the services should appear at the most. Moreover, this SR considers that the error follows a Normal Distribution. This second SR is not implemented in the CASD due to time limitations, but it is simulated outside the CASD following the designed rules with the same scenario as the first one.

6.1 Service Ranker considering Uniform Distribution

This SR has been designed assuming the error in the estimated coordinates follows a uniform distribution inside the area of the location region defined by Accuracy Weighting Factor. With this assumption, the CASD sorts all the services choosing the service that has the best score. The score of each service is calculated using the Accuracy Weighting Factor. With this value it is possible to calculate the radius of the location region, for which two possibilities exist.

$$radio = \sqrt{\frac{\left(\frac{1}{WeightingFactor}^{\frac{1}{\gamma}}\right) - 1}{\pi}} \tag{6.1}$$

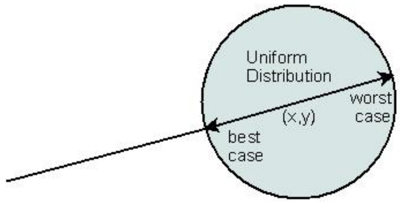

Figure 6.1: Uniform distribution assumption in the location's region

6.1.1 Taking the worst case Ranker

The score of each service is obtained calculating the distance between the estimated coordinates of the service and the estimated coordinates of the user. Then the radius of the location region is calculated and, considering the worst case, the real position of the device is the position that results from adding this radius to the calculated distance.

The score of each service is related to this calculated distance. The services with a good score are the services that are near to the user. The SR chooses the service that has the best score and then the nearest to the user.

6.1.2 Taking the best case Ranker

In the same way as the worst case ranker, the score of each service is obtained calculating the distance between the estimated coordinates of the service and the estimated coordinates of the user. The radio of the location region is calculated and then, considering the best case, the real position of the device is the position that results from subtracting this radius to the calculated distance.

The score of each service is also related with this calculated distance and used in the same way as before.

6.2 Service Ranker considering Normal Distribution

This SR has been designed assuming the CASD is going to chose the service that has higher probability be the nearest to the user up to a the distance D that the user can setup. When a user requests a service, he can determine the maximum distance that the proposed services can have. For example the user can set that he wants to find the services that are in a range of 100m radius, and the CASD has to chose the best service within this area.

The score of each service is obtained in this SR by calculating the probability with which the distance between the user and the service is lower than the value that the user has set. It is necessary to know the Cumulative Density Function (CDF) of the positioning system's error. If the distance between the user and service is calculated using the estimated coordinates by the position system and adding the random variable of the error X, the score of each service is going to be the result of the equation (6.2).

$$P(d + X < D) \tag{6.2}$$

If the interface does not know the CDF of the estimation's error then it could assume it is a Gaussian distribution with zero mean. The variance could in that case be calculated using the accuracy weighting factor ($N(d, \sigma^2)$). The reason for using this distribution is that it is a simple distribution and it allows to implement and to calculate the score of each service easily. With equation (6.3), it is possible to relate the variance of this distribution with the accuracy weighting factor. When the accuracy of the estimation is very good, the accuracy weighting factor takes the value near to 1 and then the variance of the error distribution is going to be near to zero and the distribution function is similar to one impulse. When the accuracy is very bad and the weighting factor is near to zero, the weighting factor is near to zero and the variance is going to be very large and the spread of the Gaussian pulse is going to be very large. When value of the weighting factor is $0,5$, the variance is the acceptance radius of the defined acceptance area with the decay exponent (5.1).

$$\sigma^2 = \left(\frac{1-w}{w}\right) * AceptanceRadio \quad 0 < w < 1 \tag{6.3}$$

As it has been explained, the score of each service is calculated adding the calculated distance between the user and service and the random variable of the error and calculating the probability for this distance to be less than the distance that the user has set up. The services with more probability to be near to the user they would have good score and then the service ranker would choose the service with the best score. However, the probability of in equation (6.2) depends strongly on the distance that the user has set, so when the calculated distance d between the user and services with the estimated coordinates is much lower than the distance set D, the result of equation (6.2) is going to be very close to 1. At the same time in case that the calculated distance is much larger than the set distance, the score of the equation is going to be close to zero. In this case, in order to perform the selection, the SR will consider that the distribution of the error is uniform and it will choose the best service using the same ranks rules that have been explained in the SR considering a uniform distribution. Figure 8.12, represents the case in which there are services situated at a much lower distance than the distance set by the user. In this situation the service ranker should choose between these two services using the rules of the Service Ranker Considering the Uniform Distribution, and then, in this situation, the service number 2 will be selected.

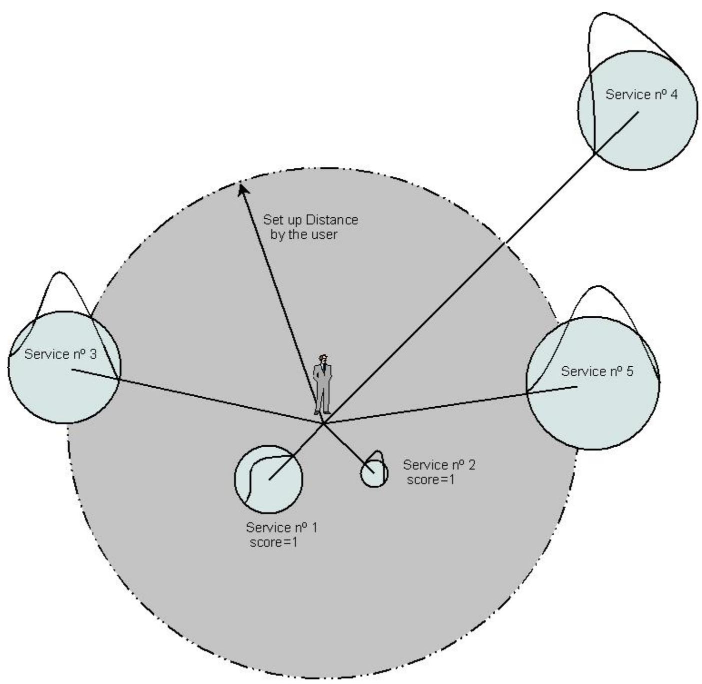

Figure 6.2: Service Ranker considering Normal Distribution and the user setting the distance

Part IV

Analysis

Chapter 7

Implementation Issues

7.1 Location Interface Implementation

The implementation of the Location Interface has been made using Java programming language. In Section 7.1 there is the UML class diagram of the implemented interface. The MagnetUPnPdevice class, which has all the steps of the Modified UPnP protocol for the communication with the CASD, is used.

On the other hand the Position System, which has tried to communicate with the Context Aware Service Discovery, is a Bluetooth Positioning System based on the Signal Strength localization technique optimized with a Kalman filter also implemented in Aalborg University (AAU). However, this Position System is not available to provide estimations of the position of one device in real time yet. That is why, it has been necessary to implement a Position System emulator base on this Bluetooth Position System capable of simulating real-time location estimations. The emulator has been implemented taking data from real location estimations using different mobile devices in the same scenario during a long time interval. The emulator has been made using a timer that start with system configuration. When there is any location request from the Location Interface, the Position System emulator looks the location estimation of the requested device at a given time up in the store data files. At that point, the Position System Emulator simulates the real time estimations, answering with the location estimations of the device that there is in the file in the time that was estimated in the experiment.

This Position System can provide information about the estimated location accuracy. The information provided in each estimation in each estimation is the trace of covariance matrix of the error. It has been assumed that the covariance matrix is a diagonal matrix assuming that the error in each

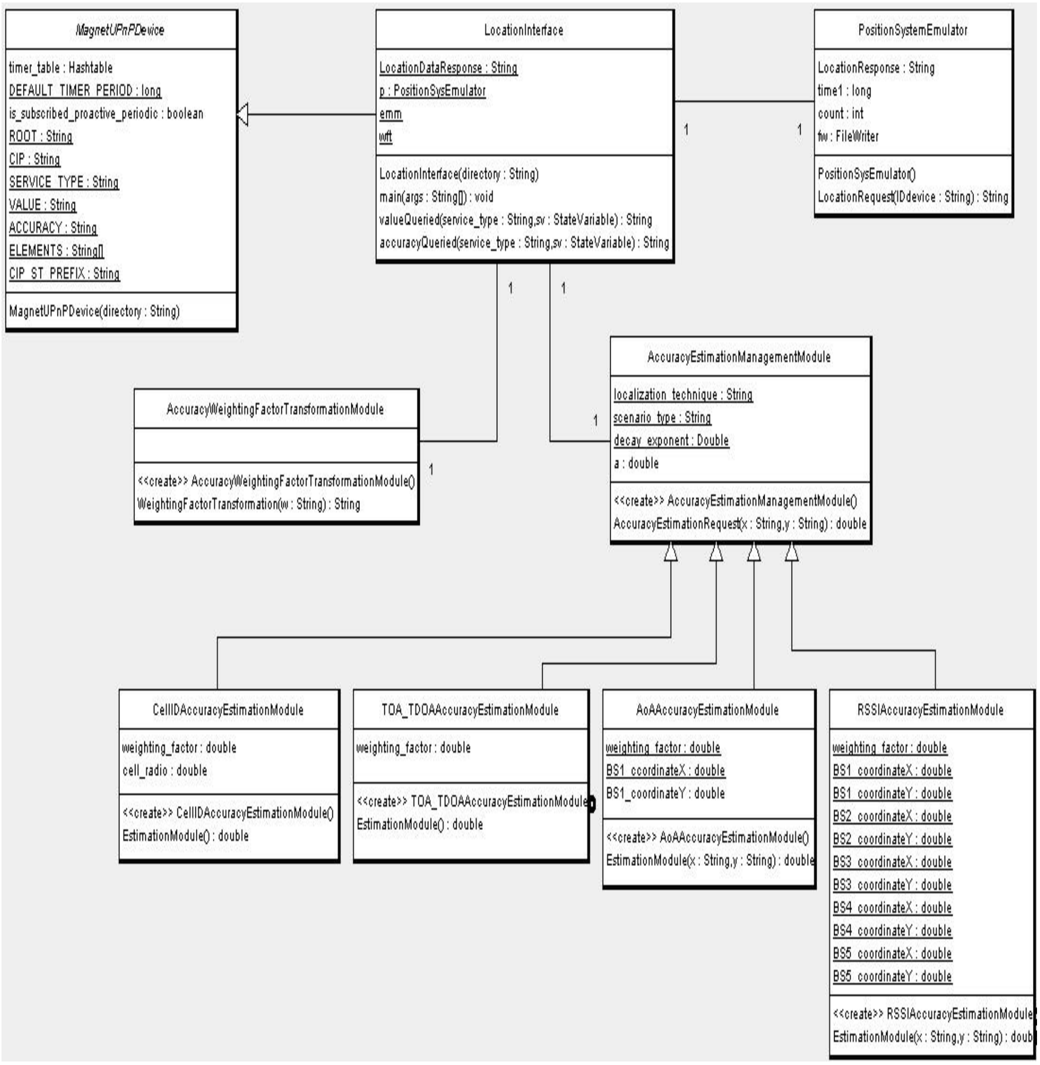

Figure 7.1: Class Diagram

axis x and y are independent. Therefore the trace of covarinace matrix is the sum of the variances of the error in x and y axis (7.1). The algorithm of the Weighting Factor Transformation set up function has been designed assuming that the errors in X and Y have Normal distribution and they are independent and they have an equal distribution. Then it is possible to assume that the variance of the error in X and Y are (7.2) . The standard deviation of the error in X and Y is (7.3) so the standard deviation of the location's error is the square root of the trace of covariance matrix (7.4).

$$trace = {\sigma_x}^2 + {\sigma_y}^2 \tag{7.1}$$

$$\sigma_x^2 = \frac{trace}{2} \tag{7.2}$$

$$\sigma_x = \sqrt{\frac{trace}{2}} \tag{7.3}$$

$$\sigma_{error} = \sqrt{\sqrt{\frac{trace}{2}}^2 + \sqrt{\frac{trace}{2}}^2} = \sqrt{trace} \tag{7.4}$$

The Weighting Factor Transformation Module calculates the accuracy weighting factor assuming the location region has a standard deviation ratio as (7.4) shows.

The Position System is based on the Signal Strength localization technique, where the coordinates of the used antennas in the estimation are known, being possible to introduce the the value of the *BScoordinates* set-up variables in the Signal Strength Accuracy Estimation Module. The estimations have been taken in an indoor environment, specifically a $48m^2$ room, and hence a urban environment has been used in the Accuracy Estimation Module due to its similar propagation conditions. This scenario could be similar to one of the user small clusters of the user case 4 of the section 1.1. From this information, the interface can estimate the location accuracy although the Position System does not provide the trace of covariance matrix.

7.2 Service Rankers Implementation

The SR1 has been implemented and introduced in the CASD in order to be able to choose the best service using the location context information. On the other hand, the SR2 has been tested outside the CASD taking the data that the location interface has sent to the CASD. Based on this data, the rankers rules have been simulated and their results have been checked and compared with the SR1.

Chapter 8

Measurements of the Implementation

In order to test how the systems works, how robust the interface is and its influence in the CASD, three different kind of measurements have been carried out.

8.1 Selected Service Measurements

These measurements have made in order to test which service is selected by the CASD using the location context information, and to check if the selected service is the nearest to the user. The scenario for these measurements is four mobile devices, one of them is the user and the other ones are the services. Figure 8.1 shows the path of the movement of each device in the same cluster, these plots are a given data by the Position System creators. The speed of the movement was different for each device and similar to one person walking slowly with the device in his hand.

In this scenario, it was selected the mobile device 4 as the user and the other three mobil devices were the services. Figure 8.2 represents the real distance between the user and services during the measurement time. In this plot the black marks represent the moment when the device pass the corners of the trajectory, furthermore in this plot of the real distances it is possible to see that there are three different intervals in the measurement. In the first interval time the nearest service is the service number 2, in the second interval after the 240 second the nearest service is the service number 3, and in the third interval, after the 285 second the nearest service is the service number 1. After the 305 second the service number 3 is not available.

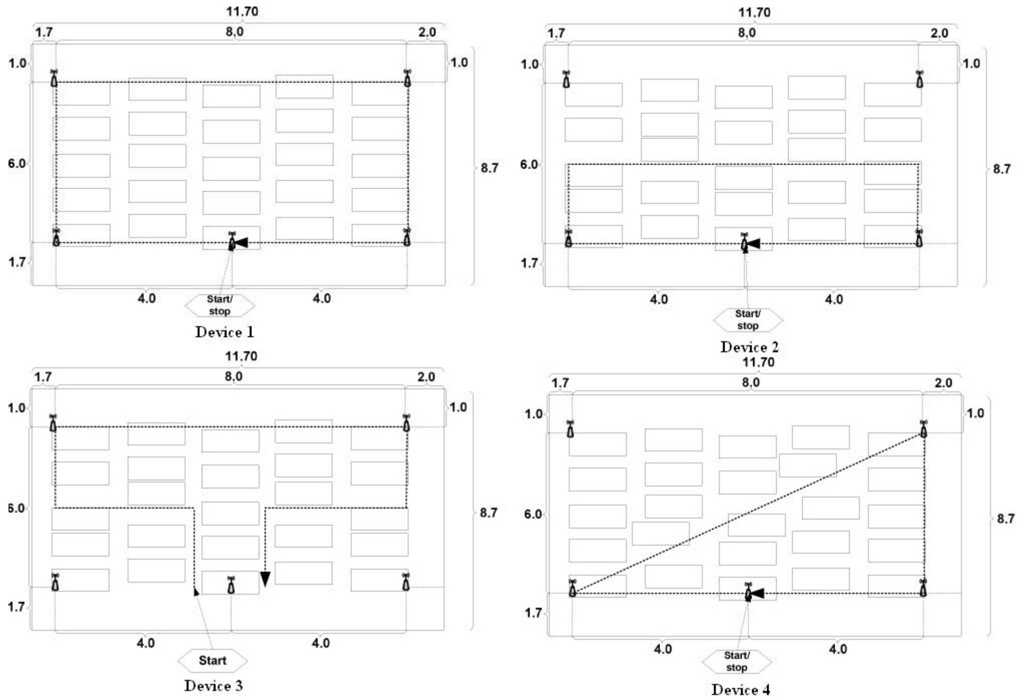

Figure 8.1: Measurement scenario path of the mobile devices

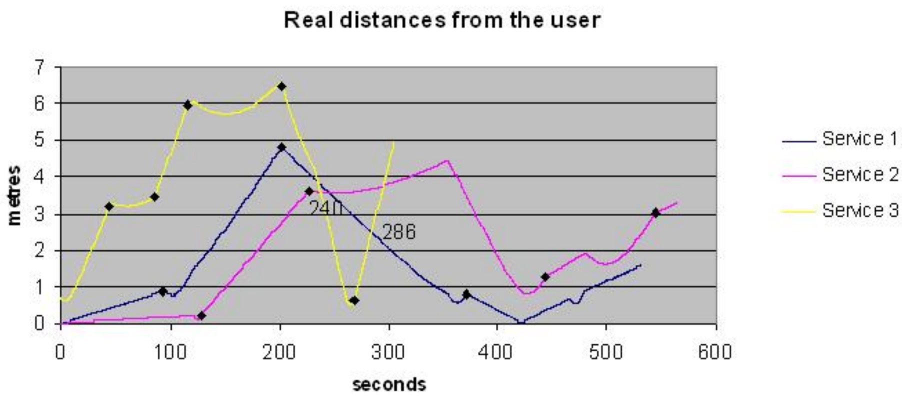

Figure 8.2: Real distance between the user and services in the measurements

On the other hand, Figure 8.3 represents the plot of the distance between the user and services calculated using the estimation coordinates of the Position System. It can be seen that there are some time intervals [0-100] or [260-300] were the distance of the location estimation of the services and user are very similar. This situation affects the measurements because in these intervals where the distances of the estimations are very similar it could be more difficult for the CASD to correctly choose the nearest service. That is why this scenario has been use for all the cases that have been analyzed.

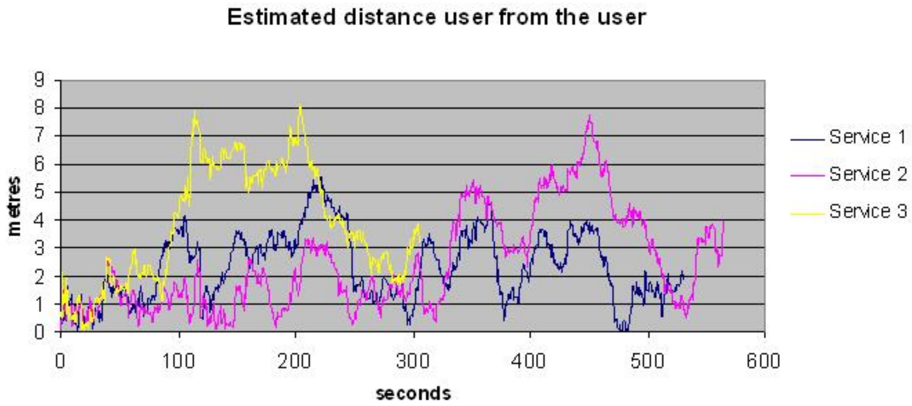

Figure 8.3: Distance between the user and services estimated coordinates in the measurement

In the figures 8.4, 8.5, 8.6, 8.7 there are also represented the estimations error of each device during the experiment time. In the 4 cases the maximum error of the estimations is around 4,5 metres.

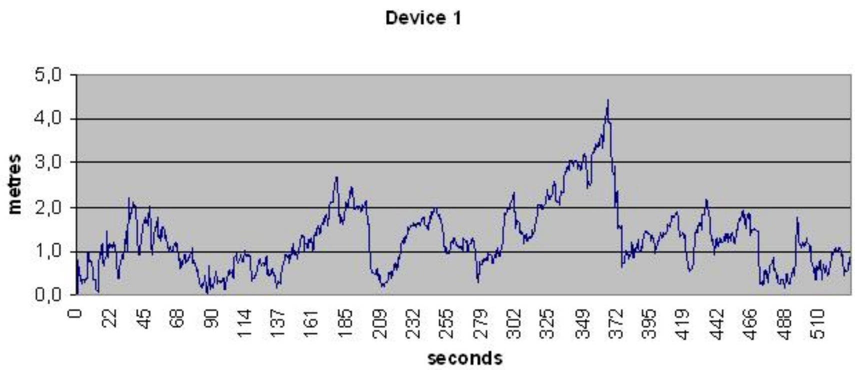

Figure 8.4: Estimation error of the Device 1

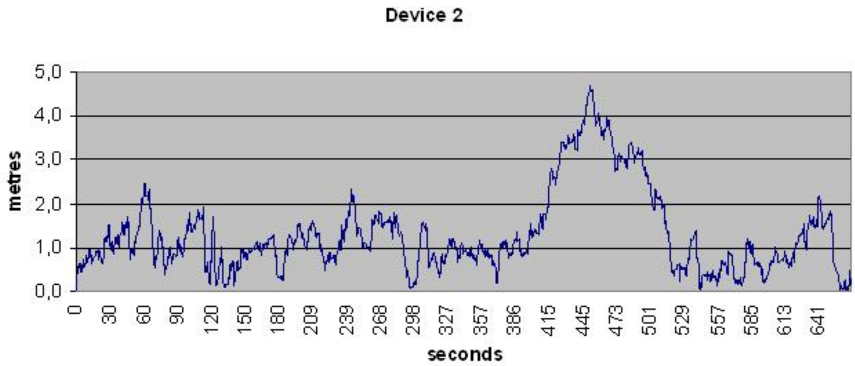

Figure 8.5: Estimation error of the Device 2

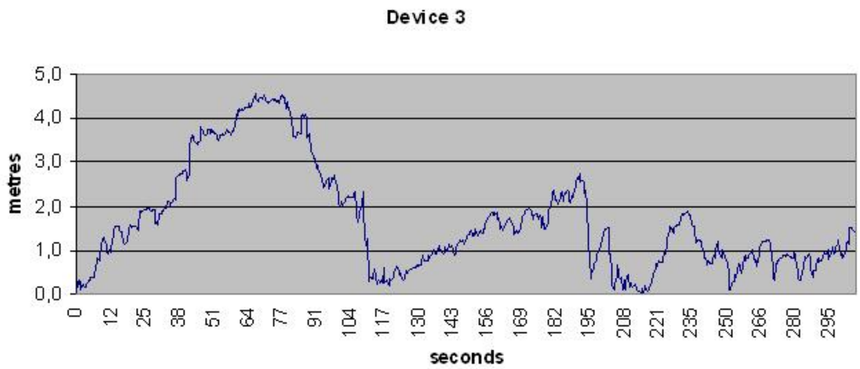

Figure 8.6: Estimation error of the Device 3

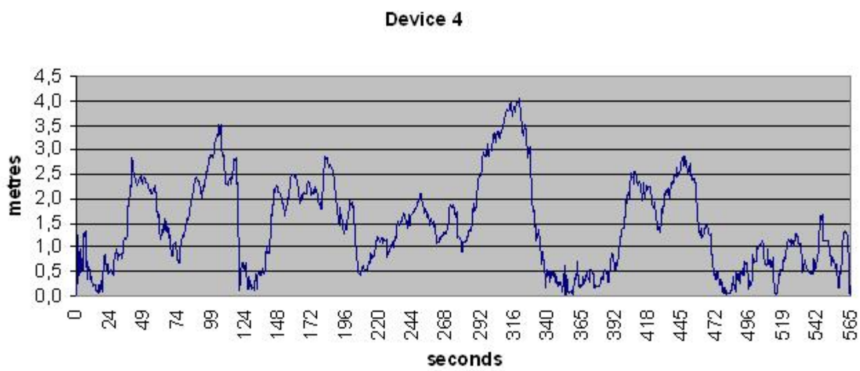

Figure 8.7: Estimation error of the Device 4

As it has been say before the device 4 was selected like the user. The user triggers the CASD different number of times in order to find the nearest service in the cluster. There is defined a new ratio in order to see how robust the system is when choosing the nearest service in the cluster during the experiment. In Equation (8.1) is defined the error ratio like the number of the wrong selection divided the number of times that the user has triggered the Context Aware Service Discovery.

$$error\ selection\ ratio = \frac{number\ of\ wrong\ selections}{number\ of\ triggers} \tag{8.1}$$

The measurement of the number of the wrong selections by the Context Aware Service Discovery in the described scenario has been made with the two proposed Service Rankers:

- **Using the Service Ranker Considering the Uniform Distribution:** the measurement has been made in four different situation in order to see how the all the system works:

  1. When the Position System provides the estimated coordinates of the services and accuracy information about the estimations, taking the worst case in the algorithm of this Service Ranker.
  2. When the Position System provides the estimated coordinates of the services and accuracy information about the estimations, but taking the best case in the algorithm of this Service Ranker.
  3. When the Position System provides the estimated coordinates of the services but the Location Interface has to estimate the accuracy of the estimations, and taking the worst case in the algorithm of this Service Ranker.
  4. When the Position System provides the estimated coordinates of the services but the Location Interface has to estimate the accuracy of the estimations, and taking the best case in the algorithm of this Service Ranker.

- **Using the Service Ranker considering the Normal Distribution and the user setting the distance:** the implementation of the Service Ranker was made outside the CASD, and hence the measurement had been made simulating the designed rules for this Service Ranker. In this case, it is necessary to set the distance that the user could set when he triggers the CASD. Due to the distance in this scenario between the user and services are less than 7 metres, the set up distance from the user has been set to 3.75 metres.

In the following figures 8.8, 8.9, 8.10, 8.11, 8.12 there are shown the measurements of the selected service by the CASD for each defined case. Each graphic represented the selected service by the Context Aware Service Discovery every time that the user has triggered the Context Aware Service discovery during the measurement. In this plot the red circles are the times that the service discovery has wrongly chosen the nearest service and the red empty marks represent the service that should has been chosen, *error selection's ratio* is also calculated.

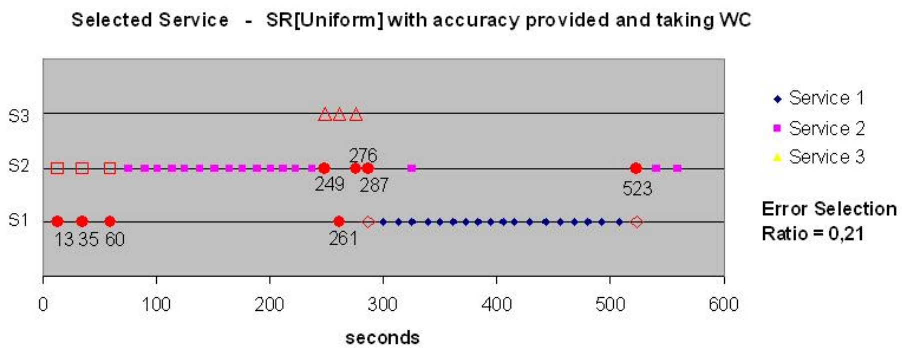

Figure 8.8: Selected Service with Service Ranker 1 taking the worst case and the Position System providing the accuracy information

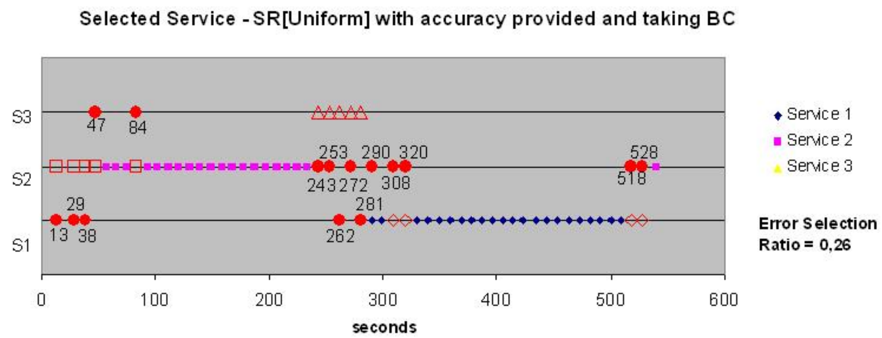

Figure 8.9: Selected Service with Service Ranker 1 taking the best case and the Position System providing the accuracy information

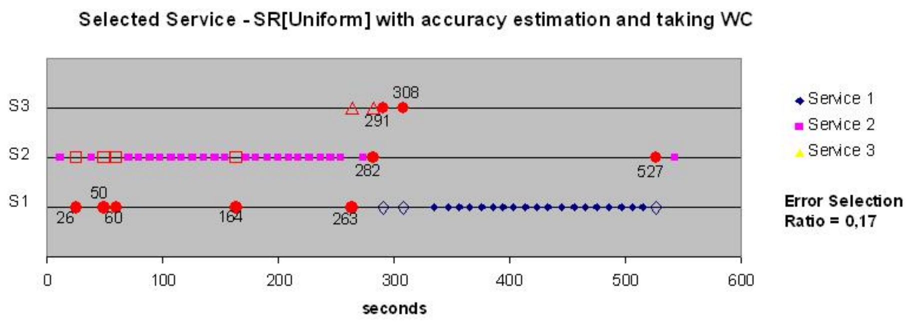

Figure 8.10: Selected Service with Service Ranker 1 taking the worst case and the accuracy estimations by the Location Interface

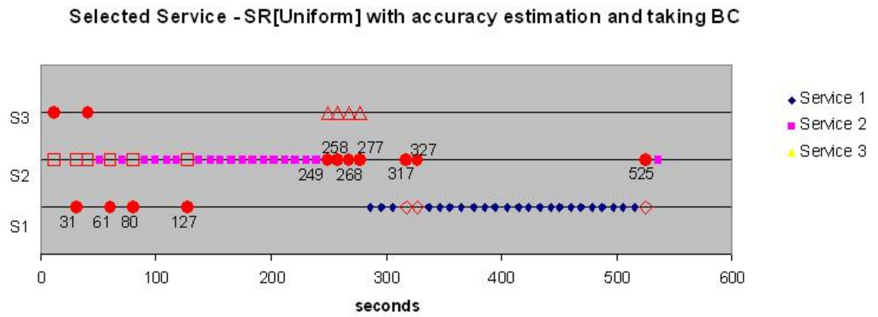

Figure 8.11: Selected Service with Service Ranker 1 taking the best case and the accuracy estimation by the Location Interface

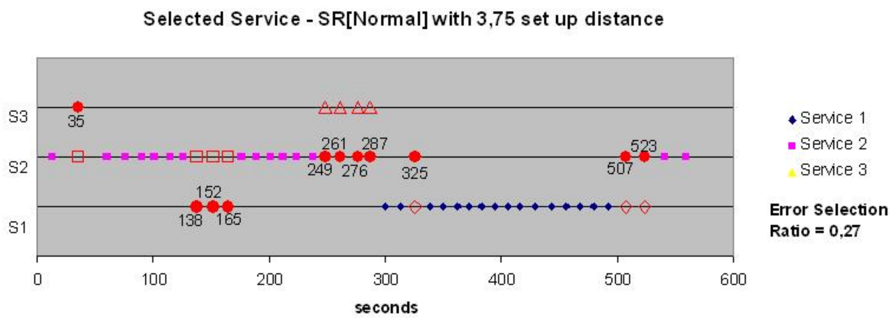

Figure 8.12: Selected Service with Service Ranker 2

8.1.1 Comparison of the Measurements

Figures 8.8, 8.9 , 8.10, 8.11, 8.12 shows that the number of wrong selections increases when the estimated distance between the user and services is very similar. However, the error selection ratio is very similar for each case, in the Figure 8.13 is represented this ratio for all the cases of the SR1 (uniform distribution).

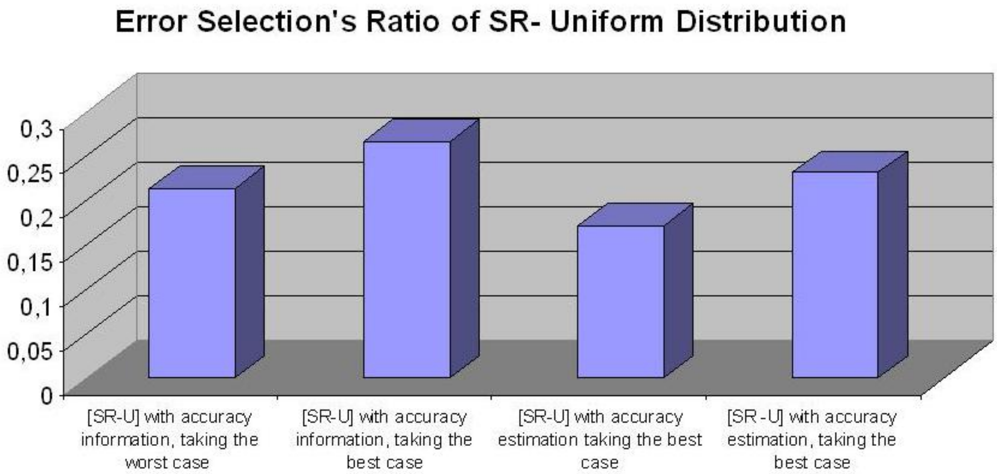

Figure 8.13: Comparison of error selection ratio for SR1 (uniform distribution) of different cases.

In the case of using the SR1 (uniform distribution), the error ratio is larger when the algorithm makes its choice based on the best case. Theoretically, the SR that takes the worst case is better because its selection is more conservative. In the case there is a wrong selection, the selected service could be, with higher probability, the second nearest service to the user. If the ranker takes the best case is more likely that it could choose the furthest service but with very bad weighting factor accuracy.

On the other hand, there is also difference between the selections measurement using the accuracy information that the Position System provides and the selection measurement using the accuracy estimations. The main reason of this difference is because in the both cases the accuracy weighting factor is an approximation to the real location accuracy.

In the case of SR2 (normal distribution) the error ratio depends on the distance that the user sets up. There is one optimum distance with the error selection ratio is better, in this case it is near to the value 3,75m. In the figure 8.14 there is represented the error selection ratio for different user's set up distance, it is possible see in this figure how the value of the ratio decreases when the distance is near to the optimum distance's value.

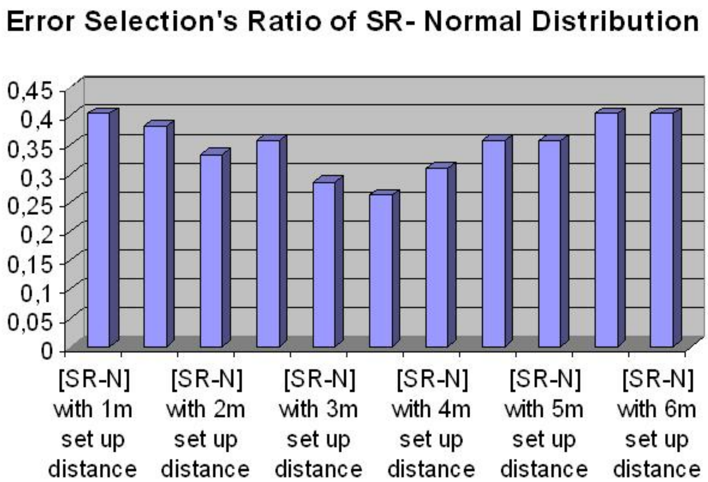

Figure 8.14: Comparison of error selection ratio for SR2 (Normal distribution) for different user's set up distance.

8.2 Time Measurements

The elapsed time between the user requests a service and the CASD chooses the best service depends on the number of services. The main reason is because the position system has to estimate the position of each service every time that the user triggers the service discovery. For this reason, local discovery time measurements have been taken using the location context information, with different number of services in the cluster, and also the same measurement of the discovery time but without the location information in order to compare how much time add the location system to the CASD.

As we can see in Figure 8.15 the Discovery Time using the location context increases linearly with the number of the services. The discovery time without the location context is very small and increase very slowly with the number of devices. However the Discovery Time using the location increase faster by a factor of 1472 and it takes quite large values. In the Figure 8.16, we can also see how the proportion of *Time with location - Time without location* increase with number of devices.

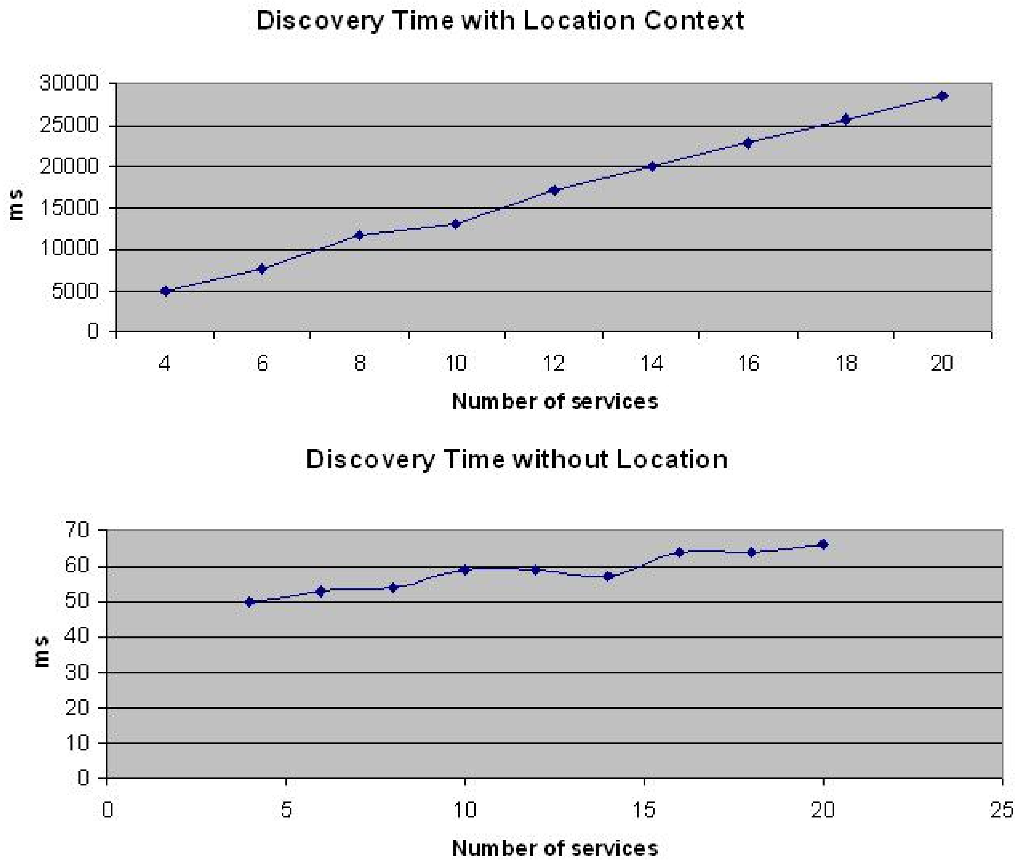

Figure 8.15: Discovery Time-number of services

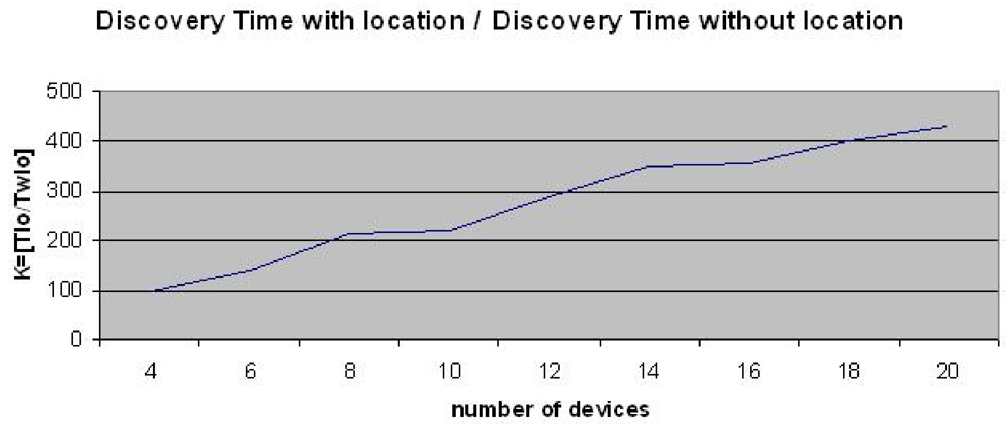

Figure 8.16: Discovery Time with location/ Discovery Time without, location increasing with the number of devices

The plot of Time with location - Time without location is possible to approach to a liner function. Then it is possible define a new factor (8.2):

$$K' = \frac{\Delta \frac{T_{LO}}{T_{WLO}}}{\Delta n} = 20,78 \tag{8.2}$$

This factor means that knowing the discovery time for the CASD without using the location context information for one number of devices, the discovery time using the location is going to be increased multiplying by this factor and the number of devices.

8.3 Network Traffic Measurement

Other important measurement is the traffic that the interaction with location system generates. This measurement also depends on the number of services. In the Figure 8.17 there is the number of packets generated for Service Discovery with different number of services. The number of packets increases linearly by a factor of 72 with the number of services with the location context.

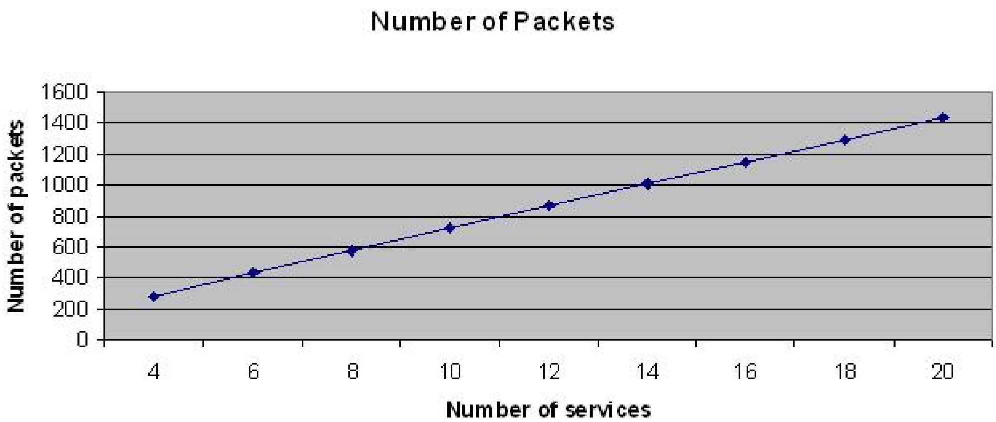

Figure 8.17: Number of packets-number of services

Part V

Conclusions

Chapter 9

Conclusions

The Context Aware Service Discovery (CASD) is an extension to Service Discovery that uses the context information to offer the most relevant service to the user. The CASD can use the geographical location information of different devices and services as a context to provide the nearest service to the user. The goal of this thesis was the design of the communication between the CASD and the Position Systems that provides the location of devices and services. During the implementation phase, the main issue was to deliver accurate information of the location to the CASD, in addition to the location itself in order to find the best service for the user. The Position System may not provide this information in each estimation and, in case of providing it, the format of this information depends on the kind of Position System.

A research on the main wireless localization techniques has been performed, i.e. Angle of Arrival, Signal Strength, Time of Arrival, Time Difference of Arrival and Cell ID. Besides, the structure of CASD and its functioning have also been studied. Afterwards, an interface between the CASD and a general Location Platform has been designed and implemented. This design has solved the problem of the accuracy information processing by the CASD. In case the Position System cannot provide any information regarding the accuracy of the estimations, the designed interface can estimate this data. In case the information on the accuracy is available, the Location Interface allows the CASD to use this data. Moreover, it has also been necessary to implement a Service Ranker (SR) for the CASD so as to select a certain service based on the location information as context. The two implemented SR have been designed considering a Uniform Distribution and a Normal Distribution. Java programming Language has been used in the development of the Location Interface. Finally, some performance measurements have been taken regarding the generated delay, the generated traffic, and the service selection by the CASD with the implemented interface and using a Bluetooth Position System based in a Signal Strength localization technique.

The measurements on de delay show the discovery time of the CASD increases linearly with the number of devices in the cluster by a factor of 1400 ms per device when it uses the location information. On the other hand, the discovery time is 21 times longer multiplied by the number of devices, in case of using the location information compared to the case in which this information is not used. Furthermore, the generated traffic by the system also increases linearly with the number of devices by a factor of 72.

Different measurements regarding the service selections have been taken in order to analyze how robust the system is in the studied cluster environment. This measurements consisted on the study of the selections triggered by the CASD. When using the SR-Uniform Distribution, the number of wrong selection is considerably low keeping the error selection ration below 0.25. In the case of the SR-Normal Distribution, although the performance depends on the maximum distance below which the user wants the service, the error selection ratio is also less than 0.25 for the values of this distance near to the optimal case. However, a wrong selection can take place more often as the distance to the different services is more similar. This is due to the fact that the accuracy strongly determines the selection in the SR of the CASD in these cases. On the other hand, the accuracy estimations by the Location Interface need at least certain information about the propagation conditions of the environment. In case of a dynamic environment, the variation on this information could affect such accuracy, and hence, the CASD decision. Therefore, it could be necessary to add a new module to manage this information and periodically or occasionally update it in order to maintain a real approach of the accuracy estimation.

This master thesis has addressed the problem of providing the geographical location of the devices and services to the CASD. This work has shown that the CASD is able to successfully provide the best service in the selection in up to 75% of the cases by using the location as context information. In a future version of the CASD it could be useful to take the geographical location of the services and users into account in order to provide the most suitable service to the user in one global interconnected network.

Chapter 10

Future work

A certain number of possible modifications have been identified in the implemented system that could lead to improve its performance, its functionality, etc. For instance, it could be of interest to study a global discovery at Service Management Network Level for the Location Interface for the CASD. This would require implementing this feature and performing measurements. The current system structure allows this feature if the interface is adapted to send the reference system together with the location coordinates in each response message (requirement number 4 of the interface). The Service Ranker (SR) could then be able to estimate the global distance between the user and services even if the services are situated in different network clusters.

A theoretical study about the SRs for the location of context information is another possible item for future research. Such study would focus on the search of the optimal distance of influence setup parameter for the designed SR-Normal distribution. Another important task could be the improvement of the service selections in the cases in which the estimated distances are very similar. This could be studied with the implementation of a more complex SR in the CASD by means of probability rules. It could be necessary to redefine the accuracy weighting factor in this new SR making a new relation between it and the variance of the estimations error. This thesis shows a deterministic study about the error in each localization technique but with a new redefinition of the Accuracy Weighting Factor it could be necessary to make a probabilistic study of the error in each localization technique in order to be able to estimate the Accuracy.

As it has been introduced in the conclusions, the dynamic environments can introduce errors in the estimations reducing the accuracy of the system.

A new module could help to ease these effects by establishing periodical or occasional communications with the Location Platform and requesting an update of the necessary setup information in order to keep the accuracy as high as possible.

Appendix A

Angle of Arrival estimated location's region area

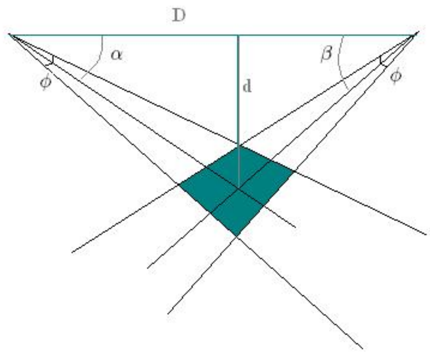

Figure A.1: Area of the location's region AoA

In the A.1 it is drawn the location's region of the device that the Angle of Arrival technique calculates using the angles of the received signal. The angles of the arrival are α and β and the azimuth spread ϕ. This figure represents the case when $\alpha > 0$, $\beta > 0$ and $\phi < \alpha + \beta$. Knowing these angles it is possible to know the rest of the angles of the figure (A.2) taking into account that all the angles of the triangle sum 180.

Afterward, using the sine theorem it is possible to calculate all the sides of the location's region. C, E, H, I:

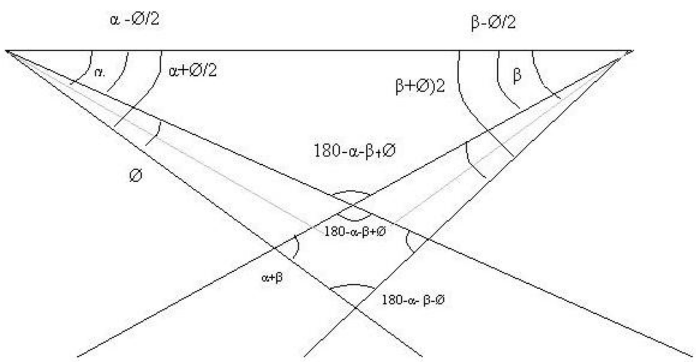

Figure A.2: Angles of the location's region

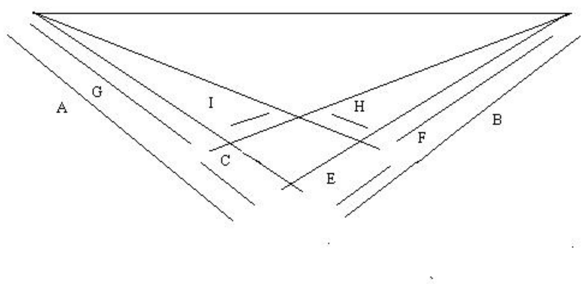

Figure A.3: Sides of the locatio's region

$$\begin{aligned}
A &= \frac{D\sin(\beta+\phi/2)}{\sin(180-\alpha-\beta-\phi)} && \text{(A.1)}\\
B &= \frac{D\sin(\alpha+\phi/2)}{\sin(180-\alpha-\beta-\phi)} && \text{(A.2)}\\
E &= \frac{A\sin(\phi)}{\sin(\alpha+\beta)} = \frac{D\sin(\beta+\phi/2)\sin(\phi)}{\sin(180-\alpha-\beta-\phi)\sin(\alpha+\beta)} && \text{(A.3)}\\
C &= \frac{B\sin(\phi)}{\sin(\alpha+\beta)} = \frac{D\sin(\alpha+\phi/2)\sin(\phi)}{\sin(180-\alpha-\beta-\phi)\sin(\alpha+\beta)} && \text{(A.4)}\\
F &= B-E \\
&= \frac{D\sin(\alpha+\phi/2)}{\sin(180-\alpha-\beta-\phi)} - \frac{D\sin(\beta+\phi/2)\sin(\phi)}{\sin(180-\alpha-\beta-\phi)\sin(\alpha+\beta)} && \text{(A.5)}\\
H &= \frac{F\sin(\phi)}{\sin(\alpha+\beta-\phi)} && \text{(A.6)}\\
&= \left(\frac{D\sin(\alpha+\phi/2)}{\sin(180-\alpha-\beta-\phi)} - \frac{D\sin(\beta+\phi/2)\sin(\phi)}{\sin(180-\alpha-\beta-\phi)\sin(\alpha+\beta)}\right)\\
&* \left(\frac{\sin(\phi)}{\sin(\alpha+\beta-\phi)}\right) && \text{(A.7)}
\end{aligned}$$

$$
\begin{aligned}
G &= A - C \\
&= \frac{D\sin(\beta+\phi/2)}{\sin(180-\alpha-\beta-\phi)} - \frac{D\sin(\alpha+\phi/2)\sin(\phi)}{\sin(180-\alpha-\beta-\phi)\sin(\alpha+\beta)} \qquad \text{(A.8)} \\
I &= \frac{G\sin(\phi)}{\sin(\alpha+\beta-\phi)} \\
&= \left(\frac{D\sin(\beta+\phi/2)}{\sin(180-\alpha-\beta-\phi)} - \frac{D\sin(\alpha+\phi/2)\sin(\phi)}{\sin(180-\alpha-\beta-\phi)\sin(\alpha+\beta)}\right) \\
&* \left(\frac{\sin(\phi)}{\sin(\alpha+\beta-\phi)}\right) \qquad \text{(A.9)}
\end{aligned}
$$

When there are calculated all the angles and sizes, splitting the area in two triangles and calculating the area of each triangle, it is possible to obtain the area of the location's region adding then area of each triangle. For calculating the area of each triangle it is necessary to use also the sine theorem.

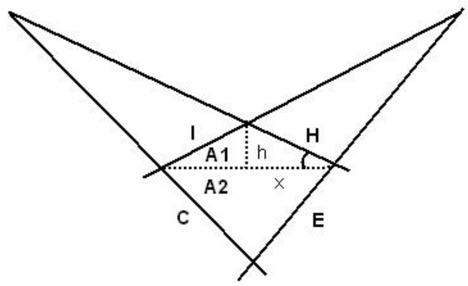

Figure A.4: Location's region split in two triangles

$$
\begin{aligned}
\sin(\sigma) &= \frac{I\sin(180-\alpha-\beta+\phi)}{x} \qquad \text{(A.10)} \\
\sin(\sigma) &= \frac{h}{H} \qquad \text{(A.11)} \\
A_1 &= H\sin(\sigma) \\
&= H * I * \sin(180-\alpha-\beta+\phi) \\
&= \left(\frac{sen(\alpha+\phi/2)}{sen(180-\alpha-\beta-\Phi)} - \frac{sen(\beta+\Phi/2)sen(\phi)}{sen(180-\alpha)-\beta-\phi)sen(\phi+\beta)}\right) \\
&* \left(\frac{sen(\beta+\phi/2)}{sen(180-\alpha-\beta-\phi)} - \frac{sen(\alpha+\phi/2)}{sen(180-\alpha-\beta-\phi)}\frac{sen(\phi)}{sen(\alpha+\beta)}\right) \\
&* \left(\frac{D^2 sen^2(\phi)}{sen^2(\alpha+\beta-\phi)}\right)(\sin(180-\alpha-\beta+\phi)) \qquad \text{(A.12)}
\end{aligned}
$$

At the same way it is possible to calculate A_2:

$$A_2 = E * C * \sin(180 - \alpha - \beta - \phi) \quad (A.13)$$
$$= \left(\frac{D^2 sen^2(\phi) sen(\beta + \phi/2) sen(\alpha + \phi/2)}{sen(180 - \alpha - \beta - \phi) sen^2(\alpha + \beta)}\right) \quad (A.14)$$

Finally the area of the location's region is the addition of A_1 and A_2. This expression is the expressed in function of angles of arrival and azimuth spread when $\alpha > 0$, $\beta > 0$, $\phi < \alpha + \beta$.

$$\begin{aligned} A &= \left(\frac{D^2 sen^2(\phi) sen(\beta + \phi/2) sen(\alpha + \phi/2)}{sen(180 - \alpha - \beta - \phi) sen^2(\alpha + \beta)}\right) \\ &+ \left(\frac{D^2 sen^2(\phi)}{sen^2(\alpha + \beta - \phi)}\right) * \left(\frac{sen(\alpha + \phi/2)}{sen(180 - \alpha - \beta - \Phi)} - \frac{sen(\beta + \Phi/2) sen(\phi)}{sen(180 - \alpha) - \beta - \phi) sen(\phi + \beta)}\right) \\ &* \left(\frac{sen(\beta + \phi/2)}{sen(180 - \alpha - \beta - \phi)} - \frac{sen(\alpha + \phi/2)}{sen(180 - \alpha - \beta - \phi)} \frac{sen(\phi)}{sen(\alpha + \beta)}\right) \\ &* \sin(180 - \alpha - \beta + \phi) \qquad \alpha > 0,\ \beta > 0,\ \phi < \alpha + \beta \end{aligned} \quad (A.15)$$

In the figure A.5 is represented the location's region in the case that $\phi = \alpha + \beta$, in this case the region is one triangle.

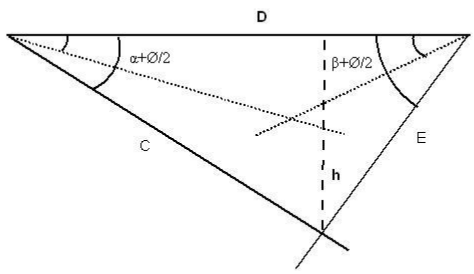

Figure A.5: Area when $\alpha > 0$, $\beta > 0$, $\phi = \alpha + \beta$

$$C = \frac{D \sin(\beta + \phi/2)}{\sin(180 - \alpha - \beta - \phi)} \quad (A.16)$$
$$h = \sin(\alpha + \phi/2) * C \quad (A.17)$$
$$A = \frac{D^2 \sin(\beta + \phi/2) \sin(\alpha + \phi/2)}{2 \sin(180 - \alpha - \beta - \phi)} \quad (A.18)$$

In the Figure A.6 there is represented the case when $\phi > \alpha + \beta$, as we can see in this case locations ares is composed by two triangles. The area of A_1 is the same than in the case before ($\phi = \alpha + \beta$), and the A_2 is calculated in the following equations.

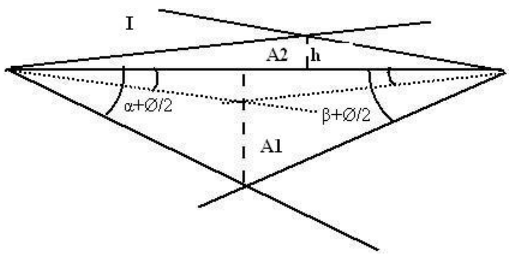

Figure A.6: Area when $\alpha > 0$, $\beta > 0$, $\phi > \alpha + \beta$

$$A_1 = \frac{D^2 \sin(\beta + \phi/2) \sin(\alpha + \phi/2)}{2 \sin(180 - \alpha - \beta - \phi)} \tag{A.19}$$

$$I = \frac{D \sin(\phi/2 - \beta)}{\sin(180 + \alpha + \beta - \phi)} \tag{A.20}$$

$$h = \sin(\phi/2 - \alpha) I \tag{A.21}$$

$$A_2 = \frac{D^2 \sin(\phi/2 - \alpha) \sin(\phi/2 - \beta)}{2 \sin(180 + \alpha + \beta - \phi)} \tag{A.22}$$

$$\begin{aligned} A &= \frac{D^2 \sin(\beta + \phi/2) \sin(\alpha + \phi/2)}{2 \sin(180 - \alpha - \beta - \phi)} \\ &+ \frac{D^2 \sin(\phi/2 - \alpha) \sin(\phi/2 - \beta)}{2 \sin(180 + \alpha + \beta - \phi)} \end{aligned} \tag{A.23}$$

In the Figure A.7 is represented the case when $\alpha = 0$, $\beta = 0$.

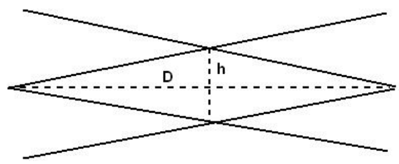

Figure A.7: Area when $\alpha = 0$, $\beta = 0$, $\forall \phi$

The area in this case is to calculated next:

$$A = \frac{D^2 \tan(\phi/2)}{2} \tag{A.24}$$

In the following equation is represented the area of the location's region for all the possible cases.

$$A = \begin{cases} \left(\frac{D^2 sin^2(\phi) sin(\beta+\phi/2) sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi) sin^2(\alpha+\beta)}\right) + \left(\frac{D^2 sin^2(\phi)}{sin^2(\alpha+\beta-\phi)}\right) & \\ * \left(\frac{sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi)} - \frac{sin(\beta+\phi/2) sin(\phi)}{sin(180-\alpha)-\beta-\phi) sin(\phi+\beta)}\right) & \\ * \left(\frac{sin(\beta+\phi/2)}{sin(180-\alpha-\beta-\phi)} - \frac{sin(\alpha+\phi/2)}{sin(180-\alpha-\beta-\phi)} \frac{sin(\phi)}{sin(\alpha+\beta)}\right) & \\ *(sin(180 - \alpha - \beta + \phi)) & \alpha > 0 \ , \ \beta > 0, \ \phi < \alpha + \beta \\ & \\ \frac{D^2 sin(\beta+\phi/2) sin(\alpha+\phi/2)}{2 sin(180-\alpha-\beta-\phi)} & \alpha > 0, \ \beta > 0, \ \phi = \alpha + \beta \\ & \\ \frac{D^2 sin(\beta+\phi/2) sin(\alpha+\phi/2)}{2 sin(180-\alpha-\beta-\phi)} + \frac{D^2 sin(\phi/2-\alpha) sin(\phi/2-\beta)}{2 sin(180+\alpha+\beta-\phi)} & \alpha > 0, \ \beta > 0, \ \phi > \alpha + \beta \\ & \\ \frac{D^2 \tan(\phi/2)}{2} & \alpha = 0 \ , \ \beta = 0 \ , \ \forall \phi \end{cases}$$

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