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DEPARTMENT OF INFORMATION TECHNOLOGY

Bluetooth wireless technology based guidance system

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ABSTRACT

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Short range wireless communication technologies provide a possibility to implement various location based services to the users for a reasonable price. A guidance system that directs the user from one place to another is one such a service.

In this thesis a guidance system based on wireless bluetooth technology is presented. Other wireless technologies are compared to Bluetooth from guidance system point of view. Different possibilities for a system architecture to locate user are presented. Location information is used to create guidance message. Methods for creating path between two places in office building are presented. As a result a cheap Bluetooth wireless technology based guidance system that can be used to provide other wireless location based services is created.

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Hakusanat: Bluetooth, langaton kommunikaatio, paikantaminen, opastepalveluarkkitehtuuri

Lyhyen kantaman langattomat kommunikaatioteknologiat tarjoavat mahdollisuuden toteuttaa erilaisia paikkasidonnaisia palveluita käyttäjille kohtuullisilla kustannuksilla. Opastejärjestelmä, joka ohjaa käyttäjän paikasta toiseen, on yksi tälläinen palvelu.

Tässä työssä esitetään langattomaan Bluetooth teknologiaan perustuva opastejärjestelmä. Muita langattomia teknologioita verrataan Bluetoothiin opastejärjestelmän toteuttamisen kannalta. Erilaisia järjestelmän arkkitehtuuri vaihtoehtoja käyttäjän paikantamiseen esitellään. Paikkatietoja hyödynnetään opasteviestin muodostamisessa. Tapoja muodostaa käyttäjän reitti kahden paikan välillä toimistorakennuksessa esitetään. Työn tulos on halpa langatonta Bluetooth teknologiaa hyödyntävä opastejärjestelmä, jota voidaan käyttää myös muiden langattomien paikkasidonnaisten palveluiden tuottamiseen.

Preface and Acknowledgements

Two years ago I heard first time about Bluetooth wireless technology. It looked very interesting technology and I was excited for the possibility to join in research to find out its possibilities. The result of that research can be seen here.

Several people have helped me to get this thesis finished. I would like to thank: professor Jari Porras for giving me the possibility to be part of the research, licenciate Virginie Verraes for proof reading the thesis and making sure it is written in proper French and all the co-workers at the Communications Laboratory of Lappeenranta University of Technology for the innovating atmoshphere, where research is fun to do.

I would also like to thank my family and friends for keeping real life more interesting than the virtual one.

No animals were harmed or illegal substances were used in making of this thesis.

And so the story begins,

Pegax

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Abbreviations

ACL Asynchronous ConnectionLess

AMPS Advanced Mobile Phone System

API Application Programming Interface

ATM Asynchronous Transfer Mode

CDMA Code-Division Multiple Access

CRC Cyclic Redundancy Checking

CSMA/CD Carrier Sense Multiple Access / Collision Detection

DECT Digital Enhanced Cordless Telecommunications

DSSS Direct Sequence Spread Spectrum

ETSI European Telecommunications Standards Institute

FHSS Frequency Hopping Spread Spectrum

FP Fixed Part

GAP Generic Access Profile

GOEP Generic Object Exchange Profile

GPRS General Packet Radio Service

GPS Global Positioning System

GSM Global System for Mobile Communications

HCI Host Control Interface

HIPERLAN High Performance Radio Local Area Network

HTTP Hypertext Transfer Protocol

IAS Information Access Service

IEEE Institute of Electrical and Electronics Engineers

IrOBEX Infrared Object Exchange

IrDA Infrared Data Association

IrLAN Infrared Local Area Network

IrLAP Infrared Link Access Protocol

IrLMP Infrared Link Management Protocol

IrMC Infrared Mobile Communications

IrTran-P Infrared Transfer Picture

ISDN Integrated Services Digital Network

ISM Industrial Scientific Medicine

L2CAP Logical Link Control and Adaption Protocol

LLC Logical Link Control

LMP Link Manager Protocol

MAC Media Access Control

MP3 MPEG-1 Audio Layer-3

OBEX Object Exchange

OFDM Orthogonal Frequency Division Multiplexing

OPP Object Push Profile

OVOPS Object Virtual Operations System

PCMCIA Personal Computer Memory Card International Association

PDA Personal Digital Assistant

PDU Protocol Data Unit

PHY Physical layer

PIN Personal Identity Number

PP Portable Part

PPP Point-to-Point Protocol

PSTN Public Switched Telephone Network

RF Radio Frequency

SCO Synchronous Connection Oriented

SDAP Service Discovery Application Profile

SDP Service Discovery Protocol

SPP Serial Port Profile

SWAP Shared Wireless Application Protocol

TDD Time Division Duplex

TDMA Time Division Multiple Access

UMTS Universal Mobile Telecommunications Service

USB Universal Serial Bus

WAP Wireless Access Protocol

WLAN Wireless Local Area Network

1 Introduction

Personal mobile devices are becoming more popular. Already mobile phones are more common than personal computers and the sale rates of Personal Digital Assistant (PDA) have been rising. With mobile communication technologies such as GSM (Global System for Mobile Communications), user of mobile phone can not only make simple calls, but have constant access to various sources of information.

As the portable devices become more common, the possibility for communication between them will come topical. Ad hoc networks are networks that are created on demand without need of any central administration provided by a third party such as ISP (Internet Service Provider) or telecommunications operator. Instead, the portable devices can form networks between themselves locally. Ad hoc networking also opens up possibility for markets, offices and like to provide their own information network. [FRO00]

When new improved devices with tons of more new features arrive in market supporting new communications technologies, the customers demand more services that can be used with their modern gadgets. Portable devices with ad hoc networking make it possible for market, office buildings and like to provide information access point that contain local information. Because there is no special network operator needed, customers and visitors can access this information through their portable device without transmitting cost to either the customer or the service provider. Not only information can be provided to the customers, but also different types of location based services. The customisation of services is evolving to not only depend on user preferences but also with the user location. [WIE00] Short range wireless data communications technologies can guarantee that the user is near to the place where service is provided.

At the same time, new markets are built bigger than older ones, office buildings get expansions that make their infrastucture more complex. In this thesis a location based service developed to ease the random visitors navigation in a modern complex office building is presented. This guidance system is based on bluetooth wireless technology.

While Bluetooth has been chosen for the used technology other wireless technologies are presented and compared to the Bluetooth. The special needs of guidance system are discussed and the suitability of presented wireless techniques is evaluated. The guidance system architecture is presented and different approaches for positioning the user and creating the walking path in the building is discussed. The final goal is to provide a service platform, which also has its own functionality.

2 Guidance system

Modern office buildings, malls and universities have huge and complex infrastructure. When a person gets into a building, he usually has no idea where to find the place or the person he is looking for. Therefore the user needs some kind of guidance to achieve his goal and find his way to the desired location. Conventionally, there is two different ways to help a person find his way:

1. Helpful information desk with a nice person.

2. Map with a red spot telling “you are here”.

In the information desk scheme, when the user enters to the building he goes to the information desk. The information desk personel then asks who he is (authentication) and where he wants to go or who he wants to meet. From there the user is either

- Given directions that he should remember.

- Given a small map of the building, where is marked his current position and the position of his target.

- Told to wait until the reception calls a person to come and show him the way to the target from the desk.

The first version works fine as long as the user remembers the directions and does not change his mind about the target. If he changes his mind, he has to go back to the information desk. A map helps to remember and also allows to change the target, as long as the user knows where the target is on the map. This might not be the case if he is looking for certain person. The person coming to pick up the user from desk and direct him to the correct place works fine, but it requires one employee per every user.

On the red spot scheme there are maps on the wall with a red spot and the text: “You are here”. The knowledge of the user location is based on the fact that the user can see the map. If the map is installed in the wrong place or the user uses binoculars to access the information, the red spot is no longer pointing to the place of the user and thus the information is false. Even when getting false information of the location, the user might be able to figure out his way to the correct place according to the plain map.

The guidance system combines these two systems to help the user find the place he wants. Like in the red spot scheme, the location of the user is determined first. Based on the user

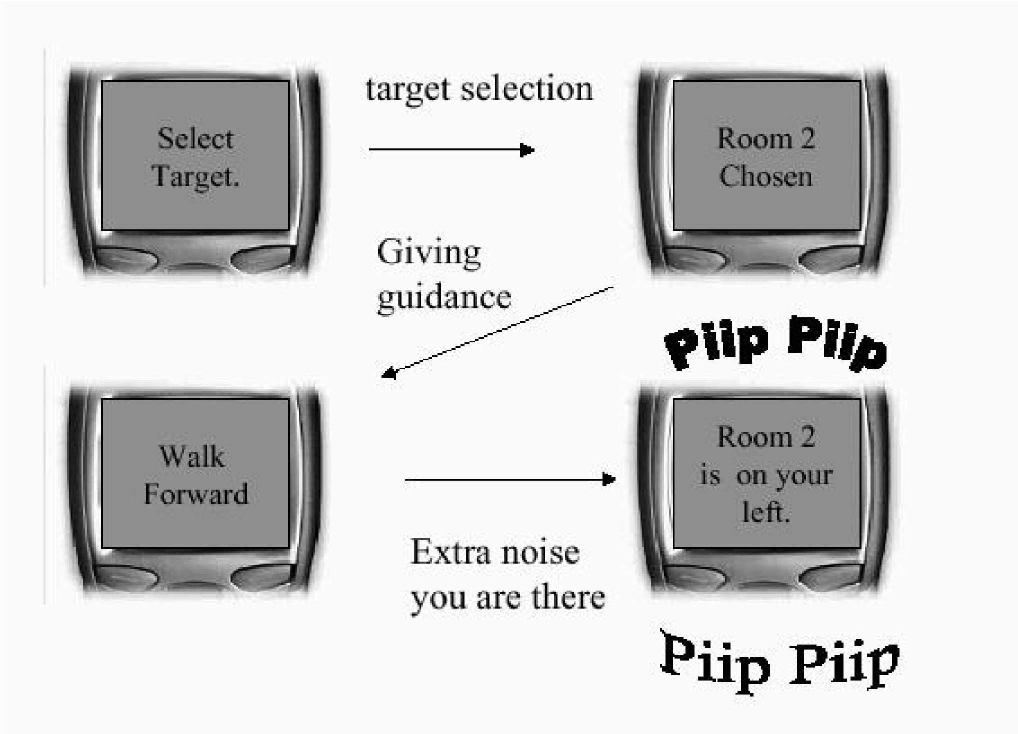

Figure 1: Modern guidance system in action

location guidance information, where to go, is given to the user. This information is directions on how to get to the place (Figure 1) like in information desk scheme, instead of plain map telling your position related to other objects, like in red spot scheme.

To be able to give correct information to the user, the guidance system has to authenticate the user or user device should hold the information concerning where the user wants to go. With a strong authentication, it is possible to create statistics about the user's movements as well as profiling him so that personalized services can be offered. Strong authentication also enables the possibility to control the automatic locks, so that sudden visitor can go only to areas necessary for him in order to get to the desired place.

For usability sake, the guidance system should work wirelessly. Hence, the user's personal commonly used portable device can be utilized to present the guidance information to the user. This means that the wireless system chosen for the system creation should support as many different types and brands of portable devices as possible. Also the information given should be simple enough so that it can be presented in various technological gadgets from mobile phones to media terminals.

When user moves around the building, he should constanly get information so that he will never feel helpless. When there is a crossing he should be told whether to turn left or right or continue, when there is stairs he should be told whether go up or down. To be able to do these, the guidance system has to be able to locate the user fairly accurately eventhough pinpointing is not necessary.

The guidance system eases the life of random visitors in the building. It provides possibility to follow people movements and creates an infrastructure that can be used to provide several other location based services.

3 Wireless technologies

For the guidance system to work, the user device has to be able to communicate with the servers providing the guidance information. Connecting device to the system with wires is impractical and takes a lot of time. It also means there should be several public plugs around the building, where people can connect the wires from their mobile devices. That is why wireless technology is chosen to be used as the communication medium between the user's portable device and the guidance system, to allow a connectivity that requires very little effort from the user.

There are several different wireless technology standards on the market, that could be used for creating a functional guidance system. While Bluetooth wireless technology was chosen for creating such a system, few other technologies are introduced and their capabilities are analysed. These technologies are:

- IrDA (Infrared Data Association) from infrared communications
- Home networking and wireless LAN (Local Area Network) technologies from RF (Radio Frequency) data communication systems
- DECT (Digital Enhanced Cordless Telecommunications) and mobile phone technologies from voice based communicating systems

After an overview, a comparison of these technologies towards Bluetooth is presented, based on their suitability for creating a guidance system. The reasons why Bluetooth was chosen rather than any of those technologies is discussed. More thorough presentation about Bluetooth wireless technology is presented in chapter 4.

There are also several proprietary technologies similar to those mentioned above, For guidance system point of view, proprietary solutions are not practical. It is unreasonable to expect that a random visitors, targeted as the system users, would have devices that support proprietary technologies.

Japan has its own wireless communication standards which would be suitable for creating guidance system in Japan. These wireless systems resemble a lot about the standards mentioned above. Therefore the decisions based on the overviews later in this chapter can be easily adapted to the Japanese standards.

3.1 IrDA standards

IrDA is an organisation that creates and promotes standards for communications that are based on a ray of light at the infrared frequency spectrum.[IRD01] The standardisation of different communication models over infrared allows interoperability between devices from different manufacturers.

IrDA standards can be divided into two groups IrDA Data and IrDA Control. IrDA Data protocols are designed for high speed short range point-to-point communication. Many of these protocols has been adopted to Bluetooth. IrDA Control is directed to lower speed point-to-point or point-to-multipoint cordless control information transmitting.

3.1.1 IrDA data protocols

Mandatory IrDA data protocols are PHY (Physical layer), which takes care of physical layer of communication stack, IrLAP (Infrared Link Access Protocol) which handles the link access, IrLMP (Infrared Link Management Protocol) and IAS (Information Access Service).

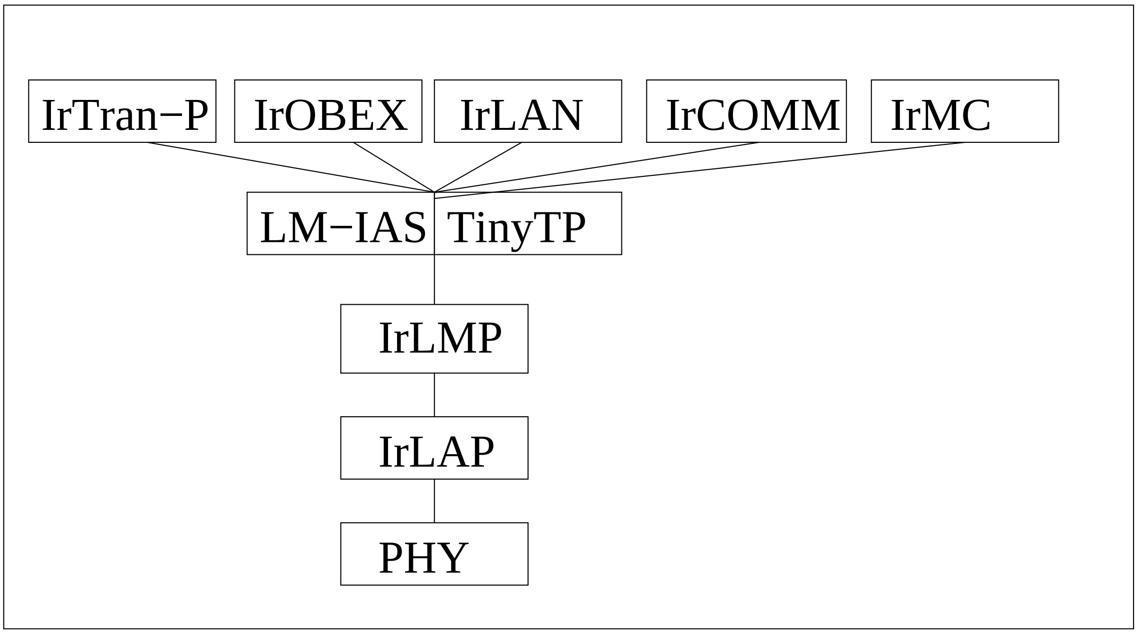

Figure 2: IrDA data protocol stack

Physical layer allows bi-directional communications for at least 1 meter range that has maximum speed of 4 Mbps. CRC (Cyclic Redundancy Checking) is used to assure data integrity. The connection can be either asynchronous 9600-115.2 kbps or synchronous for up to 4 Mbps. IrLAP handles device discovery and assures reliable data connection from device to device. IrLMP allows multiple channels above IrLAP that are multiplexed.

While the mandatory protocols allow communication among infrared enabled devices, it is the optional protocols that really enables the flexible communication between portable devices. IrCOMM allows the removal of cables that are used to connect devices together through general serial communication ports, by emulating the port and its functionality. IrOBEX (Infrared Object Exchange) has been designed for exchanging simple data objects between devices. OBEX (Object Exchange) is discussed more thoroughly in chapter 4.3.6, where the functionality of Bluetooth OBEX, derived from IrOBEX, is defined. IrLAN (Infrared Local Area Network) allows local area network access over infrared while IrTran-P (Infrared Transfer Picture) is dedicated to image transfer. For mobile telephony and communication devices IrMC (Infrared Mobile Communications) protocol is developed. IrMC defines ways for exchanging data such as phone book information, real time voice and call control information between mobile devices. IrDA specification is evolving and new data protocols for different situations are developed constantly.[IRD01]

3.1.2 IrDA control protocols

IrDA control protocols are created for communications between control devices and the device to be controlled. The protocols are used to allow wireless controlling devices, such as keyboards or remote controls, to interact with controllable devices such as laptop computers. Therefore IrDA control protocols have rather small transmission rate.

The mandatory IrDA control protocols are PHY, MAC (Media Access Control) and LLC (Logical Link Control). PHY enables minimum of 5 m range of communication with 75 kb/s data transmission rate at the top end and is optimised for low power usage. All data packets are protected with CRC.

MAC enables the host device to control up to 8 target devices and ensures a fast response time with a 13.8 ms polling rate. Asymmetric MAC provides dynamic peripheral address assignment. LLC provides data sequencing and retransmissions, allowing reliable communications. [IRD01]

3.1.3 Suitability for guidance system

IrDA protocols are supported by many different types of user devices from different vendors. Therefore, it is very likely that a random user would be able to get the guidance information from the guidance system. The data rates are high enough to deliver the guidance information or even small graphical map of the area. Since the communication has to be done from close range, it is quite easy to locate the whereabouts of the user.

On the other hand, there is need of direct line of sight and therefore the user device needs to be pointed towards the guidance system in order to form the connection. Thus getting guidance information requires user interaction every time and therefore is not transparent to the user. User authentication requires also some external method as IrDA itself provides no method for recognising different devices. There is a password based approach in IrTran-P, but typing a password every time to get an information is too much to ask from the user for this type of service. [SUV00a] [SUV00b]

3.2 Wireless local area networks

Standards for wireless local area networks have been defined by both IEEE (Institute of Electrical and Electronics Engineers) and ETSI (European Telecommunication Standards Institute). The standards themselves have slight differences, which are discussed in the following sub-chapters. From the guidance system point of view, their functionalities resemble each other so much that they can be thought as one technique. They have almost same strengths and weaknesses when creating large guidance system.

3.2.1 IEEE standards

IEEE 802.11 is the IEEE recommended specification for wireless local area networks. IEEE WLAN specifications have evolved from the original IEEE 802.11 to several newer standards. Some of these newer standards use the original 2.4 GHz radio frequency. Other standards utilize the higher frequencies to avoid frequency congestion. These technologies differ from each other on details. However, when creating the guidance system, all WLAN technologies seem quite similar at the bottom level. It is also good to remember that the specification itself does not guarantee the interoperability of the different devices from different manufacturers. Even though, in most cases all devices understand each other, there has been some interoperability issues between devices from different vendors.

Three of IEEE WLAN standards use 2.4 GHz frequency. Basic IEEE 802.11 that can be thought as two standards in one, uses CDMA (Code-Division Multiple Access) for air interface multiplexing with two different and incompatible types of spread spectrum schemes: FHSS (Frequency Hopping Spread Spectrum) and DSSS (Direct Sequence Spread Spectrum). The last 2.4 GHz frequency using WLAN standard from IEEE is IEEE 802.11b which uses DSSS. DSSS is more resilient to the interference since it transmits on all frequencies simultaneously, but it requires more power that is not available on smaller devices. [IEE01]

The last IEEE WLAN standard is IEEE 802.11a that uses 5 GHz frequency. On air interface it utilises a multiplexing technique called coded OFDM (Orthogonal Frequency Division Multiplexing). OFDM is designed to minimise the interference caused by signals bouncing from the walls and therefore provides a good reliability inside buildings. The disadvantage of 802.11a is that it cannot be used in Europe, where the 5 GHz frequency is reserved for ETSI HIPERLAN standards mentioned in next chapter. [BRA01] [CHE01] [DOR01]

IEEE 802.11 standards can be used in 2 different modes: *base station* or *ad hoc mode*. In the base station mode there is a dedicated base station that provides connections when client devices request them. In ad hoc mode the devices can create the networks ad hoc. Ad hoc mode allows more flexibility to connection creation and service providing as any device can initiate the connection. Therefore ad hoc mode is more suitable for a guidance system although it is not required. [DOR01][FRO00]

3.2.2 ETSI standards

ETSI has developed its own standards for wireless local area networking named as HIPERLAN (High Performance Radio Local Area Network). HIPERLAN is divided into two types, Type 1 and Type 2, which differ slightly from each other on radio modulation area. Both use 5 GHz frequency, which is dedicated to them, Thus other wireless devices cause very little interference. This is also the drawback of HIPERLAN as the frequency dedication applies only in Europe and therefore HIPERLAN technology can currently only be used there. [BRA01]

HIPERLAN/1 uses TDMA (Time Division Multiple Access) technology with GMSK (Gaussian Minimum Shift Keying) on its air interface modulation, providing 23.5 Mbps bandwidth. Many ideas for HIPERLAN/1 have been adopted from GSM mobile phone technology due the good experiences from that standard. Maximum of five HIPERLAN/1 channels can be used in the reserved band. The specification covers only physical and MAC layer, leaving higher layer specifications to be defined in the other standards. This might cause interoperability problems as the higher layer implementations might utilise

HIPERLAN in different ways. [ETS01a]

HIPERLAN/2 provides wireless ATM (Asynchronous Transfer Mode) by using OFDM, the same modulation used in IEEE 802.11a. There are also other similarities between these two techniques, as they also use the same radio frequency, provide 5.4 Mbps bandwidth and their physical layers resemble each other. Therefore there has been discussion to unify them as one standard. However MAC layer interfaces have a lot of differences and will cause lot of problems for unifying the systems. [ETS01b] [JOH99]

For the future, ETSI is defining two new specifications: HIPERACCESS and HIPERLINK. HIPERACCESS goal is to provide long range point-to-multipoint access with high speed (25 Mbps) for to wide variety of networks like UMTS (Universal Mobile Telecommunications Service), ATM and IP based networks. The expected band is between 40.5-43.5 GHz. First specifications are expected in this year. HIPERLINK will provide short-range interconnection of HIPERLANs and HIPERACCESS with very high-speed (155 Mbps) and is expected to work in the 17 GHz band. The HIPERLINK specification is currently just in the planning stage. [ETS01a]

3.2.3 WLAN suitability for guidance system

WLAN techniques have more than enough bandwidth for sending the guidance information. That amount of bandwidth can be used to provide a wide variety of services to the user. With the MAC address, all the WLAN cards are easy to recognise from each other and thus the user area can be identified rather easily. WLAN systems also support automatic connection creation and roaming, so the user can be connected to the server all the time and get the guidance information through the open web browser.

System	Spectrum	Data	Air Interface	Usability	Range
IEEE 802.11 (FHSS)	2.4 GHz	1 Mbps	FHSS	World	50
IEEE 802.11 (DSSS)	2.4 GHz	2 Mbps	DSSS	World	100
IEEE 802.11a	5 GHz	54 Mbps	OFDM	U.S.A	50
IEEE 802.11b	2.4 GHz	11 Mbps	DSSS	World	100
HIPERLAN/1	5 GHz	23.5 Mbps	GMSK	Europe	50
HIPERLAN/2	5 GHz	54 Mbps	OFDM	Europe	50

Table 1: WLAN specifications [ANG00] [BRA01] [DOR01]

The problems with WLAN is that it is mainly provided on PCMCIA (Personal Computer Memory Card International Association) cards which are rather expensive compared to the expected price of bluetooth or current price of IrDA. Because of the price it is not expected that most devices that common users of the guidance system would have support the WLAN. Even though it is easy to define on which WLAN base station area the user is, the exact location of the user is much harder to determine since WLAN's have a quite long range. From the range point of view, HIPERLAN and older 802.11 have a slight advantage over newer 802.11 standards as their ranges are only 50 m and thus giving a bit more accurate positioning than those which range is 100 m and higher. With directional antenna the range will be higher than with an omnidirectional antenna. The ranges presented on the table 1 are for normal communication ranges with an omnidirectional antenna. Actual devices using these techniques can be heard from longer distance, even though the communication data rate is not as high. Several companies have announced that they are developing methods to provide accurate positioning, based on WLAN technology, but no such products are on the market yet.

The power consumption is device dependent though modulation technology and radio frequency affect it. FHSS needs less power than OFDM. 5 GHz frequency consumes more power than 2.4 GHz. Therefore regarding power consumption, IEEE 802.11 (FHSS) is more likely to be supported on smaller portable devices that have light power source than those that consume more power. [ANG00] [CHE01]

3.3 DECT

DECT is the ETSI standard for cordless telephony systems. It was originally used only in Europe, but during the past years it has achieved worldwide acceptance. It works on the dedicated radio frequency between 1.880-1900 MHz. DECT uses TDD (Time Division Duplex) and TDMA on the air interface multiplexing. On one channel there can be 24 TDMA slots which results in a maximum of twelve users, because of the use of TDD. The maximum range of DECT is 300 m and it offers 1.152 Mbps gross data rate. [LIN01]

DECT system consists of base stations called *DECT Fixed Parts* (FP) and user devices called *DECT Portable Parts* (PP). The basic standard covers only the interface between FP and PP, but there are profiles that define access to different types of network, such as GSM or ISDN (Integrated Services Digital Network) network. Handover process has been defined to DECT so that when a PP moves from the radius of one FP, the connection is handed over to the new FP on which radius the PP is. [DOR01]

DECT support has been added in many office buildings to allow intercom system work freely. Therefore, existing infrastructure for guidance system purposes can already be found installed in many places. DECT network can be used to offer several simple services by utilising its data connection. The terminal identification is also possible through the dedicated PIN (Personal Identity Number). Handover system of DECT is also very useful when services are used while moving around the DECT network area, as many services rely on a stable connection.

The major disadvantage of DECT from the guidance system point of view is that practically only phones support it. Also DECT device functions only in local DECT network. Thus, it is highly unlikely that a random user would carry device with the correct DECT support with him. Roaming between different DECT networks is not possible. Since DECT supports connections of 300 m, it is really hard if even possible, to get an accurate location information, thus making the guidance system inaccurate.

3.4 Wireless home networking

Wireless home networking utilises 2.4 GHz radio frequency to transmit data and voice in home or office environment. It allows multiple devices, mainly PC's, to share wirelessly different services, such as internet connection and printers as well as mobile intercommunication system, thus offering flexibility and mobility to the users. Behind Wireless Home Networking is HomeRF working group, a coalition of several manufacturers, such as Intel, Compaq and Motorola. To achieve the goal of inexpensive RF-based data and voice connection, they have developed Shared Wireless Application Protocol (SWAP). What makes SWAP interesting is that it bases on both DECT and WLAN technologies presented in the previous chapter. SWAP tries to combine their strengths and hide their weaknesses in the home environment.

3.4.1 SWAP

HomeRF working group named its industry specification for wireless data and voice communication as SWAP (Shared Wireless Access Protocol). It works on 2.4 GHz radio frequency and uses frequency hopping to achieve reliability. SWAP system can operate either as an ad hoc network or managed network.

A wireless home network can have a maximum of 127 nodes which can be of 4 different types:

- Connection point that manages the network when there is a time critical communications such as voice conversation or video stream. Connection point can also provide a gateway to PSTN (Public Switched Telephone Network).

- Voice terminal, such as phone, is used to communicate with a base station.
- Data node, for data communications
- Voice and data node that supports both voice and data communications.

The technology for voice connection is derived from DECT and therefore voice connections use TDMA technology. IEEE 802.11 FHSS physical layer with CSMA/CD (Carrier Sense Multiple Access / Collision Avoidance) service is adopted for high speed data connection. As these technologies are well known and used in several products, it makes easier for the product manufacturers to create support for SWAP too. [BRA01] [GUP00] [HOM01] [HEL01] [KOB00]

The current version of SWAP is 1.0. Version 2.0 is due to be released by the end of 2001 and should have a better support for the streaming media. The products on the market supporting SWAP 1.0 varies widely and cover many areas important in home environment. The most common products are USB (Universal Serial Bus) dongles and PCMCIA cards that can be used on PC's and on some PDA's. There are also internet access point for PALM V as well as MP3 (MPEG-1 Audio Layer-3) audio player that will stream radio and audio stations to any room of home. An alarm clock that can function together with a PC to get a person awake early enough for meetings can also be very useful. [OHR01]

3.4.2 Suitability for guidance system

HomeRF has the necessary communicating functionalities to create functional guidance network. The 127 connections are more than enough for fullfilling the guidance system needs. The data rate of 1 Mbps is also enough for the guidance system.

The communicating radius of 100 m requires a complex system in order to pinpoint user location for the guidance information. The price for HomeRF products are lower than for WLAN products, but seems still a bit too high to be implemented on cheap and small devices. HomeRF needs a 100 mw transmitter. This means its power consumption is rather high and therefore it is not expected to be used in smallest portable devices but rather in laptops and the likes. [ISE99]

3.5 Bluetooth

Bluetooth is a short range wireless ad hoc networking standard developed by Bluetooth SIG. It resembles IEEE 802.11 in a sense that it uses 2.4 GHz ISM (Industrial Scientific Medical) radio frequency with FHSS Air Interface. Class 3 Bluetooth device has a range of 10 m with 1 mW transmitter power. The standard has also defined Class 1 and Class 2 devices which use 100 mW and 2.5 mW transmitting power and therefore have also longer ranges up to 100 m. [MET99b] Gross data rate for Bluetooth is 1 Mbps, from which one way maximum rate is 768 kbps.

The average power usage of Bluetooth card with 100 mW transmitter is 0.55 mA, when it is listening normally waiting to be called. When the device is connected to piconet the power consumption rises to an average value of 35 mA. When transmitting the peak value is 75 mA. On the low power modes, the used power is only 60 μA. [KAR00] These values mean that Bluetooth can be installed in various types of small devices as it does not require too much power. The price of Bluetooth chip is expected to go as low as $5 per chip, which furthers the chance for it to be installed on new portable equipment.

From the guidance system point of view, Bluetooth has many advantages. Its short range allows fairly accurate positioning of the user. Its low power consumption and expected low price will help the adaption of Bluetooth technology to various portable devices. The huge base of Bluetooth enabling devices makes it more likely for a random user to have such a device that can be used to receive the guidance information.

The problem with Bluetooth is that there is not many devices supporting it yet. Therefore one can only speculate whether it will become a commonly used standard or not. According to Gartner, by 2004, 70 % of new cell phones and 40 % of new personal digital assistants will use wireless technology for direct access to Web content and enterprise networks. [GAR00] Cahners In-Stat Group expects shipments of Bluetooth-enabled products to reach 955 million units in 2005.[CAH01] These figures show that there is a strong belief in Bluetooths success.

3.6 Mobile phone technologies

There are many technologies used by mobile phones such as GSM, GPRS (General Packet Radio Service) and AMPS (Advanced Mobile Phone System). These technologies rely highly on the expensive base station network owned usually by telephone companies. Different technologies have various techniques for locating users. In fact in the United States the mobile operators are required to be able to provide the location information when needed in cases like medical emergency. The location information is not very accurate and currently the user can be located within the area of 100 m radius.

Mobile phone technologies have the required functionality for positioning and providing the necessary information to the user. Therefore it would be possible to use mobile phone technologies to create a functional guidance system. The problem with such a system is that existing networks are owned by telephone companies and thus sending the guidance messages would be rather expensive to the service provider. Therefore the service would probably cost too much for the user or the company ordering the service. Creating your own network require licenses and the base station technology is very expensive. On the other hand, these technologies could be useful when the guidance system would cover a very large area, such as a part of town, especially if GPS (Global Positioning System) could be used to pinpoint the location of the user even more accurately.

3.7 Comparison of wireless techniques

The wireless technologies discussed in the previous chapter have some common features with each other. They also have their own specific areas in which they excell. For some parts, the excelling areas overlap, like in different WLAN standards. Before deciding which technology should be used, the differences should be evaluated thoroughly keeping in mind the requirements of the system under development.

Compared to the other technologies, Bluetooth has few advantages. It has a low power consumption and therefore it is presumed to be supported by most mobile devices. The huge amount of devices using Bluetooth pushes the price for a Bluetooth chip down. It has been estimated that the price for Bluetooth chip will go as low as $5 per chip while they currently can be bought for $9.

Bluetooth and IEEE 802.11 utilise the same radio frequency. This causes some interference when both technologies are used. Due to Bluetooth effective frequency hopping scheme its performance is less affected on WLAN interference than WLAN performance is affected on Bluetooth interference. [KAR00] The same frequency usage would also affect devices applying HomeRF. Different technologies have been compared more closely according to their usability in different situations on various articles. [HUN99] [OHR01] [SUV00a] [SUV00b] [ZOL01]

Different wireless technologies can also support each other. Instead of thinking technologies being competitive toward each other, they can be in some cases thought as complementary. Since Bluetooth uses some IrDA protocols it may also support IrDA development. Bluetooth usage forces manufacturers to use protocols that are similar to those in IrDA protocol stack, so that devices can inter operate seamlessly. Therefore providing IrDA access for a service would not need extra effort or extra cost, especially when we remember that infrared transceiver cost only few cents compared to the expected few dollar price of Bluetooth chip. [DOR00] A service access point would benefit of supporting both WLAN and Bluetooth wireless technologies. Bluetooth being cheap and therefore expected to be supported by most mobile would bring lot of potential users for the access point services, while through WLAN more complicated services can be offered to those that desire them.

3.7.1 Wirelessness and guidance system

Technology / Ability	Bluetooth	IrDA	Wireless LANS	HomeRF	DECT	Mobile phones
Wireless medium	2.4 Ghz RF	Infrared	2.4 or 5 Ghz RF	2.4 Ghz RF	1.88-1.9 Mhz RF	Various RF:s
Data rate	1 Mbps	1-16 Mbps	1-54 Mbps	1 Mbps	1.152 Mbps	Varies
Range	10 or 100 m	< 10 m	50 m ->	50 m	300 m	Kilometers
Id	BD_ADDR	External	MAC	MAC	PIN	SIM id
Price for user	$5 expected $9 current $200 card	Few cents	$100 ->	$50 ->	$50 ->	$100 ->
Enabling type	Integrated or external card	Integrated	External card	External card	Integrated	Integrated

Table 2: Comparison of technologies

In table 2 different wireless technologies are compared based on the attributes needed for the guidance system.

- A wireless medium should make the use of the guidance system easy for the user. Infrared connections major drawback is the need of straight line of sight, which forces the user to point the infrared port of his device towards the guidance system access point. On the other hand this also allows the user to be located very accurately.

- Short range means that the area where the device is noticed is smaller. Therefore cell based positioning is more accurate. On the other hand if other methods for positioning exist, longer range means there is a need for fewer access points to the system.
- Identification is needed for authenticating the user.
- The lower the price the more likely it is that the given technology is on the portable device the user carries. The implementation methods also affect how common the technique is. It is not likely that a user who has no need for a LAN connection on his PDA would buy a $100 PCMCIA WLAN card. Instead the PDA might have an integrated $5 Bluetooth chip or an IrDA port that costs only few cents.
- Data rate on all wireless techniques is more than adequate for a basic guidance system. If the guidance is given on other ways than plain text, or other services is implemented over a guidance system, higher data rates can turn out to be useful.

3.7.2 Conclusion on wirelessness

Bluetooth has many advantages for creating a guidance system, especially if the future of Bluetooth is as glorious as predicted. While in this thesis the guidance system bases solely on the Bluetooth wireless technology, another possibility would be to create a hybrid system. Wireless LAN or home networking implementation would complement the Bluetooth network to enable services that require more bandwidth than Bluetooth can provide. It would also allow a wider spectrum of services to be implemented. This approach has been taken by some manufacturers working on dual mode WLAN solution that implements both IEEE 802.11 and Bluetooth. [PET01]

4 Bluetooth wireless technology

In this chapter, we study the chosen technology for the guidance system: Bluetooth wireless technology. The basic functionality of this wireless technology is presented and a brief introduction to the important protocols from the guidance system point of view are introduced. More detailed and thorough presentation of Bluetooth standard and its utilisation can be found from various books. [BRA01] [MIL01]

4.1 Bluetooth basics

Bluetooth is a short range radio link that originally was intended to only replace the cable(s) connecting portable and/or fixed electronic devices. It operates in the world wide free and unlicensed ISM band at 2.4 GHz RF. Each Bluetooth device has a unique Bluetooth address defined to it that can be used for identifying different devices from each other. Bluetooth device can support asynchronous data channel, up to three simultaneous synchronous voice channel or a channel which simultaneously supports asynchronous data and synchronous voice. To add reliability, Bluetooth uses frequency hopping scheme, where the frequency hopping bases on the clock of piconet's master.

4.2 Bluetooth network topology

Bluetooth network consists of *master* and *slave* devices. The master is the device that initiates the connection creation and the slave is the device to whom the master creates the connection. After creating the connection the roles can be switched. The master can have up to 7 active connections to different slaves and several others slaves locked in park mode to follow its channel hopping sequence. This type of network formed with Bluetooth is called *piconet*.

One Bluetooth device can only be the master of one piconet. The device that is master in one piconet can be slave in others. Also one device can be slave in many piconets. Overlapping piconets i.e. piconets that have common devices form a scatternet. In figure 3 there are two piconets where one of the piconets have one master and three slaves. One of the slaves of the bigger piconet is the master of the other piconet. These two piconets therefore form a scatternet. These piconets are not time or frequency synchronised on each other, but follow the hopping sequence of their masters. Device that is member of two piconets follows hopping sequencies of both piconets. [MOR01]

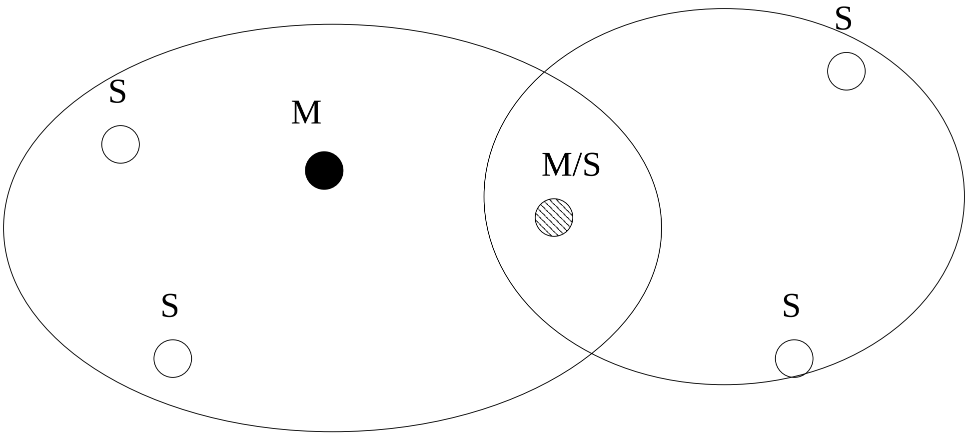

Figure 3: Scatternet consisting of two piconets

In the physical layer, Bluetooth supports two different types of links between Bluetooth devices:

- circuit switched synchronous connections (SCO, synchronous connection oriented).
- packet switched asynchronous connections (ACL, asynchronous connectionless).

SCO links are point-to-point links formed between master and specific slave, they are used for time dependent services such as voice. A master can have a maximum of three SCO links to either one slave or different slaves, while a slave can have a maximum of three SCO links to one master or one SCO link for two different masters. One voice channel supports 64 kbps of streamed voice for each direction.

ACL links are point-to-multipoint links between master and slaves in piconets and they support both asynchronous and isochronous services. There can be only one ACL link between a master and a slave. ACL links are used for data transfer with packet retransmission method applied, to ensure the integrity of the data. A master can broadcast to its slaves by not addressing the ACL packet to a specific slave. Asynchronous channel supports either 433.9 kbps synchronous channel or 723.3 kbps asynchronous where the return channel is 57.6 kbps.

4.3 Bluetooth protocol architecture

There are four basic protocols that all Bluetooth applying devices have to have implemented. These are *baseband*, *Link Manager Protocol* (LMP), *Logical Link Control and Adaption Protocol* (L2CAP) and *Service Discovery Protocol* (SDP). Baseband and LMP reside under Host Control Interface (HCI) and are usually implemented in hardware. Their functionality is controlled through HCI from the software of the device. L2CAP and SDP are software that is run on the Bluetooth applying device to ensure a minimum interoperatibility between all the devices using Bluetooth wireless technology. [GEH00]

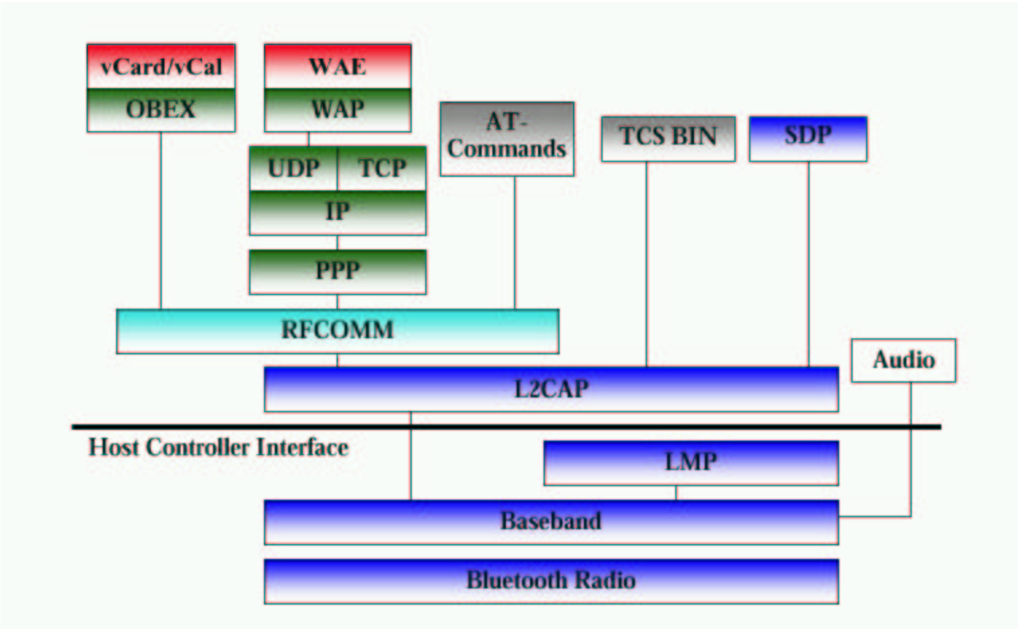

Figure 4: Bluetooth protocol architecture

RFCOMM is used to emulate serial cable connection and is referred as cable replacement protocol. Higher level protocols such as PPP (Point-to-Point Protocol) and OBEX use RFCOMM. Audio connections have their own protocols. The upper layer protocols can run on top of different lower level protocols. For instance OBEX could be implemented on top of PPP or IP instead of RFCOMM. In this project the OBEX layer was implemented on top of RFCOMM as it was defined in Bluetooth profiles in chapter 4.4. Therefore it is also used in the guidance system at that place. The whole Bluetooth protocol architecture is presented in figure 4. [MET99a][KAS00]

The guidance system needs a simple protocol to enable communication between the user and the system. The chosen protocol for this is OBEX. To allow the OBEX connection, RFCOMM is needed as well as the basic lower layer Bluetooth protocols. These protocols are overviewed in the following chapters. How these protocols are used to create a working Bluetooth application is discussed in the chapter 4.4.

4.3.1 Lower layer protocols

Lower layer protocols are Baseband and LMP. These protocols are usually implemented in the Bluetooth chip. The communication to the chip is done through HCI, which has been defined for serial port, USB and PCMCIA. While it is good to know how these protocols work, the implementor of the guidance system does not have to deal with them. Lower layer protocols take care of forming SCO and ACL links, frequency hopping, low level error connection, link level encryption and many other Bluetooth specific issues. These protocols are usually implemented in the Bluetooth chip, which is called Bluetooth host.

4.3.2 HCI

Between the Bluetooth host and the software stack there is an interface called HCI, through which the functionality of the Bluetooth host can be controlled. Most of the functionality needed by the guidance system can be done by using the higher layer protocols. However since the upper layer protocols are specified for special needs, Bluetooth specific commands cannot be done through them. For the guidance system it means that finding out the devices on the area of guide has to be done with HCI commands. HCI is also needed to find out the unique address of the device that wants to join the guidance system, as L2CAP does not show the 32 bytes BD_ADDR but instead the user friendly name for the device like “Printer”.

4.3.3 L2CAP

L2CAP resides on top of HCI. It adapts the higher level protocols over the baseband. L2CAP handles the link control for packets that contain upper layer payload while LMP under HCI takes care of other link controlling. L2CAP provides protocol multiplexing, segmentation and reassembling for upper layers connection oriented or connectionless data services.

4.3.4 SDP

SDP is used to find out what types of services the given device supports. This ensures that a device which has no support for audio, is not sent any audio messages. SDP is also used to find certain types of services such as printers or calendars when they are needed.

In the guidance system, SDP is needed to find out what kind of guidance messages can be sent to the user.

4.3.5 RFCOMM

RFCOMM is a serial line emulation for Bluetooth and is also referred as cable replacement protocol as it emulates RS-232 standard control and data signals. Many existing applications have been implemented to be used over serial cable and thus the change from cable to Bluetooth should cause very little trouble. RFCOMM protocol is also heavily influenced by IrCOMM from IrDA specification and therefore changing application to use RFCOMM instead of IrCOMM should be a fairly easy task. OBEX implementation of Lappeenranta University of Technology has been implemented over RFCOMM.

4.3.6 OBEX

OBEX is protocol adopted from IrDA specification. IrDA Object Exchange has been designed for simple data exchange between devices supporting infrared communication with IrDA protocols. The strength of OBEX is its simplicity and the good support on the portable devices already using infrared as communication medium. The chosen protocol for the guidance system is OBEX mainly for two reasons:

1. OBEX is a very light protocol but has enough functionality for the guidance system needs.

2. OBEX protocol is used on IrDA devices and therefore most of mobile devices have implemented it already.

OBEX communication bases on the model of request and response, where one device is server and another is client. Actions are initiated by the client and it can either PUSH or PULL objects to or from the server. PUSH and PULL models are presented in more detail at two theses done by workers of this project. [HUO00][KAR01] How to use OBEX is explained in the chapter 4.4 when discussing the OBEX profile.

4.3.7 WAP

Wireless Access Protocol has been developed by WAP forum [WAP01], for browsing information over a wireless communication medium. While in this thesis the chosen technology has been OBEX, the required functionality could have been done with WAP too. The current version of Bluetooth specification do not define any use case that bases on WAP. It is expected though that in the next version of Bluetooth specification, the WAP usage is defined. The new specification can open new possibilities as OBEX is suitable only for some types of services and can be cumbersome for browsing through different information. [SEE99] [WAP01]

4.4 Bluetooth profiles

Since Bluetooth can be used on several devices designed for different types of use, there has to be a common rules for these devices to communicate. Profiles provide a way to identify the capabilities of Bluetooth enabling devices. For instance, a headset supports only headset profile and is not therefore expected to understand OBEX protocol messages. Due the profile definitions, other devices do not try to contact headset with a protocol it doesn't understand. The profiles base on different use cases and guarantee the interoperability between different types of devices from different manufacturers in such a case. [ANO99]

Profiles can be divided in groups according to the service type they provide as shown in figure 5. Every Bluetooth enabled device has to follow at least the generic Bluetooth access profiles, GAP (Generic Access Profile 4.4.1) and SDAP (Service Discovery Application Profile 4.4.2). These profiles make sure that the devices have the minimum understanding of each other and do not cause problems for the functionality of each other. [ANO99]

From the existing Bluetooth profiles, the following ones have been chosen to be used in the guidance system

- *Generic Access Profile* : To ensure basic interoperability required for all bluetooth devices.
- *Service Discovery Application Profile* : To allow the user's portable device to find the services provided by the guidance network and the network to find out the capabilities of the user's device.
- *Serial Port Profile* (SPP): To provide the necessary lower layer definitions for OBEX communication.

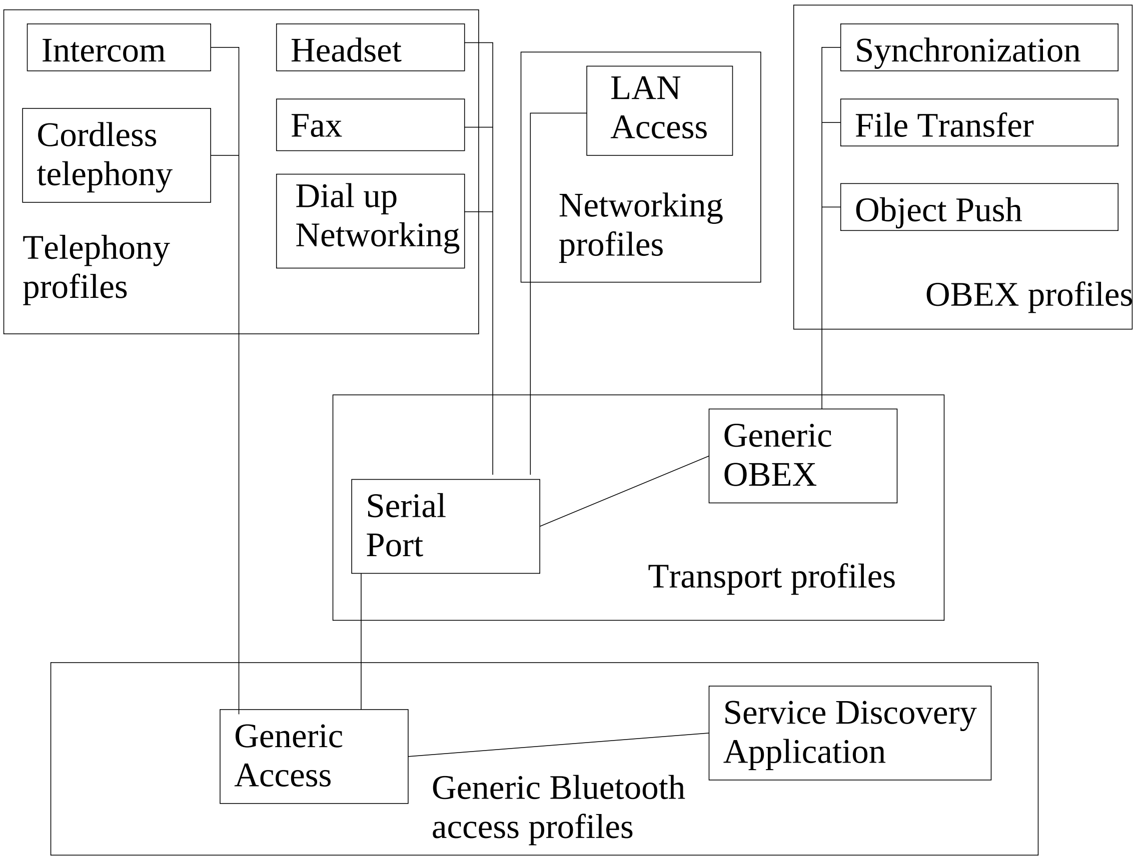

Figure 5: Profile groups and relations

- *Generic Object Exchange Profile* (GOEP): To define the basic OBEX communication needed for guidance message delivery.
- *Object Push Profile* (OPP): To allow pushing guidance message from the guidance system to the user's device.

Other profiles can be used to give more flexibility for providing services. As new profiles are also developed constantly. It might be that in the future better ways to either create such a guidance system or enhance the functionality of the system presented in this thesis appear.

4.4.1 Generic Access Profile

Whatever is the main purpose of a device utilising Bluetooth, it should at least follow the definitions of Generic Access Profile (GAP) to ensure the basic interoperatibility with other Bluetooth using devices. GAP describes the use of Bluetooth baseband and LMP and in security related issues also some of the higher layers. It tells how devices use Bluetooth wireless technology to find out other devices, how to present themselves to each other and how to form a communication line to each other.

Representation of different basic Bluetooth parameters are defined in the GAP. All devices should use same terms about these parameters and present them in the same format on the user interface. These parameters are:

- *Bluetooth device address*, which is the unique 48 bit hardware address.
- *Bluetooth device name*, which is the string that the device wants users to see.
- *Bluetooth passkey*, which is used for authentication purposes before link keys have been exchanged.
- *Class of device*, which informs the type of device defined at the Bluetooth dedicated numbers list.

The Bluetooth device address is important in following the movement of the different user units. This address value is used only at lower layers. L2CAP takes care of matching the name of the Bluetooth device visible to the user to the correct Bluetooth device address. The other two parameters are also important for the functionality of the Bluetooth, but from the guidance system creation point of view, they are insignificant.

Two devices knowing they share a link key are bonded. During bonding, the link managers authenticate each other and share the secret key to enable secured communication.

Modes

For Bluetooth devices, several types of operating modes, affect their functionality in different situations. Discoverability modes define the behaviour for the inquiry messages of the Bluetooth baseband. There are three discoverability modes: *general discoverable*, *limited discoverabl*e and *non-discoverable mode*. The general discoverability mode is used when the device needs to be discoverable continuously and it answers to devices making general inquiry. The limited discoverable mode is used for devices that need to be discoverable only temporarily for a reason or another. In this mode the device answers to limited inquiry. In non-discoverable mode, the device does not respond to any inquiry. General discoverable mode is the mode where the user device should be. This way, when guides of the guidance system search for the devices on their range, they can found the users device. All the guides also has to be in this mode.

Connectability modes define the behaviour for paging messages of Bluetooth baseband. There are two connectability modes, *connectable* and *non-connectable*. In the connectable mode the device enters periodically to the PAGE_SCAN state allowing link forming with other Bluetooth devices. When in the non-connectable mode the device does not enter to PAGE_SCAN state and thus does not respond to the paging messages.

Pairing modes define whether the Bluetooth device allows itself to be authenticated by other devices or not. The two modes are named *pairable* and *non-pairable* modes. The user device has to be in pairable mode so that the guidance system can recognise it.

Three different modes define the different levels of security. In Mode 1 no security is applied thus no authentication is done. In modes 2 and 3 authentication is arranged and encryption used. Mode 2 does not use security methods until L2CAP link is established while mode 3 applies security right when ACL link is up. [BRA01][MIL01]

4.4.2 SDAP

Devices using Bluetooth wireless technology can provide different types of services. Service discovery protocol is used for detecting the types of services that Bluetooth enabled devices offer and this way help for devices to find common methods to interact. SDAP defines the way to use Bluetooth protocol stack to create service discovery application. SDAP provides service primitives that can be used by application for service discovery, in a sense forming an Application Programming Interface (API). SDAP also lists features that are required for SDP, L2CAP, LMP and the link controller to enable services discoverable to others.

In the guidance system, the service discovery is done by the user unit, to find out what types of services the guides of system can provide. Therefore the guides have to respond to the service queries that they support at least to OBEX and PUSH profiles. If additional services are provided on top of the guidance system, the service discovery is needed to define what types of services can be provided for the given user unit. [BRA01][MIL01]

4.4.3 SPP and GOEP

Serial Port Profile and Generic Object Exchange Profile are both abstract profiles in the sense that they are not based on any specific use case. They are intended for middleware creation residing underneath the actual use case profiles, on which the actual applications will be based on. They handle the basic connecting problematics and let the higher layer profiles deal with the specific use cases.

SPP forms a basis for all the applications using RFCOMM for peer-to-peer communication between devices. For SPP the communicating devices are thus peers. Therefore the roles of master and slave have no meaning for SPP.

SPP describes exactly how to utilise RFCOMM, L2CAP and SDP protocols to establish emulated serial connections. The routine goes in a such way that at first one of the devices uses SDP to find the wanted RFCOMM server channel. These channels are used to multiplex RFCOMM connections and certain channels are reserved for certain services, like OBEX connections. When the correct channel is found out from the target device and the possible authentication procedure is gone through, then creation of L2CAP connection is done and finally the RFCOMM connection on the chosen server channel is established. After this a normal serial traffic can flow between devices.

In many Bluetooth profiles the communications are defined as peer-to-peer symmetric connections, but GOEP defines the roles for client and server when using the OBEX protocol. The roles of client and server at GOEP has no relations to the master and slave status of the device in a piconet but is defined independently. [MIL01] Server is the device that provides the object exchange service and client is the device that either pulls or pushes the objects. The separation might seem vague as what is pulled by one devices may be thought as pushed by others. The main difference is that in a GOEP model the initiator is the client, the client thus connects to the server and either pushes data or pulls data. The server can only obey the request of the client. For the guidance system this means that the user unit has to be activated as a server so that the guide is able to push the guidance information.

For authentication, GOEP uses bonding method as described in GAP. The devices engaging object exchange have to know and trust each other to avoid the risk of getting unwanted business cards advertisement and so on to the device.

GOEP also defines how to establish and terminate an OBEX connection as well as two fundamental operations: push and pull. The use of these operations when creating communicating applications is defined by other profiles namely Object PUSH, File Transfer and Synchronisation Profile.

4.4.4 OPP

The main use case profile used in guidance system is Object PUSH Profile. OPP is the simplest of profiles that bases on GOEP functionality. It defines one way traffic: how data objects can be pushed from client to server or pulled from server to client. It has been designed to solve the problem of how to exchange business cards between devices i.e. how to push a vCard to another user. Even though the design bases on a vCard, pushing all types of OBEX specified objects such as calendar entries or messages, is possible. This makes the PUSH profile usable for delivering the guidance messages to the user unit.

5 Bluetooth guidance system

When arriving to a new building it is pretty hard to find the way exactly to the desired location. In case like this, Bluetooth guidance system can help a person find the place he needs to go to. For instance, when arriving to the university, the user forms a Bluetooth connection to the university's Bluetooth guidance system. The user can make his connection with any device that supports the OBEX push and WAP profiles. On connection the user can request either a place or a person to be found. In response he gets a detailed guidance as he walks along the corridors and past crossings as shown in figure 6.

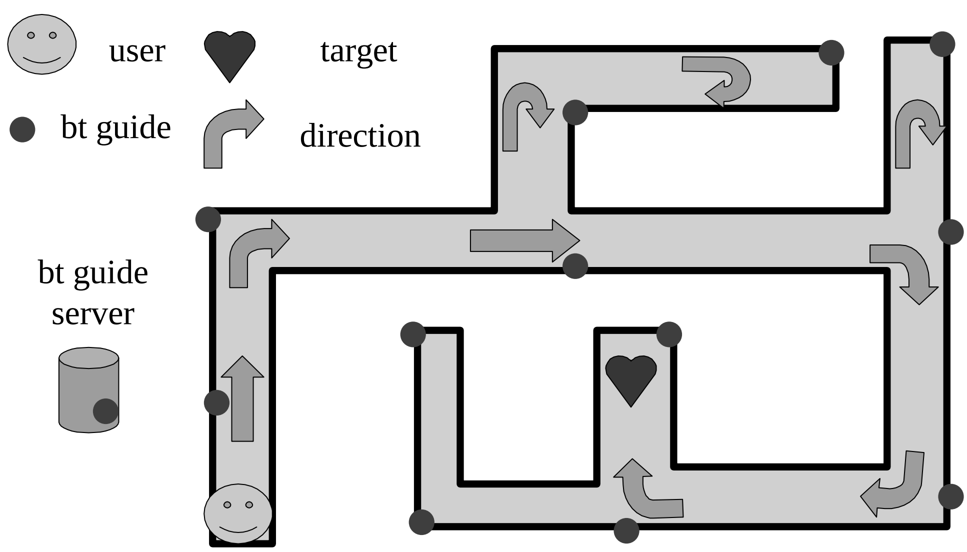

Figure 6: Bluetooth guidance system

5.1 Parts of the system

The whole system consists of 3 parts: *a user unit*, *a guide* and *a serve*r (Figure 7). In the guidance system the user unit is the users personal Bluetooth enabled device, used for requesting and receiving the directions to the target area. The guide is a small Bluetooth device installed on the corridors, crossings and other strategic points to enable a flexible guiding of the user. Several guides form a guidance network when they all are connected

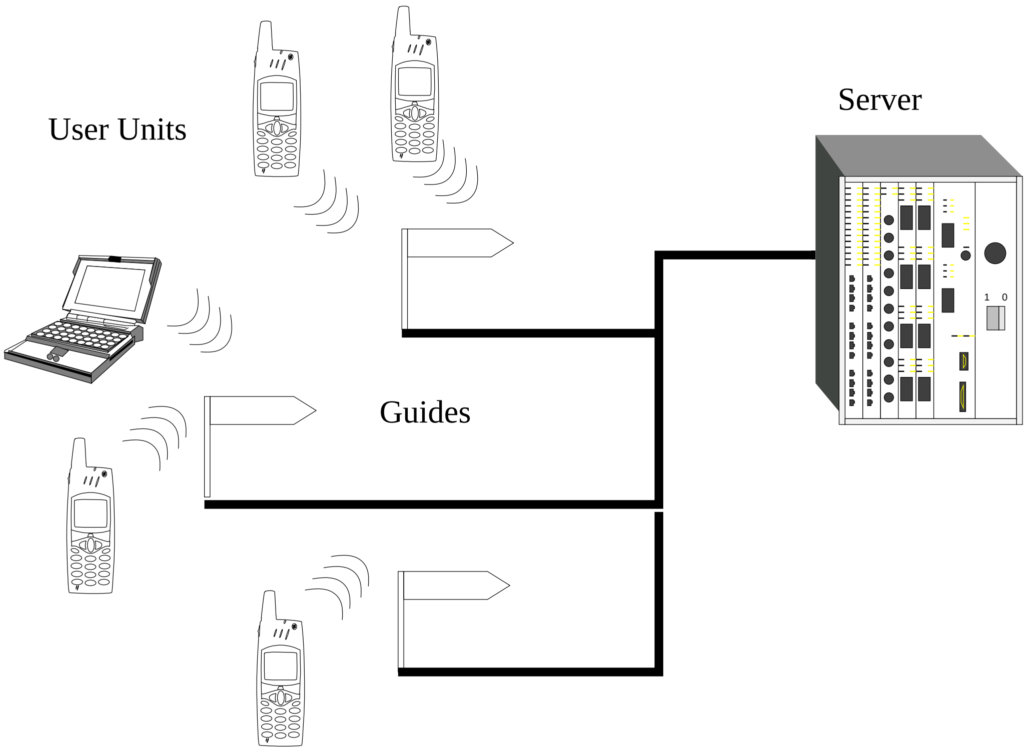

Figure 7: Parts of the guidance system

to server either wirelessly or through wires. Guides send the information about arriving and leaving user units on their piconet to the server. The server upkeeps the information about the movement of the users and informs the guide on what kind of instructions it should send to the user.

5.1.1 User unit

The user unit is the device that the person needing guidance has. Requirements for the user unit have been kept minimal to maximise the amount and the variety of Bluetooth enabling devices that can utilise the guidance system. Thus the user unit can be any kind of commonly available device that supports Bluetooth wireless communication, from PDA to laptop or mobile phone. The only requirement for the device acting as user unit is to support the OBEX profile. The OBEX support is needed to enable a fluent communication between user unit and the guides of the guidance network. Following LAN profile and capability of WAP connection can provide more services and allow an easier interface for browsing possible locations, but are not required features for the user unit.

5.1.2 Guide

The guide is the communication node between the server and the user unit. The communication to the user unit is based on OBEX protocol while the communication to the server is handled with TCP sockets over fixed or wireless network. All messages from the user unit are routed to the server as well as the messages from the server to the user unit.

The guidance system consists of several guides. They have been kept as simple as possible, in order to keep the price low. Simplicity means also that there should be little need for upgrading the guides or changing them to new versions. The guide polls its surrounding to find out what Bluetooth enabling devices are around. It can keep a list of these devices to make the system work faster. When a new device arrives in its range it adds it on its list and informs the changes to the server. The same procedure is used when a device goes out of the guides range. The device is removed from the list of guide and the server is informed about the change. The guide also delivers the messages coming from the server to the correct user unit.

5.1.3 Server

The server is the heart of the whole guidance system. It holds the crucial information such as the database containing the possible locations and routes to them, list of the user units that have been logged on to get guidance information and the routes those units have used so far.

The server creates the answering packets to the requests made by the user units and transmitted by the guides. It also creates the messages that are pushed to the user unit by the guide.

5.2 Interfaces

The whole guidance system has two different interfaces: the *user-guide interface* and the *guide-server interface*. The user-guide interface enables the user an access to the guidance system with the Bluetooth wireless technology. This interface has to rely heavily on known protocols to allow interoperability of the various devices. The guide-server interface is used for informing the guidance system server about the important events at the network and forwarding the user requests to it.

5.2.1 User unit - guide interface

The interface between the user unit and the guide is influenced heavily by the user unit capabilities. Since the user of the guidance system should be able to use various Bluetooth applying devices of different types and from different vendors, it is important that the interface between the user unit and the guide follows the common Bluetooth profile and utilises general universal protocols. Situations where user-guide interface is used are:

- The user joins to the system.
- The user requests services or information.
- The user wants to quit using the system.
- The guide gives information to the user.
- The guide scans, which devices are on its range.

As mentioned in chapter 4.4.1, GAP defines the generic interface that all Bluetooth devices have to follow so that they can find out what profiles the other Bluetooth device can understand. To enable all the functions mentioned above, plain GAP is not enough, and support for other profiles and protocols is needed.

The Bluetooth profile stack provides several possible profiles that utilise protocols usable for the guidance system. To allow the maximum amount of potential system users, the communication between the user unit and the guide should follow a protocol that can be expected to be implemented on the users device. There is three possible profiles that can be used either alone or together to provide the guidance system and the services:

1. Object exchange with Object PUSH profile
2. LAN profile utilising common internet protocols
3. WAP protocol on top of PPP or RFCOMM (no profile defined yet)

Currently most portable devices feature infrared ports to allow external communications to other devices. It is safe to assume that since the OBEX protocol stack has already been implemented on these devices for IrDA interoperability, it will also be supported in the future on similar devices. Instead of using IrDA, Bluetooth wireless technology can be used as communication medium.

In the guidance system, the communication is initiated by the guide. The guide connects to the user device to give the guidance message instead of the user requesting guidance messages all the time. To accomplish this the Object PUSH Profile from the OBEX based profiles is used, where the guide acts as OBEX client who pushes the information to the user unit acting as OBEX server. This means that when a user joins to the guidance system he has to enable his devices OBEX server that registers the used RFCOMM channel for service discovery.

The LAN profile has been used by most manufacturers on their Bluetooth access points and it is therefore quite likely that portable devices of the future will also support the LAN profile. With the LAN profile it is possible to offer several other services that are based on IP protocols, such as HTTP (Hypertext Transfer Protocol). It is not likely that the smallest devices would support the LAN profile as the hardware requirements are bigger than the benefit for applying the protocols needed for the profile.

WAP, discussed in chapter 4.3.7, is a protocol that has been developed for moving hypermedia documents over wireless networks. Therefore WAP would be a good choice to enable browsing through lists of possible locations and persons to find way to. It should be supported by most of the mobile devices with some kind of screen. There are also many existing services that already support WAP. Those services could be implemented to the guidance system later on since they share a common communicating interface. Unfortunately there is currently no profile defined for WAP, which will narrow its usage only on top of the LAN connection.

For compatibility reasons, support for all the profiles mentioned would be very useful and allow high compatibility rate for the whole system. On the other hand, it would also make the guides more complex and raise the total price of the system. In this work, only the OBEX with a PUSH profile is supported as it provides the needed functionality for the project. Other protocols are kept in mind so that implementing them at a later stage would not require many changes on the existing system structure.

5.2.2 Guide - Server interface

At the user-guide interface, the features of the user unit give the restrictions for the communication protocol and mainly define how the interface has to work. That is not the case at the guide-server interface. As both guide and server are self designed specifically for the guidance system needs, the protocol they use for communicating can be specified as is seen best. To ease up the protocol design, implementation and testing, an efficient protocol framework, such as OVOPS (Object Virtual Operations System) [OVO99], could be used. [JÄP00]

In order to define the interface between guide and server, the knowledge of the guidance system functionality is needed. The situations when communication is needed between server and guide are:

- When the user wants to join the guidance system.
- When the user arrives/leaves the area of the guide.
- When the server wants to give a message to the user.
- When the user quits using the system.

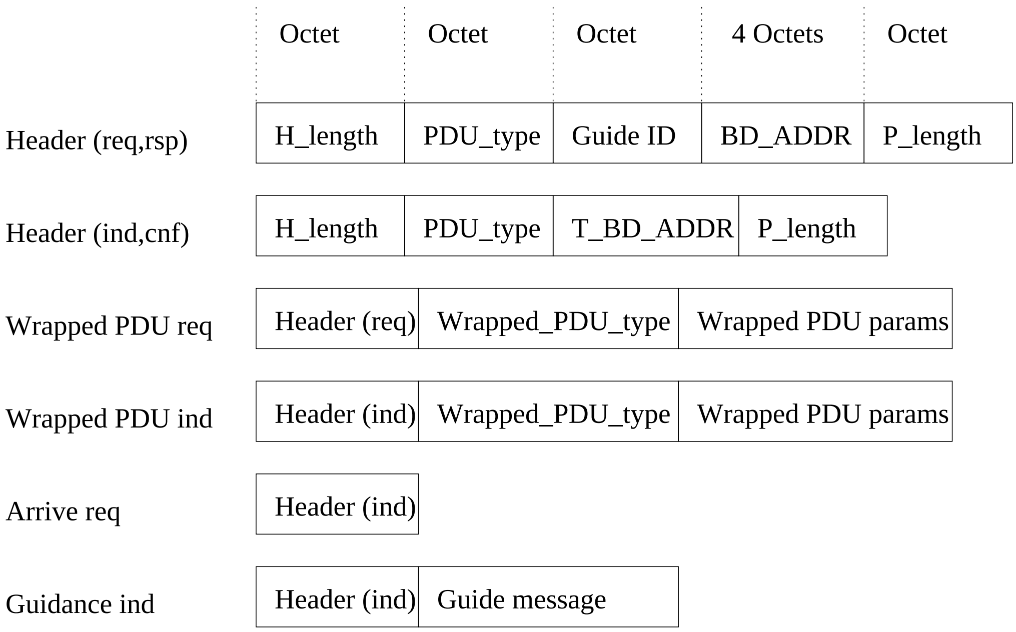

Figure 8: PDU's between guide and server

These situations need different types of variables delivered to the server. In Figure 8 the structure of different PDU's (Protocol Data Unit) going between guide and server are defined. Messages going from the guide to the server are requests (req) and responses (rsp) while messages going from the server to the guide are indications (ind) and confirms (cnf). [ROS90]

Requests and responses have a common header that consist of:

- *H_length*, which denotes the length of header.

- *PDU_type*, denoting the type of PDU sent, like wrapped_PDU_req.
- *Guide ID* is the identification of the guide sending the PDU. If the connection between guide and server is done over TCP connection, this field is not necessary as the server would know the guide from the connection identifier.
- *BD_ADDR*, Bluetooth hardware address of the user device that the PDU is concerning about.
- *P_length*, denotes the length of the packet, excluding the header.

Indications have their own headers. The indication PDU does not have to hold the information about the guide to which it will be delivered. Routing the message to the right guide is taken care by the server and the transport layer.

- *H_length*, denotes the length of the header.
- *PDU_type*, denotes the type of PDU sent, like wrapped_PDU_req.
- *T_BD_ADDR* is the Bluetooth hardware address of the target user device the PDU is concerning about. The guide delivers the message based on this address to the correct Bluetooth device.
- *P_length*, denotes the length of the rest of the packet, excluding the header.

Everything starts when a user joins the guidance system. Joining the system can be done by using OBEX or WAP to request the targets and then the same protocol to inform the chosen target. If the functionality of the guide is wanted to be minimal, the incoming PDU type should only be identified. Then the actual PDU from the user unit is wrapped to the PDU generated by the guide for the server. The same method can be used to produce other WAP or OBEX functionality to the user as well as to leave from the system.

The fields in the wrapped PDU are:

- *Header*, where the PDU_type is Wrapped_PDU_req.
- *WPDU_type* denotes the type of PDU sent (ie. WAP, OBEX or something else).
- *WPDU_params* holds the actual PDU sent by the user device.

To reply on these messages, the server has to create the correct PDU that will be delivered to the user unit, thus the server forms the PDU based on the protocol used by the user and wraps it to Wrapped_PDU_ind. When Wrapped_PDU_ind arrives to the guide, the guide picks up the target BD_ADDR. Then it removes the wrapping from the PDU and sends it to the user unit that has the correct BD_ADDR.

Wrapped_PDU_ind consists of the following fields:

- *Header*, where PDU_type is Wrapped_PDU_ind.
- *Wrapped_PDU_type* denotes the type of PDU sent (ie. WAP, OBEX or something else) used to determine which protocol is used to communicate to the user device.
- *Wrapped_PDU_params* holds the actual PDU that is delivered to the user.

The Information about the arrival of the user to the area of a guide is fairly simple. All the necessary information is on the request header. Thus PDU_type is on that case arrive_req and naturally P_length is zero. As response to this message, the server can send the guidance information to the guide to be forwarded to the user unit. The indication header is used with guidance_ind as PDU_type. The type of message pushed to the user is on the guide message field.

The server-guide interface definition here has been designed mainly thinking about the needs of the guidance system. If additional services and more complex functionality are desired changes to the protocol defined here might be needed. Most of the services can be provided by using the wrapped PDUs.

5.3 Guidance system operations

The guidance system has several operation steps gone through in order to get the user guided to the place he desires.

- Joining the guidance system.
- Discovering the user unit.
- Positioning the user and determining his facing.
- Creating the route from his current location to the desired location.

- Forming the guidance message.
- Sending the guidance message.

All these operations are necessary for a fully functional guidance system. Some of these operations can be used by other applications to enhance the service they provide. What is done in these operations is discussed in the following subsections.

5.3.1 Joining the guidance system

Before any guidance can be arranged, the user has to join the guidance system. The joining should be easy for the user but on the other hand should require as little functionality of the guides as possible, to keep the guide implementation simple. In chapter 5.2.2 OBEX was chosen as the protocol to be used for communications between the user and the guide. The problem of using OBEX in joining is that there is no use case definition that apply to OBEX that would support flexible browsing of possible locations and services. For WAP there would be WAP browsers and LAN connection can use HTTP browsers. The lack of browser support results in that the user has to know the correct way to inform the target he wants to get to. In this thesis the destination is defined by sending a plain room number.

The process of joining the system has to be initiated by the user. Due to the advertisement on the wall, by general knowledge about the existence of a guidance system or just by pure curiosity, a user scans the Bluetooth devices on his Bluetooth units range. When the user discovers the existence of the Bluetooth guide that reports it supports OBEX profile, he forms an OBEX connection to the guide. After the OBEX connection is formed, the guide should send some kind of help text and maybe a list of possible targets ie. room numbers. The user then chooses the place he wants to go to and delivers it to the guide. The guide wraps the incoming message to the PDU and delivers it to the server as defined in chapter 5.2.2. The server adds the new user to the guidance system and sends the initial directing message to the user through the guide. How the messages are sent to the user is described more closely in chapter 5.3.6. After all this the user should enable the OBEX server on his portable device in order to allow the guides to send the guidance information later on.

5.3.2 Discovering the user unit

In order to get the location of the user unit, there is a need to know which guide or guides can connect to the user unit. Since the implementation of guides is expected to be done by using HCI and upper layer protocols, the names for messages used in the following subchapters are those used on HCI. Through HCI, the necessary functionality for discovering the user unit can be done. The lower layer functionality is done by the Bluetooth host and is expected to follow the Bluetooth specification.

Discovering the device bases on the fact that the guide can poll its surrounding to find out what Bluetooth devices are around it. This information is sent to the server that uses it for approximating the users position, with schemes discussed in chapter 5.3.3. Depending on how much intelligence is wanted to be implemented on the guide there are two possibilities for detecting the users in the area.

1. Using inquiry to detect all the Bluetooth devices on the range of guide.
2. Using paging.

Plain Inquiry

When using plain inquiry the guide does not have to hold the information about the users of the guidance system. It just sends inquiry messages to its surrounding and wait responses from the Bluetooth devices in the range to identify them. For more effective inquiry, it is also possible to set the guides in a periodic inquiry mode where they constantly send inquiry messages at random intervals to find out what devices are in the range. When the Bluetooth devices have responded to the guide, the guide informs about the situation in its area to the server. The server then decides about whether sending a message and the type of the message depending on the system used. It is good to remember that all Bluetooth devices set in the general discoverability mode will reply to the inquiry and not just those that have joined the guidance system.

Figure 9 shows the generic communication between the user unit, the guide and the server when delivering the guidance information.

1. The server inquires about the Bluetooth devices in its range.
2. The response from the device holds its BD_ADDR. The guide sends the BD_ADDR of the responding device to the server.

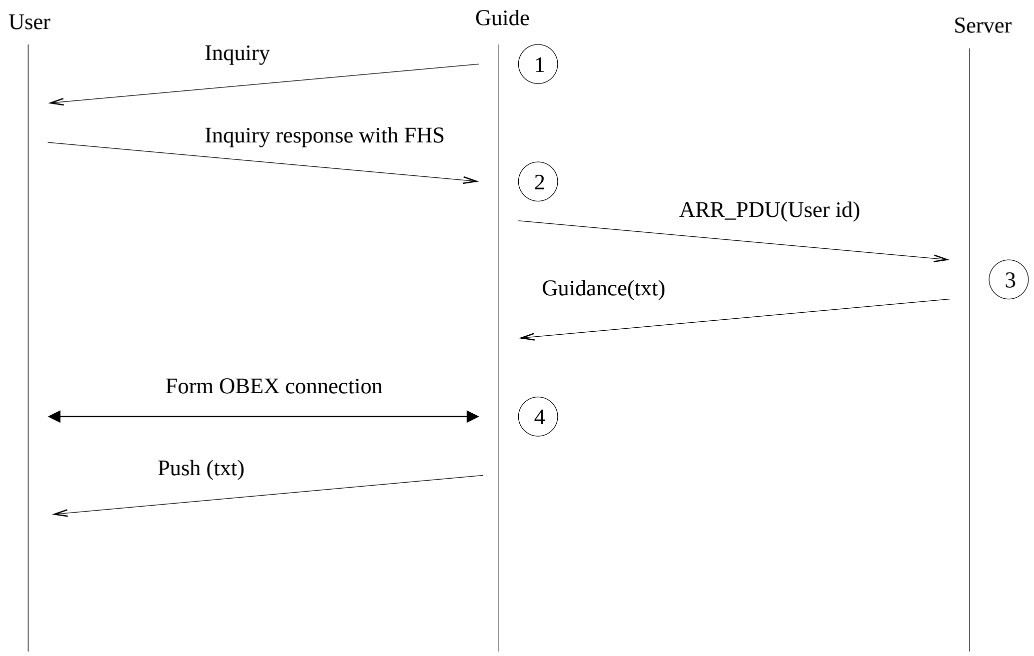

Figure 9: Generic MSC for communicating

3. The server checks its database to verify whether the device, which BD_ADDR it received, is using the guidance system or not. If it is a guidance system user, the server checks if the user has been notified already on its current area. If not, the area is added to the units direction vector. After that the server determines what kind of guidance information the user needs and sends it in Guidance PDU to the guide.

4. The guide forms a connection to the user unit and pushes the guidance information it got from the server to the user unit.

As there can be plenty of Bluetooth devices in the communication range of the guide, many answers may result to the inquiry. Since the server gets this kind of information from several guides, it can get easily overloaded from the useless messages provided by devices not using the guidance system. Therefore it is a better idea to let the guide keep list of the devices that are on its perimeter and inform the server only when the system user either arrives or leaves from its area.

To narrow down the communication between the guide and the server, the guide should not only have a list of devices in its area but should also be informed by the server about the devices using the guidance system. When a guide has the knowledge about the Bluetooth devices using the guidance system and the knowledge about what devices it has informed to the server, it can narrow down the messages it sends to the server. There are two different ways to filter the messages sent to the server from the guide.

1. The guide does the filtering itself, when it gets the answers to the inquiry.
2. Set_Event_filter is used to filter the messages already on the bluetooth hardware.

Paging

While using a plain inquiry, only the server knows what Bluetooth devices use the guidance system and therefore if plenty of Bluetooth devices are carried by people, there is quite a large amount of information sent to the server. If the guides are informed about the devices that are using the guidance system, their existence within range can be found out by using paging. Paging requires the knowledge of the frequency hopping scheme followed by the user unit. This is faster than inquiry, as the guide knows the frequency hopping scheme the user device is following and therefore does not have to randomly go through different frequencies to find where the user unit responds. How to deliver the frequency hopping scheme from the user unit to the server and from the server to the guide is not an easy task and is not on the scope of this thesis.

Paging is used as a part of connection establishment between two Bluetooth enabled devices. The easiest way to use paging is by applying remote_name_request HCI command. It is meant for finding out the name of the Bluetooth enabling devices which BD_ADDR is already known. The problem with remote_name_request is that the guide believes the device it pages is in its range. If the device is out of the range, guide waits its response even though there is no-one there to send the response. How long the response should be waited have to be defined.

From the above methods inquiry is used in this thesis, because the simplicity of implementation. Also, the amount of devices is not currently very high. Therefore, server congestion is not expected. In the future, other ways to detect the devices will be necessary as the amount of devices utilising the Bluetooth wireless technique will grow. The response time of the devices is a bit long and causes a delay on the discovering the devices in the range.

5.3.3 Positioning and facing

There are many different possibilities for positioning a person in order to direct him to the correct place. Bluetooth 1.0 specification does not define any method or suggest any way on how the location information could be relayed between the Bluetooth devices. Therefore even if the user unit has the capability of locating itself on its own, for example through GPS (General Positioning System), there is no standard way to relay this information forward. In this thesis, the positioning is done by the guidance system and there is no need for external positioning device. The positioning approaches here are based on the Distributed Location System [HAR94], that was designed to be used with infrared badges in an office environment.

Getting the location information has to be done with existing methods and in such a way that it does not need any additional functionality from the user unit. Besides the location of the user, the server also needs to know which way the user is facing in order to give the right guidance information. Here the facing of the user is referred as the compass points (north, south, east, west).

On-arrival positioning

On-arrival positioning determines the users position at the time the user arrives to the area of the guide. The facing of the user is determined by the area he is coming from and the area he is arriving to. These areas form a direction vector showing the movement of the user.

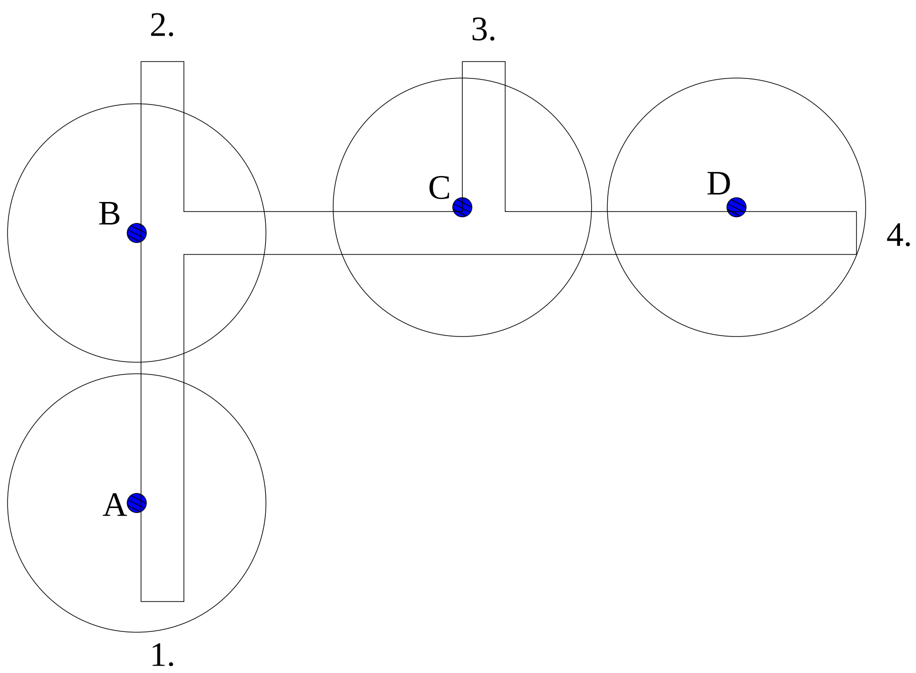

Figure 10: On-arrival positioning

Lets assume that in Figure 10 a user comes to area B and has last visited area A. The direction vector therefore points to the north and we can safely assume that the user is facing north. If the user wants to go to place 4, the guide B can send a message that tells: “Turn right”. If the user instead is heading to 1 and for some reason has turned back towards B after already been in the area of A, he gets a message to turn 180 degrees in order to find the place he wants to go to.

In on-arrival positioning, the determining of what type of message is sent to the user is done by the server. The guides only send the information to the server about the arrival of a new Bluetooth device. According to this information, the server decides what type of message is needed for the user to find his way in the building. A simple version could just inform the presence of all the devices in its area and let the server do all the work to decide which devices are new in the area. A more complex guide should hold the information about the devices existing its area and inform only of the new arrivals.

Statechange positioning

In on-arrival positioning, the user unit was located by the guide that noticed its arrival. The guides have to be placed so that they notice the user a bit before it is time to send him a new message. This will work fine when the distance between the message sending points is long enough. On the other hand, when the active points where the message to the user should be sent are getting closer, the amount of needed Bluetooth guides is increased. In cases like this statechange positioning can be used.

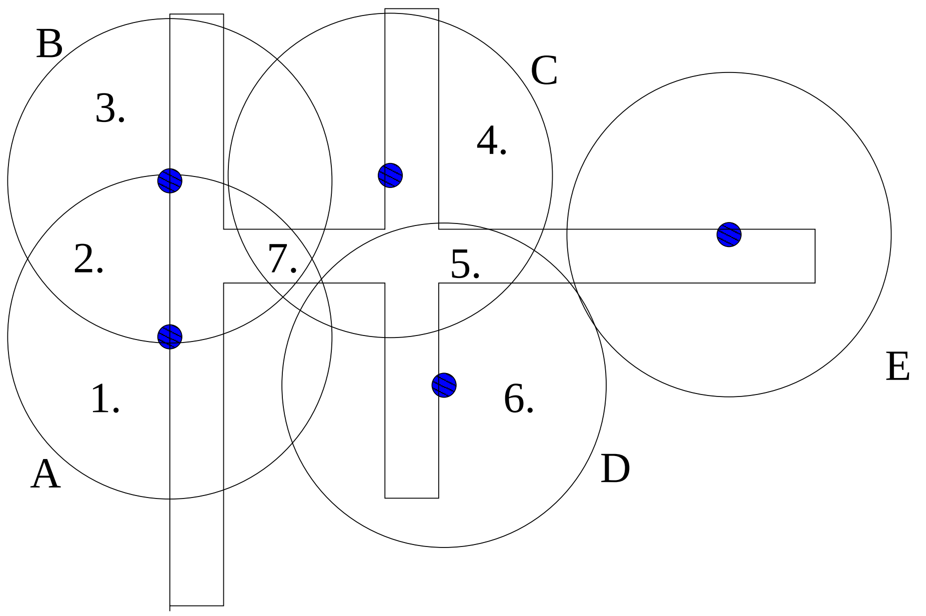

Figure 11: Statechange positioning

Statechange positioning bases on the changes of reachability of the user device. The guides reside close to each other and their range can overlap. While it would be possible in statechange positioning for guides to just inform about the devices in their surroundings, that would cause a lot of useless messages to be delivered to the server. Instead, the guide should hold a list of devices in its area and inform the server only about the changes in that list. Also, it would be useful for the guide to have the information about the users needing guidance, so that it can limit the amount of messages delivered to the server.

In Figure 11, there are five guides named A, B, C, D and E. Their communicating areas cross and form nine different states. The user unit is considered to be in state one when only guide A can reach it and in state seven when it can be reached by guides A, B and C. Locating the user and determining his facing can be dealt in statemachine. The statemachines must be complete, so that there is specified action for each reported state change.

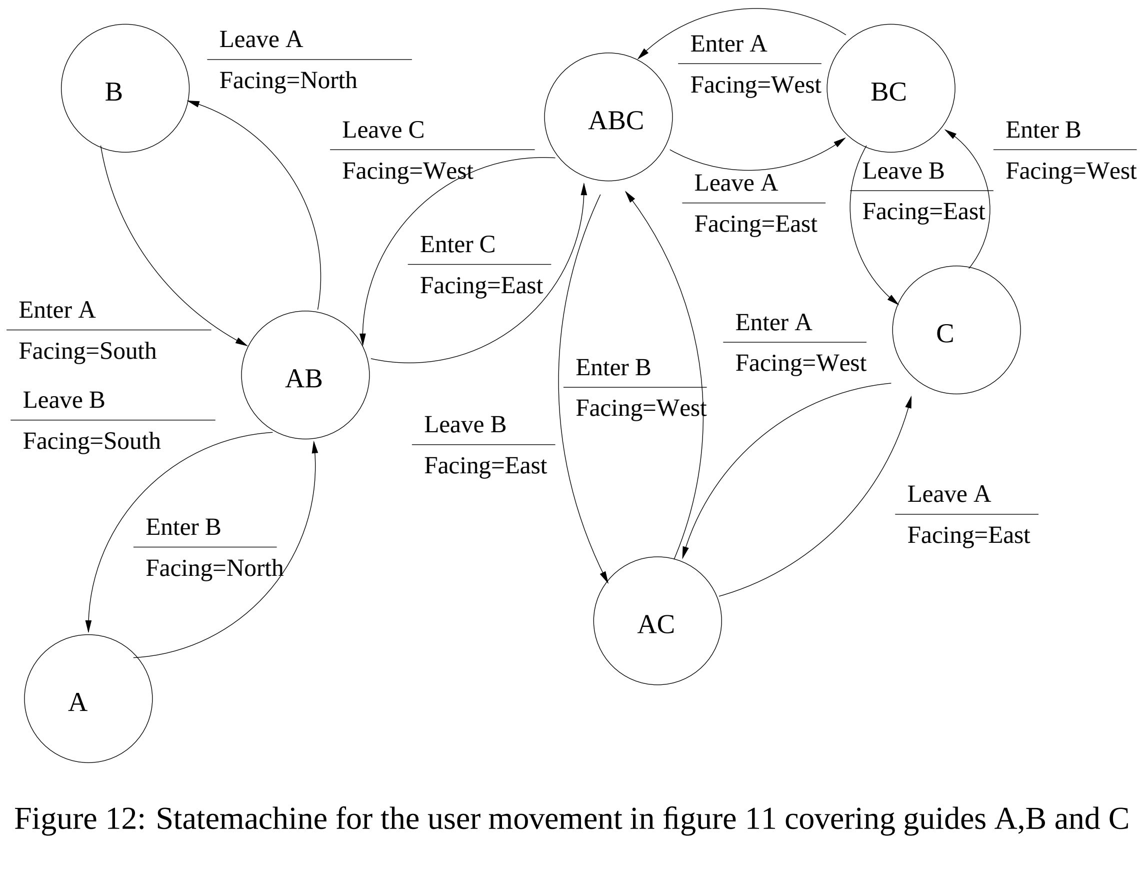

Figure 12: Statemachine for the user movement in figure 11 covering guides A,B and C

In figure 12 the movement of the user is presented as a statemachine. To make it clearer the statenames are a combination of the guides that can connect to the user unit at that state, instead of numbers as used on figure 11. Let's assume user starts from area A. He resides in statemachine in state A. When guide B notices arrival of the user, the user unit state is changed to AB and the facing variable is set to north. If we assume that the user is heading to a room in area D, the server can check from its routing list that a user in state AB has to go towards ABC in order to get to state D. As the user is facing north and ABC is west from AB, the server can give the user an order to turn right.

It is good to remember that not all state changes are meaningful for the guidance system. Therefore, the statemachine can be simplified so that only the changes that results in a message to the user unit are added. There should be a definition for all the possible incoming and leaving messages though, to keep the statemachine complete. The detail level of statemachine depends highly on the level of accuracy needed. Some services might need more accurate positioning than what the guidance system itself would need.

Self-aware network

The former version of positioning relied heavily on the server. The server got the information about all the changes in the network and made the guidance decision based on the information it got from the guides. If the server gets stuck the whole system gets stuck and messages to users get delayed and people get lost.

Self-aware network bases on the idea that most or all of the intelligence is on the guides. The guides communicate to each other and inform about the happenings at their surroundings. They also make the guidance decision. All this would make the system less dependent on one point, especially since different guides cover partly each others area. The downside is that the additional functionality will raise the price of the guides and thus the whole system is getting more expensive. Also the amount of guides needed might be raised due the fact that every guide has to have another guide in its range. Thus the maximum distance from one guide to another is 10 m when class 3 Bluetooth devices are used.

Intelligent guides communicate to each other. They inform about the happenings in their area, in a similar manner than the server is informed in statechange positioning scheme. Since the area that guides cover overlap and in several places are covered by many different guides, the statemachine for one guide does not have to react to all the changes that happen, while the user moves. For example, in figure 13 there is no point for guide E to react when the user arrives to area F, since there is no guidance information or action to be done for E in that stage.

When creating the statemachines for the guides, it is important to think about the guidance system as a whole. The user should not get multiple guidance information, yet all the

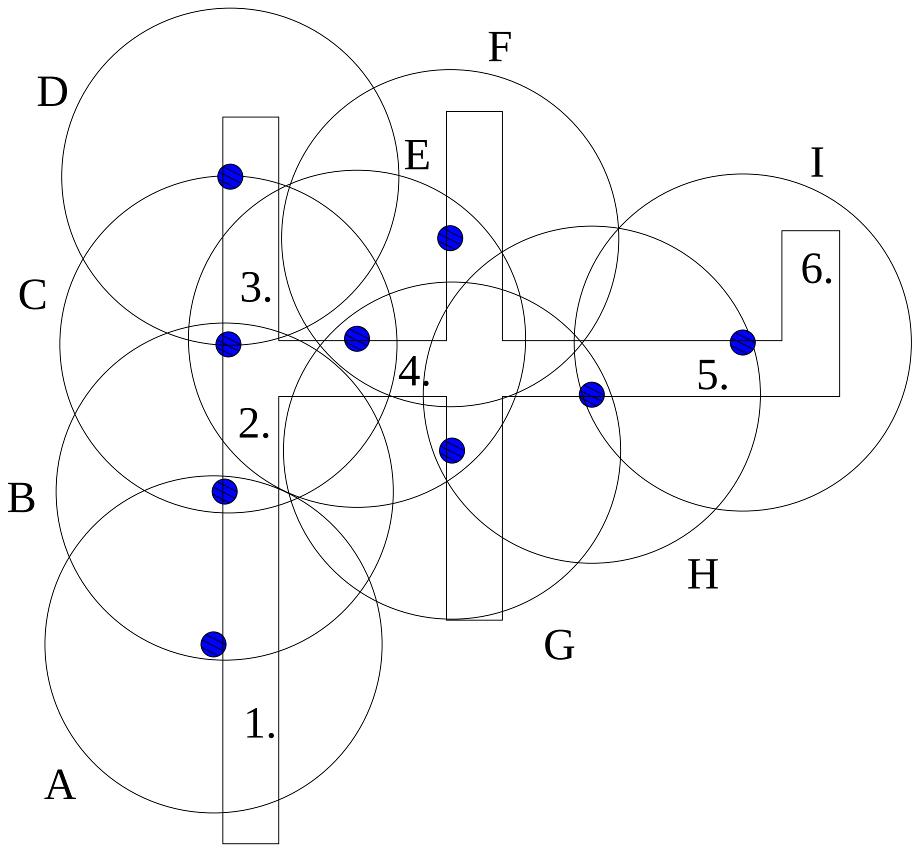

Figure 13: Self-aware network

necessary information has to be delivered to the user. Figure 14 shows one possible statemachine for the guide E of figure 13. Here it has been decided that E gives the guidance information to the user when the user arrives from crossing 2 towards crossing 4.

Once new user registers himself as user of the system, the guide that took the registration informs about it to the guides that are in its range. It also informs the destination where the user wants to get. In figure 13 is presented a self aware network where the user is moving from area A to the room residing on area I. The numbers present the action points that are explained below.

1. At this point, the user registers himself to the network and informs about the target he wants to get to. Guide A takes the registration and informs guide B about the user id and the users destination. As the user walks northwards, B notifies it and informs C about the user and A about the arrival of the user.

2. C notifies of the arrival of the user and looks in its routing table which way I resides. As C knows that the user is coming from B and needs to be directed towards E to

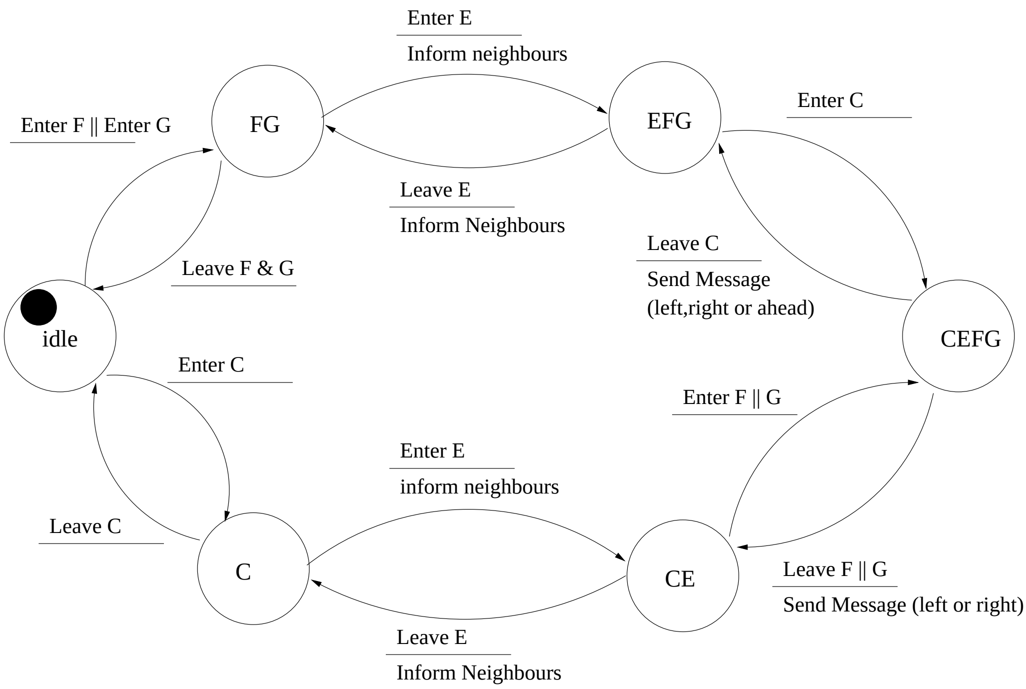

Figure 14: Statemachine for guide E in figure 13

get to I, C can inform the user to turn right. After that, C informs D and E about the user's and his target and B about the user arrival to its area. Now B, D and E know that the user was seen in area C and if the user arrives to their area they can give correct directions.

3. The user got lost and arrived in the area of D. Since C informed about the user to D, D checks its route table and notices the user should go to C in order to get to I. Therefore D sends to the user the order to turn around and turn left. D then informs C about the user's arrival in its area. Since the user is coming from area D, C just informs about the arrival of the user to its neighbours, but sends no message to the user.

4. E has seen the user ever since the user arrived in location two, but according to statemachine on figure14, E does no other action than inform the neighbours, until C sends the information about losing touch to the user. Then E sends to the user the information to just move forward.

5. When the user arrives to the range of I, it tells the user to turn left at the end of the corridor.

6. The range of H ends a bit before the user should turn to the left and therefore it can

be rather hard to determine when the user has actually turned. A rough estimation can be done by starting a timer when the user has left from area H. After the timer has run for 10 s a message is sent to look at the door on the left to find the place where the user wanted to go to.

The problem with self-aware network is that when a new service is introduced or a service is upgraded, all the Bluetooth guides need upgrade. In a large building, this would be a rather big task, unless it is possible to issue the upgrading process through the network nodes. This might open up security risks that can cause a lot of damage.

5.3.4 Forming the route from one place to another

After the user has informed the guidance system where he wants to go and his location and facing are resolved, it's time to resolve his route from his current position to the desired location. There are several different routing algorithms, such as OSPF and RIP, that are designed for packet routing in datacommunications networks. Since the route in the building from one place to another is static, except on the rare case of earthquake or construction work, these algorithms are too heavy. For simple routing problem like this more straightforward approach is needed. In this thesis two different schemes, *static table route* and *pre-approximated route*, are presented to form the route from one place to another.

Static table route

In static table route scheme, the server has a list of targets for every guide on its area. The server has also a table for every guide on the system. In the table are stated the direction user has to be guided at in order to reach the area of certain guide.

Figure 15 shows a route table for guides in figure 11. If user wants to find an office that number is 123, the server first checks from database, on which guides area room number 123 resides. Let's presume room number 123 is at the proximity of the guide D, and the user arrives into area of guide A. The server reads from the routing table of guide A that in order to get to area of guide D, user has to walk north. Since user joined to system through guide A ,we presume user is facing north. Since user is facing north and needs to go north, server can send guidance note telling him to walk forward. Next the server should get information from the guide B about the user arrival. From routing table of guide B, the server can check that in order to get to guide D user needs to go east. Routing the users continues this way, until the user gets to his destination.

Table for A

Target	Route
B	North
C	North
D	North

Table for B

Target	Route
A	South
C	East
D	East

Table for C

Target	Route
A	West
B	West
D	South

Table for D

Target	Route
A	North
B	North
C	North

Figure 15: Route table for guides in figure 11

pre-approximated route.

Table for A

Neighbour	Route
B	North

Table for B

Neighbour	Route
A	South
C	East

Table for C

Neighbour	Route
B	West
S	South

Table for D

Neighbour	Route
C	North

Figure 16: Table of neighbours for figure 11

If the amount of guides rise, the amount of tables as well as the size of the table for each guide grow extensively. Another approach is to only hold list of the neighbouring guides for each guide (Figure 16). When the user wants to go at the certain place, the route is generated right away.

The information needed for generating the pre-approximated route are: table of neighbours for each guide, guide from where the route starts and the guide where the route ends. The route is generated using the following algorithm:

1. Check that the starting location guide and target location guide are not the same.
2. Add the starting location guide in routelist A and target location guide in routelist B (Phase 1 in figure 17).

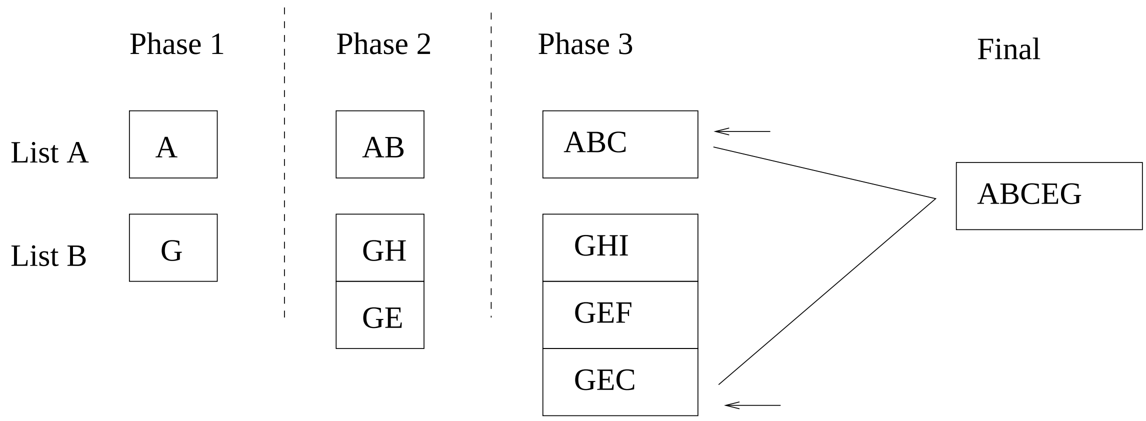

Figure 17: pre-approximated route generation

3. Get the neighbours of the last guides on the routes on routelist A. Create routes to the neighbours and put the routes in routelist A.

4. Check if any of the last guides added on the routes, match on the last guides on the routes in route list B, if so jump to 7.

5. Get the neighbours of the last guides on the routes on the routelist B. Create the routes to the neighbours and put the routes in the routelist B.

6. Check if any last guides added in routes, match on the last guides in the routelist A, if so jump to 7 else jump to 3

7. Concatenate the lists with the matching guide.

Once the route is formed, the list of the guides on route is stamped with the users id. When the user reach the guide on the route, the guide is removed from the routelist. Now if user goes to the wrong place, the guide that notices the error informs server about it. Server creates new route from the place user is currently to the place where he catches the guide of the previous route. The new route and the previous route are then concatenated to form the final route from the new place to the desired place.

Static table route vs. pre-approximated route

The two mentioned route creating schemes have their own pro's and cons. Pre-approximated route is a bit slower for making the first directing decision, but it is faster for making the decisions when user is moving along the route. The more guides there are in the system the bigger is the speed advantage of the pre-approximated route. In the static table route the server has to go through the long tables in order to find the next target.

The static table routes advantage is on cases where the users target is moving ie. when trying to get to a person that is moving. In cases like this the end point of route changes all the time and system have to able to react on these changes. The static table route is also easier to implement and with small amount of guides the speed difference is not a big factor.

5.3.5 Forming the guidance message.

Guidance message delivered to the user should be clear so that the user can easily follow its instructions. Therefore using the compass point like in the pirate game described in [NOB83] is not useful. Instead left and right should be used even though it means that facing of user has to be determined.

The type of message sent to the user depends on the facing of the user and the direction where he wants to go. On previous examples we have had four main directions: north, east, south, west. For the program we can make numbers from zero to three represent them. Now with simple subtraction the needed guidance information can be found out. Subtract value of the direction where the user is heading from the value of the direction where user is facing, and compare the result to the following:

- If value = 0: user should continue the way he was heading
- if value = 1 or -3 user should turn right
- If value = -1 or 3 user should turn left
- if value = 2 user should turn around

Another approach would be to provide place specific guidance messages such as: "Walk towards the cafeteria." This type of messages are easier to create and is also easy to use. On office building with many similar looking corridors a descriptive message is hard create.

5.3.6 Sending the guidance message

After the choice of what type of message is to be sent to user is done, it is first delivered to the guide and then it has to be delivered to the user device. The delivery of message should not need any action from the user after he has requested the guidance to certain place. With current specification this would need the user device to set in the stage to accept all connection requests or add the all the BD_ADDR of guides in guidance system as trusted ones. The latter is not practically possible and the former method would allow not only guides, but all Bluetooth devices to push messages on the user unit.

To solve this problem flash notes can be used for sending authenticated notes from the server to the client. To identify themselves the guides present certificates, which have been issued by the certificate authorities. Now the user only have to accept the messages from the devices that have been certified by a certain authority. [JÄP01] The problem with this approach is that it has to be supported by the user unit. If the architecture or something based on it gets to the Bluetooth specification it is more likely that the user units will support it.

5.4 Building the guidance system

Correct placing of the guides in the guidance system is important for the functionality of the entire system. It is not an easy task. Different types of interferences can affect the communicating range of the guides. The interference can vary in time to time. It is good to remember that the positioning of the user is never exact and some kind of marginal has to be taken into account. Predicting the path of signal in the building is also hard and is affected by the basic infrastructure of the building. Radio signals can wander between different floors of the building making it even harder to find the proper place to install the guide. Therefore when installing the guides it is good to measure the area they can be heard to find the optimal positions for them.[KAR00]

The time needed for creating the connection has to also be taken into account. Due the nature of the Bluetooth technology it is impossible to give exact timings how long it will take to form a connection to the user device. Connection forming time from standby state through inquiry to the paging and finally to the connected state will take typically average of 5.12 s. It takes only approximately 0.6 s when the frequency hopping scheme of the user unit is known and no inquiry is needed.[KAR00] If we assume walking speed in guilding is maximum of 6 km/h, the distance that is walked in 5.12 s is about 8.5 m. In 0.6 s the distance would be 1 m. This means that minimum reaction distance for the guidance system is 1 m, while it can ne almost 10 m in worst case.

6 Conclusion

The guidance system can help a random visitor of a building to find his way from one place to another. For usability reasons the guidance system should be created by using wireless communicating technologies. From various suitable wireless technologies Bluetooth has the best qualities to create such a system. This doesn't mean that Bluetooth should be the only wireless technology used. Other wireless technologies can be used to complement Bluetooth. Wireless technologies that support higher bandwidth open up the possibility for more complex guidance services such as video messages.

Bluetooth proved to be very capable for creating functional guidance system. The accuracy of system is adequate when the target is walking and the points where guidance is needed are not too close to each other. Finding user units and connecting to them is rather slow process, which affects to the reaction time of the system. This is the biggest obstacle for getting high accuracy with Bluetooth technology. Newer version of specification might bring better solution and enable faster connection times. New profiles will also bring new possibilities to locate user more accurate and enable more flexible co-operation with other wireless standards.

While the guidance system itself is a helpful application, it also forms good basic access network. It can be used to provide additional services to the people visiting the office building. Implementation of these new services in the guidance network can be done on the server and they can benefit from the location information that the guidance system provides.

References

[ANG00] Angel, Jonathan. Look Ma, No Cables. Network Magazine Vol 15 No11, November 2000

[ANO99] Anonymous. The power of profiles. SIGnal Newsletter no. 5, 1999

[BLU99] Bluetooth Special Interest Group. Bluetooth Specification 1.0B. Available at: http://www.bluetooth.com/ , 1999 [Referred 20.1.2001],

[BRA01] Bray, Jennifer, Sturman, Charles F. Bluetooth: Connect Without Cables, Prentice Hall 2001

[CAH01] Cahners In-Stat. Cellular online magazine. Available at: http://www.cellular.co.za/news_2001/05012001-Bluetooth_not_making_the_connect.htm, May 2001 [Referred 10.5.2001]

[CHE01] Chen, James J. IEEE 802.11a - Speeding Up Wireless connectivity in the Home. Communication System Design, Vol 7, No 2, February 2001

[DOR00] Dornan, Andy. Can Bluetooth Sink Its Teeth into Networking?. Network Magazine Vol 15 No11, November 2000

[DOR01] Dornan, Andy. The Essential Guide to Wireless Communication Applications. Prentice Hall, 2001

[ETS01a] ETSI. HIPERLAN/1 specification. Available at: http://www.etsi.org/technicalactiv/hiperlan1.htm [Referred 20.5.2001]

[ETS01b] ETSI. HIPERLAN/2 specification. available at: http://www.etsi.org/technicalactiv/hiperlan2.htm [Referred 21.5.2001]

[FRO00] Frodigh, Magnus, Johansson, Per, Larsson Peter. Wireless ad hoc networking - The art of networking without network. Ericsson Review No. 4 2000

[GAR00] Gartner Group. Gartner Says ’Supranet’ Will Advance Bluetooth Technology But Device Vendors Must First Add Security. Wireless Development Network, Available at: http://www.wirelessdevnet.com/news/2000/255/news4.html, September 2000 [Referred 7.5.2001]

[GEH00] Gehring, Burkhard, Koutroubinas, Stelios. Designing Cableless Devices with the Bluetooth Specification. Communication System Design Magazine, February 2000

[GUP00] Gupta, Puneet. Short-Range Wireless Connectivity: A Complementary Comparison. Wireless Developer Network, available at: http://www.wirelessdevnet.com/channels/Bluetooth/features/Bluetooth_irda.html , 2000 [Referred 10.7.2001]

[HOM01] HomeRF working group. HomeRF homepages. Available at: http://www.homerf.org [Referred: 15.5.2001]

[HAR94] Harter, Andy, Hopper, Andy. A distributed Location System for the Active Office. IEEE Network vol 8 Issue 1, 1994

[HEL01] Held, Gil. Data Over Wireless Networks: Bluetooth,WAP, & Wireless LANs. McGraw-Hill, 2001

[HUN99] Hunn, Nick. Bluetooth versus 802.11. Incisor magazine, July 1999

[HUO00] Huomo, Markus. Bluetooth ja PUSH operaatio. Thesis, South Carelia Polytechnic, 2000

[IEE01] IEEE. IEEE 802 standards. Available at: http://www.manta.ieee.org/groups/802/ [Referred 30.4.2001]

[IRD01] IrDA. IrDA standards. Available at: http://www.irda.org/standards/standards.asp [Referred 15.4.2001]

[ISE99] Isenberg, David S. A Home Where Devices Can Roam. America's Network, April 1999

[JOH99] Johnsson, Martin. HiperLAN/2 - The Broadband Radio Transmission Technology Operating in the 5 Ghz Frequency Band. white paper, HiperLAN/2 Global Forum, 1999

[JÄP00] Jäppinen, Pekka, Kvist, Arto, Pärssinen, Juha, Heinonen, Jukka, Von Knorring, Niklas, Turunen, Markku. Frameworks for Protocol Design. 9th Summer School on Telecommunications, August 2000

[JÄP01] Jäppinen, Pekka, Porras, Jari. Flashnotes over Bluetooth. International Conference of Wireless LANs and Home Networks, December 2001

[KAR00] Karasti, Olavi, Siirtola, Harri, Rantala Seppo. Bluetooth in industrial Applications. Technical Research Center of Finland, Automation 2000

[KAR01] Karjalainen, Henri. Bluetooth ja PULL operaatio. Thesis, South Carelia Polytechnic, 2001

[KAS00] Kasatkine, Dmitri. IP over Bluetooth network support for Linux OS. Master of Science Thesis, Lappeenranta University of Technology, June 2000

[KOB00] Koberstein, David. HomeRF: Wireless Networking for the Connected Home. Communication System Design Magazine, February 2000

[LIN01] Lin, Yi-Bing, Chlamtac, Imrich. Wireless and Mobile Network Architecture. John Wiley & Sons, 2001

[MET99a] Mettälä Riku. Bluetooth Protocol Architecture 1.0. White paper, Bluetooth SIG, August 1999

[MET99b] Mettälä, Riku. Synchronization of Personal Data using Bluetooth. Master of Science Thesis, Tampere University of Technology, May 1999

[MIL01] Miller, Brent A. , Bisdikian, Chatschik. Bluetooth Revealed. Prentice Hall 2001

[MOR01] Morrow, Robert. Connecting With a Bluetooth Piconet, Wireless System Design, Bluetooth Winter Issue 2001

[NOB83] Noble, Tony. The VIC-20 for Children. 1983

[OHR01] Ohr, Stephan, HomeRF looks to gain ground on Bluetooth. EE Times, Available at: www.eetimes.com [Referred 2.6.2001] 10.1 2001

[OVO99] OVOPS homepages, Available at: http://ovops.lut.fi, 1999 [Referred 6.8.2001]

[PET01] Peterson, K.E. Bluetooth and 802.11: A Tale of Two Technologies. 10meters.com, Available at: http://www.10meters.com/blue_802.html [Referred 30.5.2001]

[ROS90] Rose, Marshall T. The open book: a practical perspective on OSI. Prentice Hall 1990

[SEE99] Seetharaman, Uma. WAP in a Bluetooth Piconet. Signal Newsletter no. 4, 1999

[SUV00a] Suvak, David. Irda versus Bluetooth: A Complimentary Comparison. Available at: http://www.affixcce.com/text_france/IrDa_Bluetooth_com.htm , 2000 [Referred 2.6.2001]

[SUV00b] Suvak, Dave. Comparing the benefits of IrDA and Bluetooth. Wireless Systems Design, May 2000

[WIE00] Wieland, Ken. Where are the location-based services? Telecommunications magazine, September 2000

[WAP01] WAP Forum. WAP specification 2.0. July 2001

[ZOL01] Zoltek, Thomas. Comparing Bluetooth And IEEE 802.11. Wireless Systems Design, Bluetooth Winter Issue, 2001