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TECHNOLOGY BEHIND REAL-TIME LOCATION SYSTEMS

Radio Frequency-based Systems

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Ilari Alatalo
Bachelor's Thesis
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PREFACE

This bachelor's thesis is made as part of Information Technology Degree Program in 2012. The idea for this thesis work came from the guiding teacher Leo Ilkko from Raahe Campus of Oulu University of Applied Sciences. This thesis will explain the basic principles of radio frequency based Real Time Location and indoor-positioning systems; how they work, what are the pros and cons and what types of solutions are not capable of indoor positioning. Indoor positioning is a quite new invention, although the technologies behind it have been used for a long time. The thesis is concentrated on the author's theoretical studies in radio-based positioning systems. There is very little scientific literature in the subject area and the major part is written in English and therefore the thesis is written in English.

30 April, 2012

Ilari Alatalo

TIIVISTELMÄ

Oulun seudun ammattikorkeakoulu, Raahen tekniikan ja talouden kampus
Tietotekniikan koulutusohjelma

Tekijä: Ilari Alatalo

Opinnäytetyön nimi: Technology behind Real-Time Location Systems

Työn ohjaaja: Leo Ilkko

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Tämän insinöörityön idea tuli Oulun seudun ammattikorkeakoulun, Raahen yksikön Ubilaboratoriosta sekä osittain kirjoittajan omasta kiinnostuksesta sisätilapaikannukseen ja tekniikkaan niiden takana. Tavoitteena oli tutkia radiotaajuuksia käyttäviä järjestelmiä ja vertailla niitä keskenään sekä löytää erilaisia sovelluksia, joissa voidaan käyttää reaaliaikaisia paikannusjärjestelmiä tai sisätilapaikannusta ja mikä ero näiden termien välillä on.

Tässä työssä on perehdytty sisätiloissa käytettäviin paikannusjärjestelmiin, niissä käytettäviin tekniikoihin ja menetelmiin sekä eri sovelluksiin, joissa voidaan hyödyntää näitä tekniikoita. Yleisimmät järjestelmät perustuvat radiotekniikalla toimiviin järjestelmiin, joihin tässä työssä keskitytään, esimerkiksi Bluetooth ja WLAN. Alun perin näitä tekniikoita ei ole suunniteltu paikannuskäyttöön, joten työssä on myös kerrottu niiden perinteinen käyttötarkoitus. Työssä kerrotaan lisäksi perusteet radiotekniikasta, jolla pyritään selventämään paikannustekniikoiden toimivuutta sisätiloissa sekä mitkä asiat vaikuttavat signaalin etenemiseen.

Sisätilapaikannusjärjestelmien toteutus vaatii tarkkaa suunnittelua, jotta järjestelmä toimii halutulla tavalla. Radiotekniikkaa käyttävien järjestelmien heikkoudet tulee selvittää ja tehdä kiinteistöön tarkat mittaukset ennen järjestelmän asennusta. Parhaiten soveltuvan tekniikan valitseminen riippuu monesta tekijästä. Kuinka tarkkaa paikannustietoa tarvitaan, mitä sillä halutaan paikantaa ja voidaanko hyödyntää olemassa olevia järjestelmiä? Perinteisen paikannussovelluksen lisäksi on kehitetty myös esimerkiksi paikkatietoon perustuvaa palveluntarjontaa, sekä myös järjestelmiä, joilla voidaan navigoida sisätiloissa.

Asiasanat: *Paikannus, WLAN, Bluetooth, RFID, ZigBee, UWB, RTLS*

ABSTRACT

Oulu University of Applied Sciences, Raahe Campus
Degree Programme in Information Technology

Author: Ilari Alatalo
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The original idea for this Bachelor's thesis came from Oulu University of Applied Sciences, Ubilab and partly from the author's interest in real-time location systems and the technology behind them. The aim was to study different systems and compare them with each other and also discover different applications where real-time location systems or indoor positioning systems are used and what is the difference between these terms.

This thesis examines indoor positioning systems, the technologies and methods that are used and introduces the various applications in which these systems can be used. The most common systems are based on radio technology, in which this thesis work will focus on, such as Bluetooth and WLAN. Originally, these techniques are not designed for positioning, so the traditional use is also explained. The basics of radio technology are also described, which clarifies the operation of positioning technologies in indoor usage and the factors that affect signal progression.

The indoor positioning systems require careful planning, so that the system is performing optimally. The weaknesses of radio based systems need to be discovered and accurate measurements need to be done to the property before installing the system. The most appropriate choice of technology depends on many factors. How accurate positioning information is needed, what is being located and is there an existing system that can be used? In addition to the traditional tracking solution, there are many applications developed, e.g. location based services, as well as systems that can be used to indoor navigation.

Keywords: *Positioning, WLAN, Bluetooth, RFID, ZigBee, UWB, RTLS*

TABLE OF CONTENTS

1 LIST OF ABBREVIATIONS

RTLS	*Real Time Locating System*
WLAN	*Wireless Local Area Network*
RFID	*Radio Frequency Identification*
IPS	*Indoor Positioning System*
AOA	*Angle Of Arrival*
TDOA	*Time Difference Of Arrival*
TOA	*Time Of Arrival*
TOF	*Time Of Flight*
RF	*Radio Frequency*
RSS	*Received Signal Strenght*
RSSI	*Received Signal Strenght Indication*
UWB	*Ultra Wide Band*
LBS	*Location based Service*
WPAN	*Wireless Personal Area Network*
dB	*Decibel*
dBm	*Decibel milliwatt*
LAN	*Local area network*
GNSS	*Global Navigation Satellite System*
GPS	*Global Positioning System*
LWAPP	*Lightweight Wireless Access Point Protocol*
LOCP	*Cisco Location Control Protocol*
SNMP	*Simple Network Management Protocol*
SOAP	*Simple Object Access Protocol*
XML	*Extensible Markup Language*
WCS	Wireless Control System

2 INTRODUCTION

Nowadays navigation is very familiar to us and it has been made extremely simple. There are a lot of different types of devices that we can use to navigate our route to unknown destination whether we travel by car, by foot, or by bicycle. These navigation devices use satellites to measure our location and the destination that we are going to. Satellite positioning is very accurate and it almost always leads us correctly to our destination. Satellite positioning is applicable when we are outdoors but our need to navigate indoors requires another solution because satellite positioning does not work indoors. Indoor positioning is quite a new invention and it is now finding its penetration to the markets. The technology that it is based on is not new as it has been used for some other purposes e.g. a wireless local area network is used to connect a laptop to a network wirelessly. All the applications for indoor positioning basically use radio based technologies. The aim of thesis is to introduce different radio based location and positioning techniques and to compare them with each other and to clarify the different uses of indoor positioning.

2.1 RTLS

Real-Time location systems are used to track people or assets indoors, e.g. hospitals have a lot of expensive equipment and they need to know where the equipment is located. First of all there is a risk that the assets can be stolen or get lost. The assets can be equipped with some type of RTLS-tags, so their location can be monitored. Tracking people inside buildings could be needed for safety reasons. In case of fire, the system can tell us if there are people inside the premises and where they are located. Also, tracking tags can be used for employees if there is a risk of violent customers. The tag can be equipped with a panic button that can be pressed if one needs help from a security officer. The tag gives the position of the person who pressed the panic button. There are different types of RTLS-solutions based on different techniques, e.g. WLAN, RFID and Bluetooth. The basic principles on each technique will be explained later. (Malik 2009 62-64)

2.2 Locating persons and assets

Many systems have been developed to prevent e.g. vehicle thefts. These systems are used outdoors and they mainly use satellites and cellular phone networks for positioning. The movement of the vehicle can be tracked and a stolen property can be found. The same idea applies to indoor-positioning except that the system that is used is some type of wireless system e.g. WLAN,

Bluetooth or RFID. RTLS-systems have mainly been developed for asset management to keep track of assets. Markets for the business developing indoor-positioning systems are mainly hospitals. Staff members and hospital equipment as well as newborn babies can be located with different wireless location systems. (Bensky 2008, 5)

Parents' worry of a child going missing in an amusement park or shopping centers can be solved with wireless positioning. A child can be tagged with some type of a transceiver and parents can track the child's movements with a handheld device e.g. a tablet computer or a smart phone. The area needs to be equipped with access points that send the information to a location engine which measures the whereabouts of the tags. (Bensky 2008, 5)

When technologies improve, the tags can be made smaller and they can be installed into smaller devices and e.g. person tags can be unobtrusive. There are many technologies in the market that can be used for real-time positioning. Only the various applications where the systems can be used need to be discovered. (Bensky 2008, 5)

2.3 RTLS VS IPS

The basic issues of RTLS (Real Time Location System) are standardized by the International Organization for Standardization and the International Electro Technical Commission, under the ISO/IEC 24730 series. The standard defines RTLS as follows: "Real time locating systems are wireless systems with the ability to locate the position of an item anywhere in a defined space (local/campus, wide area/regional, global) at a point in time that is, or is close to, real time. Position is derived by measurements of the physical properties of the radio link." (Wikipedia 2012a, date of retrieval 26.3.2012)

There is no standard or accurate definition given to Indoor positioning systems (IPS). When tracking assets inside buildings the term positioning is regarded wrong. The right term should be locating, though both terms are referring to the same thing. The technologies are basically the same and there is reason to believe that in future, there will be standard definitions for the terms.

Real time location services, which are used today, are good at finding and tracking assets and people. These systems offer information for the users mainly on a client software and assumably they are hard to use for a person that is not familiar with computers and networking. Indoor posi-

tioning systems are meant to serve the client, e.g. users of smart phones and tablets. These systems track the location of the devices and tell the user where they are located, e.g. Google's service that will be introduced in chapter 8.2. The difference between RTLS and IPS systems is that RTLS is meant for companies to track their assets or people, providing the history where the item has been and where it is now. This mainly serves the company's interests. IPS systems are meant to serve the smart phone user to find or to navigate the route to somewhere inside buildings and also perhaps for LBS services.

2.4 Satellite positioning

Satellite positioning is used to navigate a route to a desired destination, e.g. a car navigation. The most common system is GPS (Global Positioning System). It was developed by the government of the USA for military use. GPS has been operating from early 1990's in military purposes and in civil purposes from the year 2000. Fully functional systems are GPS and Glonass in 2012. Glonass is the Russian satellite navigation that has been operating from 2011. Glonass is an alternative to GPS. European Union has its own satellite system under development. It is called Galileo. It is designed to have 30 satellites and it will be under a civilian control. (LaMarca & de Lara 2008, 16)

The satellite positioning system that has a global coverage is called GNSS Global Navigation Satellite System. The global systems consist from 20 – 30 satellites spread between several orbital planes. These satellites send radio signals to the listening receivers such as a car navigation or a smart phone. The satellite systems send the signal from 1,5 GHz to 1,6 GHz frequencies in civil use. The receiver calculates the distance to the satellite and then calculates its own location in satellite coordinates. The receiver must receive at least four satellite signals to calculate the position. The problem using a satellite to navigate inside buildings is that the signal is not strong enough to carry through obstacles, thus a clear view to the sky is required. (Malik 2009, 156)

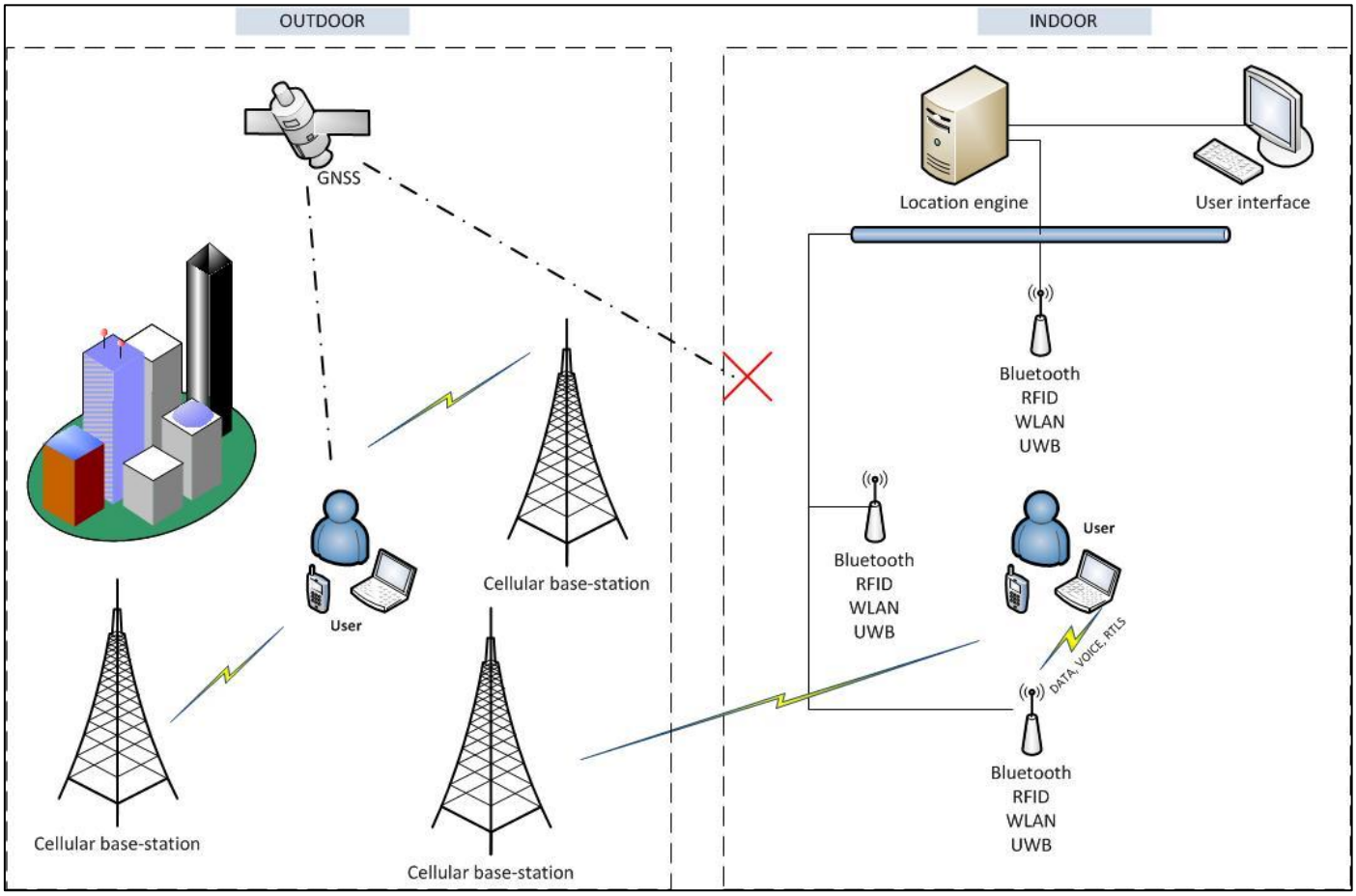


Figure 1. Positioning technologies

3 RADIO WAVES IN DATA TRANSMISSION

Common indoor positioning and RTLS systems are based on the technics that use radio waves or more precisely an electromagnetic radiation. To understand how a radio based location works and what it is capable of, it is very important to know the basics of radio techniques. There are many factors that effect to the signal propagation, e.g. a transmission power, a signal pulse width, surrounding materials and a noise. Antennas play a major role in how a radio device works, no matter what the device is. The efficiency of the antenna performance is often described as the antenna gain and radiation pattern.

Electromagnetic waves from a radio device usually travel directly to the direction where they are headed, i.e. in free space, where there are no obstacles. Indoors this is impossible and the path is altered by a reflection, a refraction and a diffraction. There may be scattering, e.g. from thick walls. These alternations are shown in figure 3. The intensity of radio waves diminishes due to geometric dispersion known as the inverse-square law. The energy may also be absorbed by mediums trough which the signal has to go, e.g. building materials. A noise is also a physical interference that alters the desired signal. The noise is an electromagnetic interference that comes from natural and artificial sources, such as other transmitters. (Wikipedia 2012b, date of retrieval 18.3.2012)

A radio system transmits information to the transmitter. The information is transmitted through an antenna which converts the RF signal into an electromagnetic wave. The transmission medium for an electromagnetic wave propagation is free space. The electromagnetic wave is intercepted by the receiving antenna which converts it back to an RF signal. Ideally, this RF signal is the same as the one that was originally generated by the transmitter. The original information is then demodulated back to its original form. In figure 2 there is a basic RF-system. The transmitter sends data and the receiver picks it up. The data is transmitted and received with antennas and the medium is free-space. (Breeze Wireless Communications Ltd, 2012a, date of retrieval 18.2.2012)

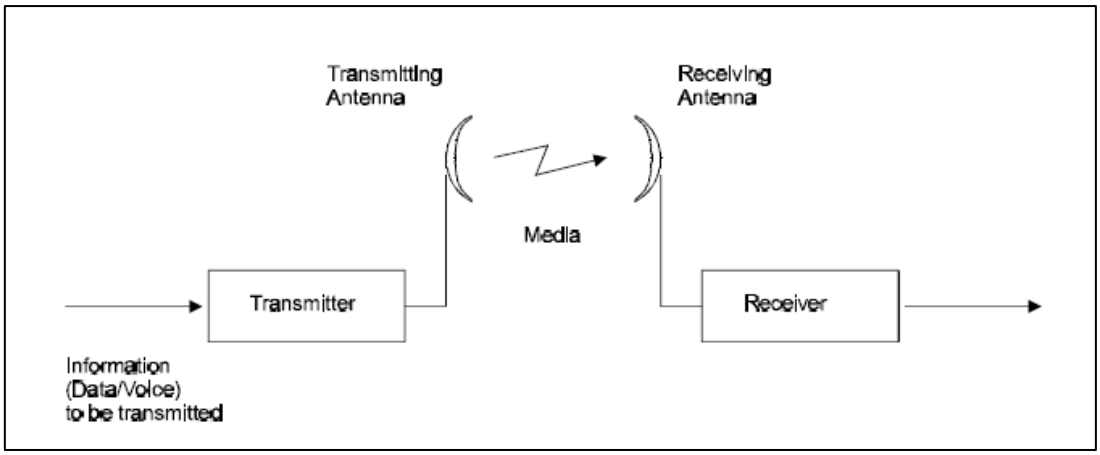


Figure 2. Basic RF-system

3.1 Environmental factors to an RF-signal

When designing a system with a radio technology, it is very important to notice the environmental factors that can cause problems to the signal propagation. There are many factors that affect the propagation especially if indoor positioning is used inside buildings.

3.1.1 Obstacles (building material)

When radio waves pass through a wall or another obstacle, the power of the signal decreases. How much it decreases, depends on the material and its thickness. Obstacles cause reflection and shattering on the radio wave and also absorption of the material in the obstacle. (Sputnik inc, 2004, date of retrieval 21.2.2012)

3.1.2 Attenuation

Different objects in the environment affect the radio signal in different ways. When a signal goes through an object it attenuates. The attenuation depends on the material and its properties, i.e. how strongly it absorbs the energy of the radio signal. Also, the thickness of the material increases the attenuation. Different metals and concrete are materials that have strong properties to absorb the energy. (Sputnik inc, 2004, date of retrieval 21.2.2012)

3.1.3 Scattering

Radio signals reflect from the objects between the transmitter and the receiver. The reflected signals combine with the direct signal. The reflected signal also travels a longer time because the path is not direct. This is also described as a multipath fading and signal dispersion. When a scattered and a direct signal combine, the signal can be distorted. The distortion lowers the ability of the receiver to recover the signal that it receives. (Sputnik inc, 2004, date of retrieval 21.2.2012)

3.1.4 Multipath fading

When designing a radio transmission system, a multipath fading must be taken into account. Especially indoors the signal will reach the receiver not only by a direct path, but also as reflections from objects such as walls, furniture, doors, building material, etc. A Multipath fading occurs, when a receiver receives multiple copies of a transmitted signal. The receiver receives a sum of signals that have travelled through different paths. As a result the received signal may have errors that cannot be interpreted. Figure 3 shows how the signal is affected when it hits an obstacle. The reflection and scattering bounce the signal back to where it is coming from and as a result, the signal will not reach the receiver if the obstacle is e.g. too thick. The diffraction and refraction move the direction of the signal, also affecting that the receiver will not receive the signal or there is a possibility of multiple copies of the signal. (Malik 2009, 193; Radio-Electronics.com, 2012a, date of retrieval 21.2.2012)

3.2 Signal parameters

When using a radio transmission to measure a distance and a location, the accuracy depends on the basic system characteristics of a bandwidth, a noise and a clock rate of the signal.

3.2.1 Bandwidth

A bandwidth is the difference between the upper and lower frequencies in a contiguous set of frequencies. In radio transmission, the bandwidth is the frequency range occupied by a modulated carrier wave. (Wikipedia 2012c, date of retrieval 6.3.2012)

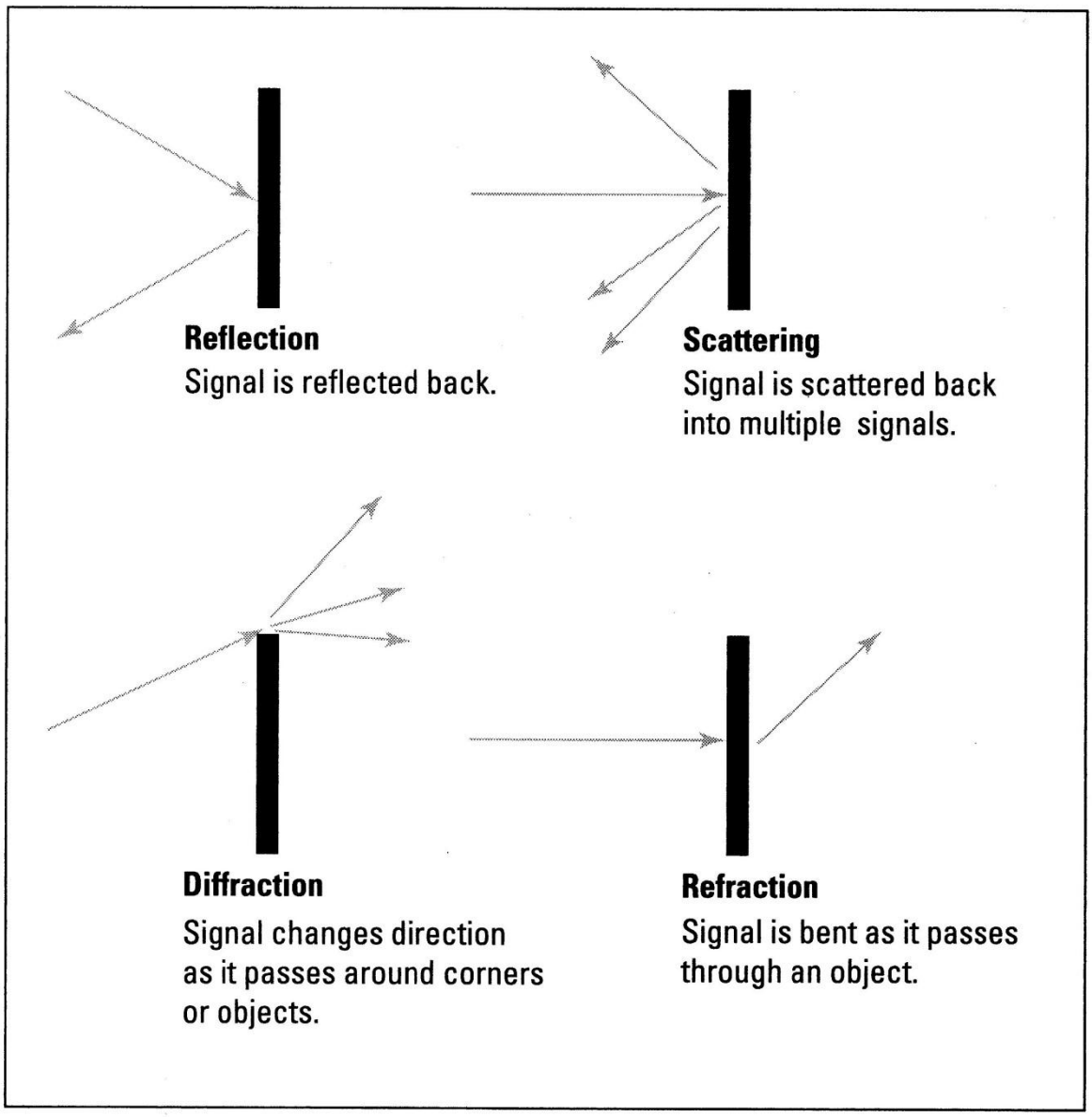


Figure 3. Signal propagation

3.2.2 Noise

In signal processing a noise can be considered as a random unwanted data without a meaning; i.e. data that is not being used to transmit a signal, but is simply produced as an unwanted by-product of other activities. A Signal-to-noise ratio refers to the ratio of useful and irrelevant information. It compares the level of desired signal to the background noise level. The noise causes limitation to the communication efficiency and range. (Wikipedia 2012d, date of retrieval 18.3.2012)

4 POSITIONING MEASUREMENT TECHNIQUES

All radio-based positioning systems use nearly the same measurement techniques to measure the location. The angle, time, and strength of the radio signal are values that can be measured and they can be used to calculate the position of the desired device.

4.1 Angle of arrival (AoA)

Angulation can be used to determine the position of the device. AoA measures the direction and angle of the radio wave incident on the receiver's antenna. It needs two or more values for locating. The receiver antennas are direction-sensitive antennas. The position of the device is estimated by finding the intersection of different signal propagation paths. AoA is dependent from the range and if the location sensor is too far away small errors can result and cause a large location error. AoA needs directional antennas; the accuracy of location depends on the directivity of the antennas. Electronically steered antennas are used for finding the right direction. The angle of the arriving signal can be measured as shown in figure 4, X is the target that is located. The angle of arrival of the signal is measured in sensors A and B. (Kushki etc. 2012, 57, Malik 2009, 39, Bensky 2008, 29).

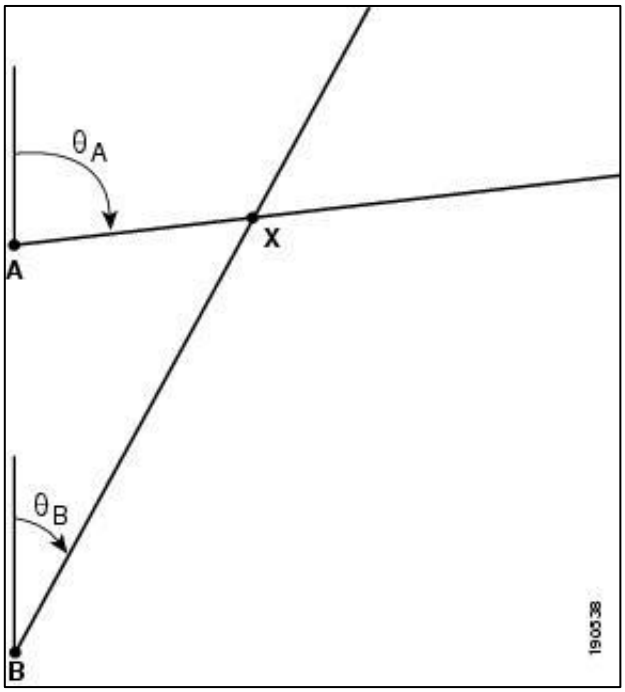


Figure 4. AOA

4.2 Time of arrival (ToA)

Radio signals travel at a known speed (propagation delay). ToA can be used to determine the distance between the transmitter and the receiver. A good example of estimating a distance with ToA is the estimation of a thunderstorm by counting seconds from the flash to the hearing of the thunder. ToA is also used to determine the distance in radar and sonar systems. (Pottie, Kaiser 2005, 276)

A ToA positioning system needs three or more terminals to a three-dimensional location. A circular lateration can be used to find the position of a device. Two terminals are needed to a two-dimensional location. A propagation delay can be converted into distance between the device and the location sensor and multiplying it by propagation speed of the signals. ToA requires synchronized clock at the tag/device and a location sensor. When using ToA, the location is found using only distance data. Two measurement techniques, a received signal strength and a time-of-flight can be used to estimate the distance. (Kushki etc. 2012 57; Malik 2009, 38; Bensky 2008, 29)

Figure 5 illustrates how the calculation is made with three sensors A, B and C while X is the object that is been located. The calculation formula is D = c(t). D is a distance in meters. A propagation velocity c is known (approx. 300 m/μs) and t is time in microseconds. Each of the sensors are calculated as D_a, D_b and D_c. These values are used to construct a circular plot around the points A, B and C. X is considered to allocate somewhere along this plot. The accurate location is in the intersection of the three circular plots. (Cisco systems, 2008, 2-4)

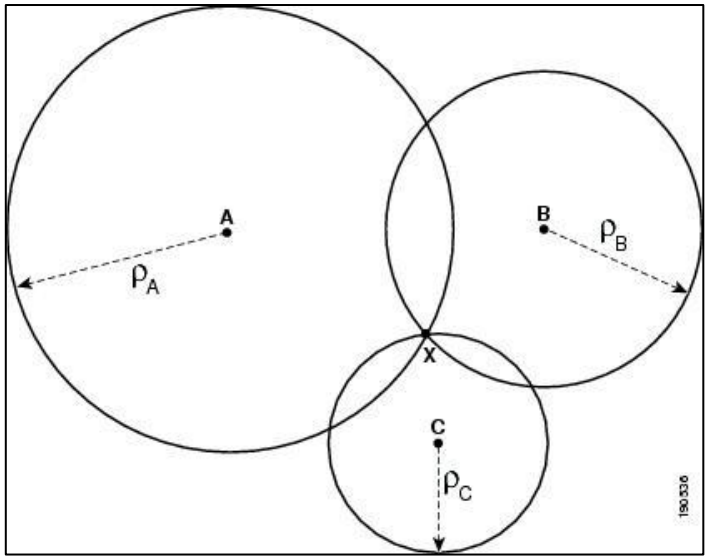


Figure 5. TOA

4.3 Time difference of arrival (TDoA)

In TDoA method two sources that are synchronized, generate signals where a receiver can determine the time difference of arrival from the travelled signals. ToA and TDoA require synchronization between the base stations/access points. TDoA measures the difference in transmission times between signals received from each of the transmitters to a tag/device or other way around. TDoA requires that all location sensors are exactly time synchronized. Three or more measurements can be used to locate a tag/device using a hyperbolic lateration. (Pottie, Kaiser 2005, 279)

Figure 6 describes how the hyperbolic lateration is calculated. There are three sensors, basestations A, B and C. X marks the object that is being located. Position X is located in the intersection of two hyperbolas $TDOA_{C-A}$ and $TDOA_{B-A}$.

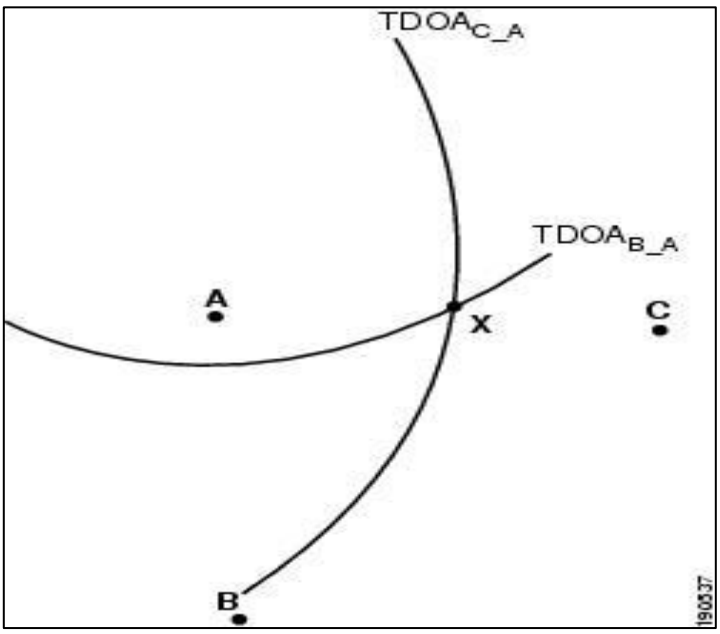


Figure 6. TDOA

4.4 Received signal strength (RSS)

RSS measures the radio signal power present in a received signal of the tag/device. The signal attenuates when it leaves from the transmitter, the power of the signal drops. The drop is logarithmic. If the power level at the start of a transmission and the signal attenuation in an open space and through different mediums are known, RSS can be used to determine the distance that

the signal has traveled. RSS is used e.g. in laptops or mobile phones as a WLAN signal strength indicator called RSSI (Received Signal Strength Indicator). RSS is very complicated to measure because it is affected by several factors, e.g. obstacles, a multipath fading, a temperature and a humidity, furniture and a human being or any other thing on the way of the signal. (Malik 2009, 39)

A signal power in free-space between the transmitter and the receiver is inversely proportional to the distance. When the transmitted and received powers are known, the distance between e.g. an access point and a WLAN-tag can be calculated, i.e. in an ideal environment. Real environments are not as easy, because there are a lot of factors that interfere the signal propagation. (Kushki, Azadeh etc 2012, s.59)

RSS can be implemented on an existing wireless communication system with little or no hard-ware changes. All that is needed is the ability to read an RSSI output. In picture 7 there is a screen shot of a Buffalo WLAN base station configuration tool. The base station shows wireless clients that are connected to it. It measures the connection uptime, TX and RX rate, signal which is the RSS measurement, noise and signal-to-noise ratio. From the RSS value, it is possible to measure the distance of the device. The buffalo base station also shows the transmission power and frequency.

Example of RSSI calculating

The distance between an access point and a WLAN- device can be estimated with RSSI when the following variables are known:

- Radio frequency attenuation in free space
- Transmission start power level
- Power drop when the signal goes through surrounding media

Radio frequency signal attenuation in free space can be calculated with the following formula:

$$Path\ loss = -38 + 20\ log_{10}(f) + 10 \times n \times log_{10}(d)$$

f = transmission frequency (MHz)

d = distance specified in meter

n = path lost constant

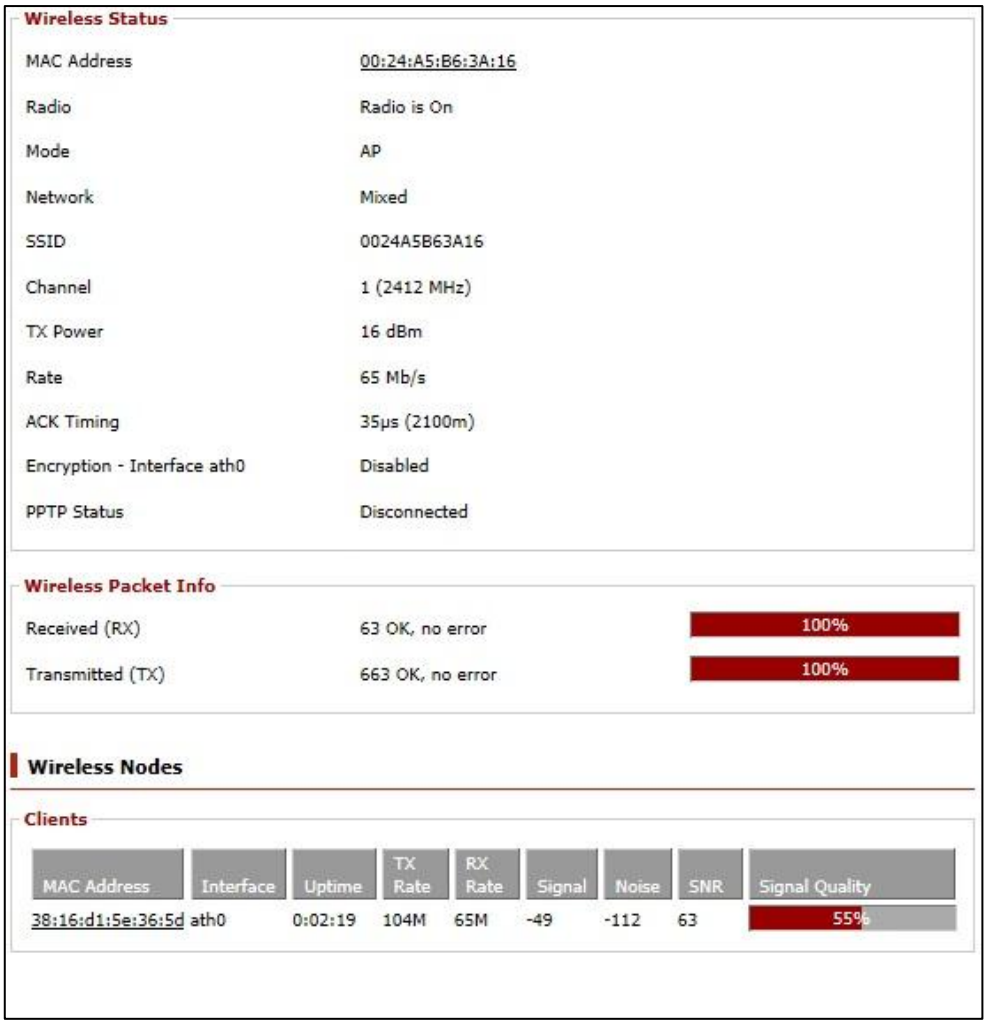


Figure 7. Buffalo WLAN configuration tool

4.5 Fingerprinting

Fingerprinting is a technique where the position is measured from reference/anchor points made earlier when the system is designed. Positioning is based on the known locations that are stored in a database. When the system is in use, the location is estimated from the closest reference points. Figure 8 describes the fingerprinting technique. Fingerprinting is based on the anchor points that are measured from the desired place. The measurement is made e.g. with a laptop and a program that collects and measures the data, then it can be stored into a location engine. The location engine compares the data that the base stations send to the measurement that is stored in the location engine. A Finnish company called Ekahau uses the fingerprinting method in

its positioning system. Ekahau RTLS is based on a WLAN-technology. (Kushki, Azadeh et al 2012, 38)

Fingerprinting is laborious to do because the data has to be collected densely and when the target place is a large building with many floors. The position of the object that is been located is the position of the nearest anchor point not necessarily the actual point where the object is. It is an estimation of the location. There is a reason to believe that the fingerprinting is a guaranteed method for positioning but many variables can alter the result like in many other techniques e.g. furniture, humans, doors and other factors that affect the radio signal.

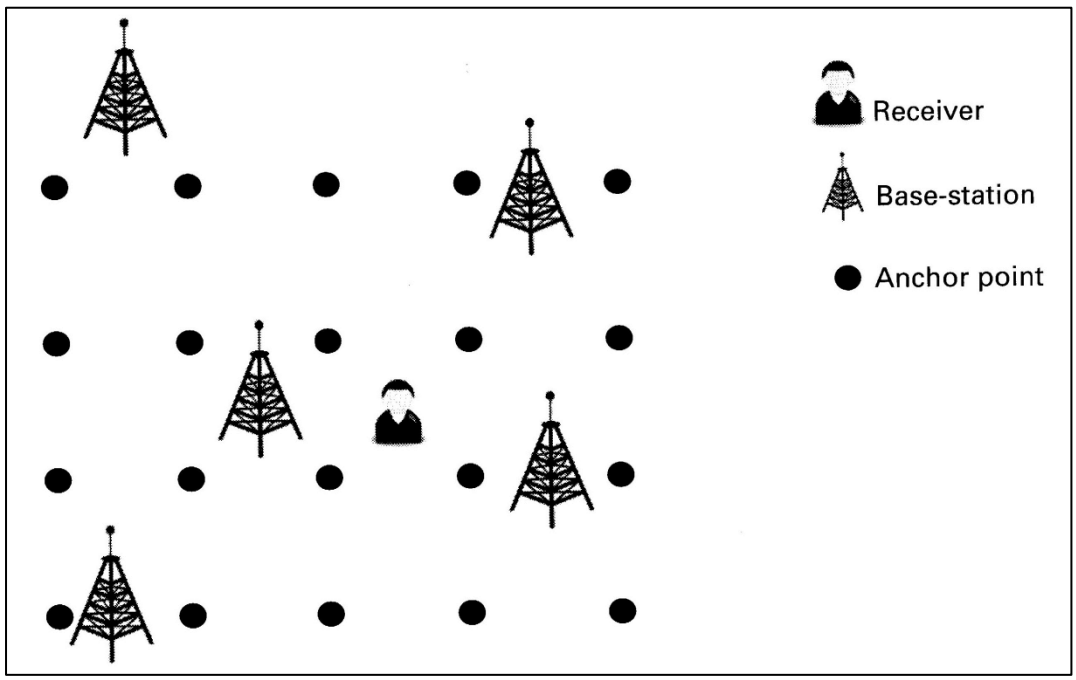


Figure 8. Fingerprinting

5 POSITIONING ALGORITHMS

Computing the position can be done with several algorithms. An algorithm is some type of mathematical formula that a location engine calculates. The location engine is a device which has a software that is executing the calculation of algorithms. It is the centerpiece in RTLS-systems that collect the data of the location sensors and use some type of algorithm to calculate the location of the desired object. The location engine usually has a database of the location information and a user interface software. (Malik 2009, 38)

5.1 Trilateration

Trilateration can be used to determine the distance when the object can be measured from three different locations. Multilateration is possible when the measurements can be done from more than three locations. (Malik 2009, 40)

5.2 Triangulation

Triangulation can be used to estimate the position of a target object if the line angle is known between the measured object and three different locations with a reference line such as a line pointing up. (Malik 2009, 40)

5.3 Nearest neighbor

Nearest neighbor is a technique where relations to neighbors are used to estimate the location. It is based on any ranging techniques such as RSSI. The device can be detected e.g. with location sensors placed in the space where positioning is done. These sensors detect the device and send the information to the location engine, which calculates the location. If a room e.g. has three sensors A, B and C with a known location, the location of the device can be estimated as the following simplified example: If A and B sensors can see the device, but C cannot, the device is inside the room. If A and B cannot see the device, but C can, the device is outside the room near the C-sensor. (Malik 2009, 43)

6 INDOOR POSITIONING TECHNOLOGIES

There are lots of different technologies in the market. In this chapter the principles of the most common indoor positioning radio-based techniques; Bluetooth, RFID, ZigBee, UWB and WLAN are described.

6.1 Bluetooth

Bluetooth is a wireless networking standard (IEEE 802.15) designed for a communication in a personal area networking (PAN) environment. Nowadays nearly all mobile phones are equipped with Bluetooth. Bluetooth is not designed for positioning, but it is very ideal for that purpose, because it has a mechanism to identify devices using a Bluetooth technology in the area and create a communication link between them. (Malik 2009, 195)

The Bluetooth operation frequency is 2,4 GHz. The typical Bluetooth device transmission power is 1 milliwatt for devices with a 1-meter range, 2,5 milliwatts for devices with a 10-meter range and 100 milliwatts for devices with a 100-meter range. Bluetooth devices use a technique called FHSS (Frequency Hopping Spread Spectrum). In FHSS a device will use one from 79 different, randomly chosen frequencies within an assigned range and it will frequently change frequencies from one to another. Bluetooth devices hop frequencies 1600 times per second. When hopping the frequencies more devices can use a portion of the radio spectrum. Bluetooth devices also use Adaptive Frequency Hopping (AFH) to avoid crowded frequencies or to avoid channels that have a bad quality of wireless signal. (Malik 2009, 196)

6.1.1 Using Bluetooth for positioning

Bluetooth is used by many devices so the asset tracking can be done without external tags. Bluetooth is also standard based. Bluetooth has a low power consumption and a high accuracy (approx. 2 meters). Its range is not very wide so the access points have to be close to each other, approximately 15 – 20 meters. Tracking the devices can be done by an inquiry process on the location engine. The location engine can inquire the tags to find all nearby tags or just a specific tag. Access points measure and report the tags RSSI to the location engine (Malik 2009, 196-197)

6.2 ZigBee

ZigBee is a technological standard by the ZigBee Alliance for control and sensor networks. It is based on IEEE 802.15.4. ZigBee is a protocol that enables high throughput and low latency for low duty-cycle applications. ZigBee is normally used to control e.g. home automation devices such as lights and thermostats. It is also capable of positioning because it is a self-forming and self-healing mesh network. The mesh network enables messages to travel from one node to another from multiple paths so when one route is disconnected the message can still reach its destination. (Malik 2009, 207)

6.2.1 Using ZigBee for positioning

ZigBee is very reliable and tolerant for errors due to the mesh network. The devices that are connected to a ZigBee-network can join and reroute fast in case of failure. ZigBee devices are very power efficient and ZigBee has a very large network capacity. The end devices that are located can measure on demand or periodically signals from nearby ZigBee routers and tell the information to the location engine. (Malik 2009, 207)

6.3 RFID

RFID (Radio Frequency Identification) is a general term for technologies operating in the radio frequencies used in the products and objects for observation, detection and identification. The technology is based on an information storage, an RFID tag, and its wireless reading of the RFID reader using radio waves. A RFID system consists of RFID readers and tags and the communication between them. There are passive, semi-passive and active RFID-tags. Passive tags have no own power source e.g. a battery. For that reason the tags can be made very small to fit smaller products. The passive tags receive the operational power, e.g. from the corresponding interrogator. Active tags typically have internal battery and a transmitter or a transceiver. They have a long range and that is why they can be used for real-time location systems and indoor positioning. (Malik 2009, 28; RFID-lab, link a, date of retrieval 18.3.2012)

6.3.1 Using active RFID for positioning

The system consists e.g. of RFID tags that can send beacon signals in a given time interval. The readers, which are installed to the premises, receive the signals from the tags. The readers take

the measurements e.g. RSSI, TOA and AOA and send the information to the location engine. The location engine does the computing of algorithm. The RFID tags can also be tags that listen the messages from the RFID readers. In this type of solution the tags can send the information to the location engine or to the RFID readers that take the measurements and then send the information to the location engine. The challenges for an RFID-system are that it is a completely own infrastructure that needs to be maintained. This is also a good side because it does not interfere other systems, e.g. WLAN that is used for networking. (Malik 2009, 202-203)

6.4 UWB

Ultrawideband as the name refers has a very wide bandwidth, typically 1000 MHz. UWB is normally used as a high-speed data link for short ranges, e.g. a wireless USB. UWB is a carrierless communication scheme. UWB technology's first applications were related to radar technology. UWB has an IEEE approved standard 802.15.4a. (Malik 2009, Thales research and technology, 2006a, date of retrieval 23.2.2012)

Similar to other positioning solutions, UWB systems have receivers installed to the premises that continuously monitor the clients. A UWB-based locating uses UWB signals and that is the difference to other RTLS-systesms. UWB radio signals have a very wide bandwidth. UWB is very accurate positioning method, up to few centimeters. UWB does not interfere with other RF-systems because the signal types and radio spectrum mainly differ from other systems. UWB is also quite immune to a multipath fading. Some disadvantages that UWB has are that line of sight or timing cables between UWB-receivers are needed for time synchronization. Also, other UWB devices, applications and non-line of sight propagation can result ranging errors. (Malik 2006, 206; Ekahau inc, 2006a, date of retrieval 13.3.2012)

6.4.1 Using UWB for positioning

UWB provides very accurate locating, up to a few centimeters. UWB has a good performance in highly reflective environments that have e.g. a high metal content, such as manufacturing plants because of short low-duty-cycle pulses. UWB pulses are narrow and occupy the entire bandwidth so they are relatively immune to a multipath fading. UWB is also immune to other RF-systems interferences due to the differences in signal types and radio spectrum. (Malik 2009, 205-206)

6.5 WLAN

Wireless local area network (WLAN) is a wireless data transfer technology based on the IEEE 802.11 standard. Normally, it is used to connect your device to the Internet or other network without using cables. Wireless WLAN networks are very common these days from public buildings to shopping centers. That is why it offers a good basis for a WLAN based RTLS-system. With a wireless network and an RTLS functionality it is possible to track different types of assets inside buildings e.g. laptops, smart phones or other devices that are equipped with a built-in WLAN radio or with a WLAN-tag. (Malik 2009 185)

The basic principle of a WLAN-based positioning is the received signal strength (RSS) and time difference of arrival (TDOA). RSS is the measurement of the power present in the received radio signal. Different devices use it to indicate the signal strength from the access point to the device. The RSS can be used to estimate the distance between tags and an access point. In a simple way here is how it works: The WLAN device sends data to its surroundings and all the access points that are in range receive the signal and measure the RSSI. The actual access points or the tags will not do any calculating; instead the access point sends the information to the central computer that is called the location engine, which does all the calculating. (Malik 2009, 185)

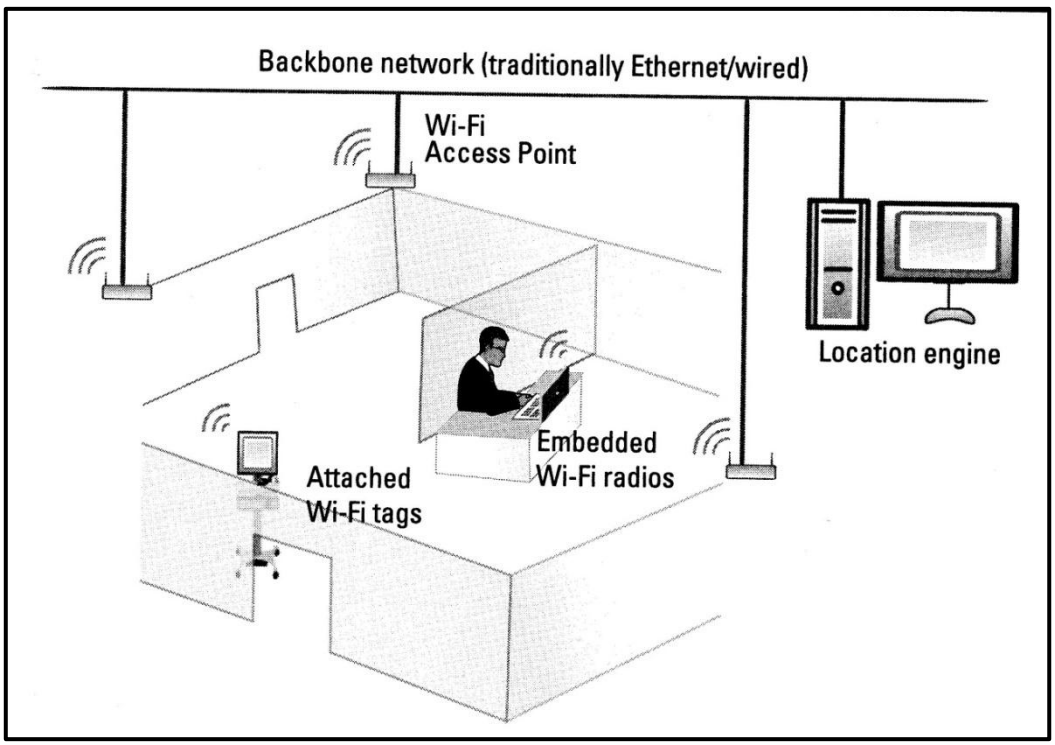


Figure 9. WLAN RTLS

In figure 9 there is a typical WLAN-RTLS. The access points and the location engine are connected to backbone network (wired ethernet). There are embedded WLAN-devices such as laptops, mobile phones and maybe some devices that have a tag attached to them.

6.5.1 Using WLAN for positioning

Basically, the WLAN positioning principle is that the WLAN tags do the signal transmission. They send a probe request to the nearby WLAN access points. The access points that receive the signal make the measurement of e.g. RSSI, TDOA, etc. and send the information to the location engine that calculates the location of the tag. WLAN has many advantages compared to other RTLS and indoor positioning technologies. First of all it has a low cost because WLAN is very common nowadays. The devices and network needed for positioning may already have been installed to the building. WLAN is a multipurpose network that can be used for data, video, voice and so on. WLAN is not very accurate for positioning, but in many cases it is sufficient enough. Accuracy can be improved by adding more access points/base-stations. (Malik 2009, 186)

7 CHOOSING AN RTLS-TECHNOLOGY

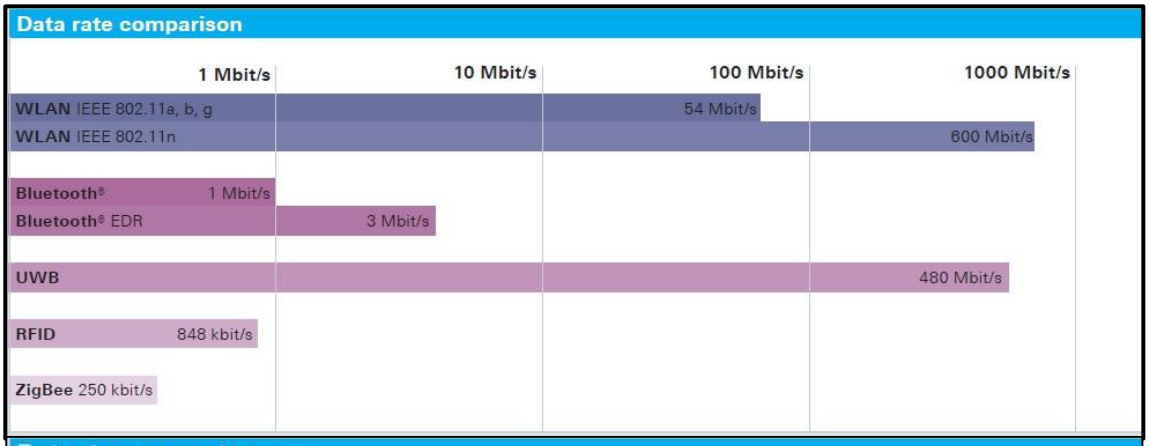
All technologies that are introduced above have qualities that make them capable of using in a location system. One key factor is that what the demands are for the system:

- What are the targets that are being located e.g. humans, assets and does the asset already have a Bluetooth or WLAN capability?
- Are there already technologies in use that can be used for location services, e.g. WLAN
- How accurate the system should be?
- What kind of environment it is where the system would be installed?

The RFID differs from the other radio-based systems used. Other solutions are basically used to transmit and receive data wirelessly. The RFID is designed to identify objects from a close range e.g. access control readers. The RFID tags memory has some type of information stored in it. Depending on which frequency is in use the range varies from few centimeters to tens of meters. Vehicle recognition uses a microwave frequency and the identification can be made from 10 – 20 meters. Cisco location appliance (introduced in chapter 9) is capable to track WLAN devices but also compatible active RFID-tags. The tags can be assembled to a person, assets etc.

Bluetooth and WLAN are the most common systems used. Bluetooth is a standard that is used in many devices and this is why it is a good choice for location systems. When using Bluetooth the system has to be built and designed well. The Bluetooth's range is not very long so the access points need to be installed every 15-20 meters. In large premises this might be considered as a problem because of huge amount of devices are needed. Bluetooth's data rate is slow compared to WLAN or UWB as shown in figure 10.

WLAN is one of the easiest and probably the cheapest systems to take in use and likely the most common system. It is not necessarily the most accurate but and again it all depends on the demands. If the need for location accuracy is that the target is located in room level, WLAN is accurate enough. The accuracy of all systems depends highly on how many and how dense the access points/base-stations are installed. There are many devices that use WLAN so these devices can easily be tracked.



Technology parameters

	Wireless connectivity					Satellite navigation	
	WLAN IEEE 802.11a, b, g, n	**Bluetooth®**	**UWB** WiMedia® (MB-OFDM) ECMA-0368	**RFID, NFC*** ISO 14443 (NFC), ISO 15693, ISO 18000 (EPC)	**ZigBee** IEEE 802.15.4	**GPS**	**Galileo**
Frequency range	2.4 GHz to 2.497 GHz (b, g, n) 5.15 GHz to 5.35 GHz (a, n) 5.725 GHz to 5.825 GHz (a, n)	2.4 GHz to 2.4835 GHz	3.1 GHz to 10.6 GHz	0 MHz to 30 MHz, 125 kHz to 134 kHz, 6.7 MHz, 7.4 MHz to 8.8 MHz, 13.56 MHz, 27 MHz, 125 MHz, 433 MHz, 868 MHz to 928 MHz, 2.45 GHz, 5.8 GHz 24.125 GHz	2.4 GHz to 2.4835 GHz (world) 902 MHz to 928 MHz (North America) 868.3 MHz (Europe)	L1 1575.42 MHz L2 1227.60 MHz L5 1176.45 MHz	E6a 1176.45 MHz E6b 1207.14 MHz E6 1278.75 MHz L1 1575.42 MHz
Modulation	BPSK, QPSK, 16QAM, 64QAM (a, b, g, n) DQPSK, CCK, PBCC (a, b, g)	GFSK enhanced data rate (EDR): GFSK for header, 8DPSK for data	QPSK	FSK, ASK, PSK, PJM, BPSK	BPSK (868 MHz, 915 MHz), OQPSK (MSK) (2.4 GHz)	BPSK	BOC
Multiple access	OFDM, CSMA/CA	FHSS	TFI-OFDM	TDMA, FDMA	CSMA/CA		
Duplex (uplink/ downlink)	TDD	TDD	TDD	TDD, TDM	TDD		
Channel bandwidth	20 MHz (a, b, g) 20 MHz or 40 MHz (n)	1 MHz	528 MHz	typical: 200 kHz / 600 kHz	5 MHz	20.46 MHz	E6a 24 MHz E6b 24 MHz E6 40 MHz L1 32.736 MHz
Number of channels	2.4 GHz: 14 (overlapping) 3 (non-overlapping) 5 GHz: 12 (non-overlapping)	79	6 band groups	as required by local radio regulations (USA: 79 channels)	1 (868 MHz) 10 (915 MHz) 16 (2.4 GHz)	up to 32 satellites	up to 30 satellites
Peak data rate	54 Mbit/s (a, b, g) <600 Mbit/s (n)	1 Mbit/s 3 Mbit/s (EDR)	480 Mbit/s typical	848 kbit/s	20 kbit/s (868 MHz) 40 kbit/s (915 MHz) 250 kbit/s (2.4 GHz)	50 bit/s	E6a 50 sps E6b 250 sps E6 1000 sps L1 250 sps

Figure 10. Technology parameters

8 APPLICATIONS FOR INDOOR POSITIONING

The markets for RTLS- systems are quite small and mainly concentrate on hospitals that track different types of assets. Hospitals use positioning for assets because they are expensive, buildings are large and sometimes the assets are needed very quickly in use. Indoor positioning markets are also very small because there has not been a provider for this type of service. I believe that in future especially indoor positioning and location based services will have growing markets.

One big thing is the RFID that is designed to be the replacement for bar codes and it is said that the future is in "internet of things" which means basically that all items that you buy from a shop are tracked with RFID tags. It helps manufactures and resellers to keep track of items that are in a storage and it helps and brings saving for logistics. When the RFID tags prices go downwards the manufactures will begin to add the tags to their products. There are already stores that insist that the products that are delivered to them are equipped with RFID-tags e.g. Wal-Mart the world's largest retailer. "Internet of things" will help e.g. customers to find products in the shop and maybe the products can advertise them self. (Tekniikka ja talous- lehti, 2008, date of retrieval 26.4.2012)

8.1 LBS

A location-based service (LBS) is an information or entertainment service, which is accessible with mobile devices through the mobile network and which uses information on the geographical position of the mobile device. LBS can be used e.g. for marketing in shopping centers. When you enter some part of a shopping center, you can get a message or another announcement to your mobile phone from shops that are marketing its products. This is called a location-based marketing or geomarketing. LBS can also be used to find products and services in shopping centers. (Kushki etc. 2012, 25; Wikipedia 2012e, date of retrieval 13.3.2012)

8.2 IPS

Google Inc. has developed and launched a service for indoor maps in the USA and Japan. This service gives opportunity to navigate inside buildings with a mobile device. The floor plan of the building can be uploaded to Google's servers to be used in indoor positioning. USA today website tells that you can find a bathroom or an ATM e.g. at airports. Big shopping centers have taken this service in use. Google says that the service works in Android devices. The USA today tells that the application gives your position in the shopping center with a blue dot and figures out in which floor you are in. Eweek.com site tells that the Google's indoor maps use GPS, a mobile cellular network and WLAN to measure the location of the device indoors. When Google mapped the Google maps- application, it also collected information on WLANs and I believe this is the reason why they did it, to use the information in indoor maps. (USA today. 2011. Google indoor maps. Date of retrieval 13.3.2012; Eweek.com. 2012a. Google Maps for Android Well-Positioned for Mobile Commerce. Date of retrieval 13.3.2012; Tietokone-lehti,2010, date of retrieval 13.3.2012

Nokia also has an IPS-system under development. Unfortunately, there is very little information available from a Nokia IPS-system. The commercials say that it will be very accurate. Its locating precision would be approximately 30 cm. It is said that it would use Bluetooth 4.0 for positioning technology. Bluetooth 4.0 is a very promising technology because it uses a fraction of the energy compared to earlier Bluetooth standards, so when using a mobile phone, the battery will last longer. (Puhelinvertailu.com. 2011, date of retrieval 19.3.2012)

Indoor positioning could also be used in safety applications. The system could be used in case of fire or other danger situation in companies, organizations and institutions that have a lot of employees or other people in large facilities to notify people and perhaps give instructions on how to get to a safe destination. Also, the information on how many people are inside building is very important for rescue services. This type of application could use e.g. WLAN or Bluetooth of a mobile phone, a tablet or laptop. The system could send a map for the nearest exit point to the device, based in the location of the device.

8.3 The future of positioning

Broadcom the world's largest GPS-chip manufacturer has made a chip for smart phones that has very precise location abilities, approximately few centimeters vertically and horizontally in and outdoors. The difference to other systems is that the Broadcom 4752 chip can receive signals from navigation satellites, mobile phone cells, WLAN access points and also get information from the smart phones gyroscope, accelerometer, step counter and altimeter.

The news article from Technologyreview.com says the following:

"The variety of location data available to mobile-device makers means that in our increasingly radio-frequency-dense world, location services will continue to become more refined. In theory, the new chip can even determine what floor of a building you're on, thanks to its ability to integrate information from the atmospheric pressure sensor on many models of Android phones. The company calls abilities like this "ubiquitous navigation," and the idea is that it will enable a new kind of e-commerce predicated on the fact that shopkeepers will know the moment you walk by their front door, or when you are looking at a particular product, and can offer you coupons at that instant." (Technologyreview.com, 2012a, date of retrieval 18.4.2012)

When implementing the information from many different sources the accuracy of positioning grows. In future, it is possible to get more precise information on our location or the location of some items in a super market. How will these kinds of services manage in future? It is reason to believe that nowadays people are very busy and want to do things as simple as possible. So when you go to a shopping center and you can get the precise location of the items with your smart phone, you will use it to save time and your feet. One idea could be that you make a shopping list at your home with your smart phone and the software does the search for a shop that is nearest from your location and also finds the seller who has to offer you your shopping list items.

9 EXAMPLE OF LBS SYSTEM DESIGN BY CISCO

9.1 Cisco location appliance

The Cisco Wireless Location Appliance is a solution that can track 802.11 WLAN devices and compatible extension tags. The Cisco Wireless Location Appliance uses the Cisco RF fingerprinting technology to determine the location of wireless devices. The accuracy is few meters. The system enables a user to get notifications from a device movement, absence, battery levels etc. In figure 11 there is a structure of the Cisco location appliance. (Cisco systems inc. 2007, date of retrieval 30.4.2012)

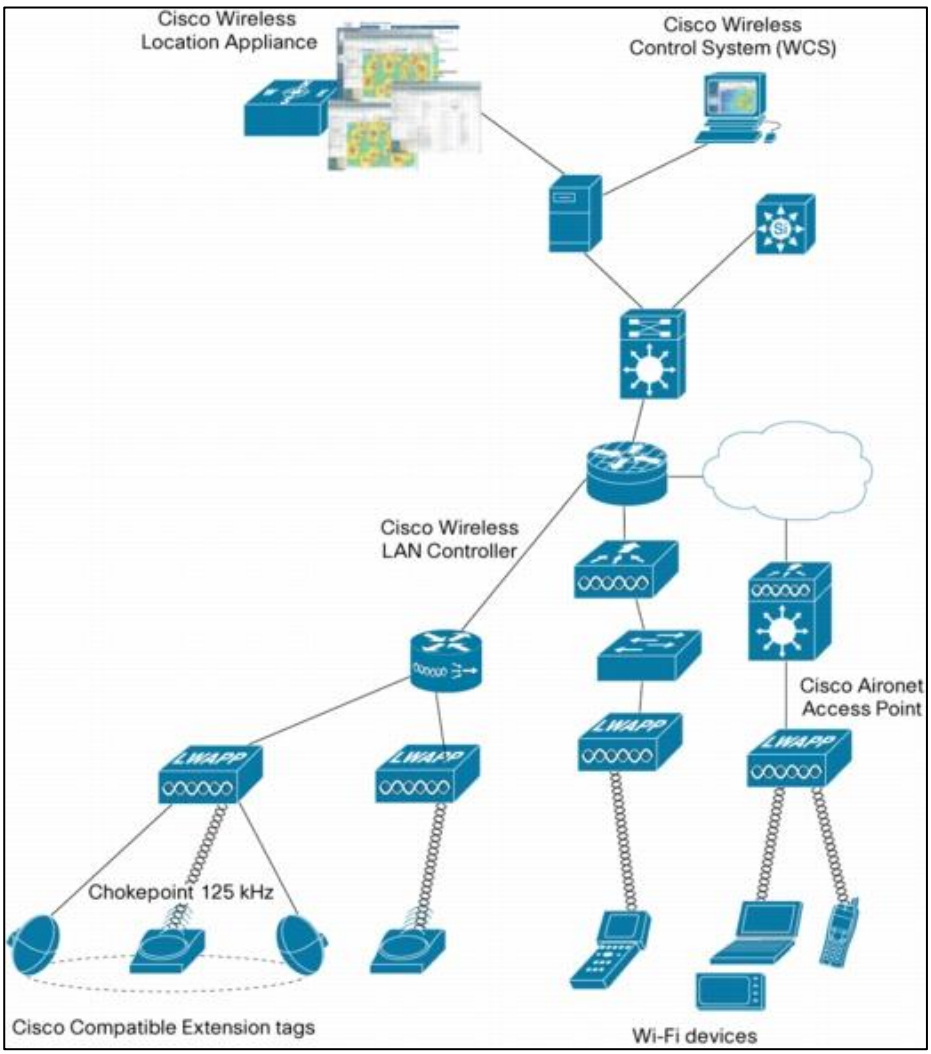


Figure 11. Cisco LBS system

9.2 Cisco location based service system

The main components for a location based service WLAN-system are: Location client, WCS (Wireless Control System), Control client and Location server. In figure 12 we can see how the system is built. A WLAN system consists of controllers, access points and clients. From the controllers the information goes to a location server. The location server runs the algorithms that calculate the client location. It may also have the storage for a database that saves the history of location information. In Cisco UWN the Cisco Wireless Location Appliance works as a location server. With the Cisco Location Appliance it is possible to track WLAN-devices such as laptops, smart phones and people. Also the tracking of rogue or unauthorized access points and clients can be done. The Cisco Location Appliance is also capable of tracking RFID-tags that can be placed to equipment, tools, devices and people. RFID-tag is shown in figure 13 below. Cisco Location Control Protocol is a protocol that is designed to improve the communication efficiency of location appliances and a WLAN controller. Location client is a user interface for the information stored to the location server. The Cisco WCS controls the WLAN controllers and access points. WCS acts as the control client in the Cisco UWN environment. The control client gathers information to the location server of the physical environment where the system is used, e.g. a network structure, floor maps and access point locations. (Cisco Systems, Inc. 2008. Wi-Fi Location-Based Services 4.1 Design Guide. 3-7, 3-8)

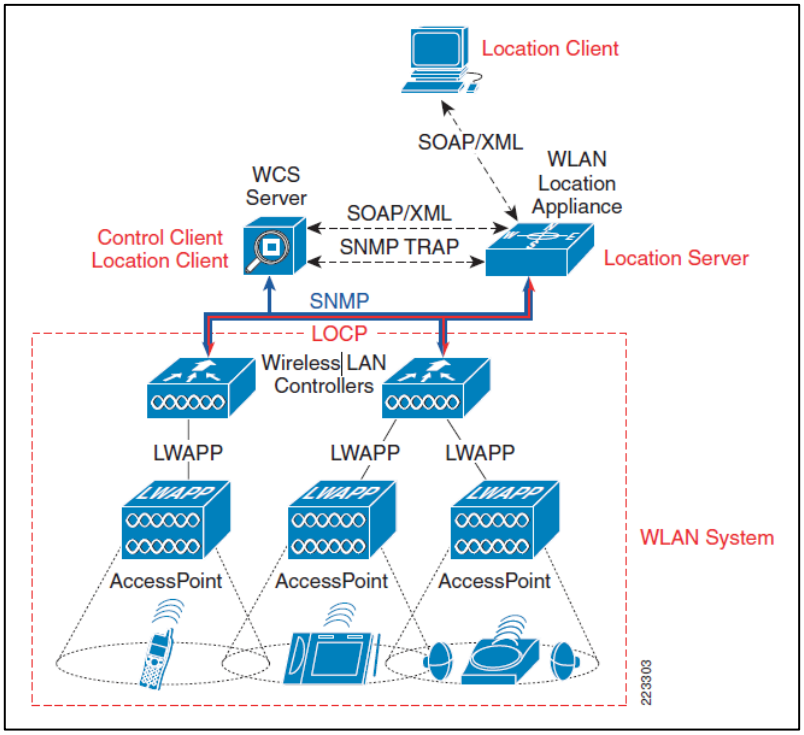


Figure 12. WLAN RTLS

Figure 13. PanGo Active RFID-tag

10 SUMMARY

This thesis introduces the radio-based technologies that can be used for real-time location systems and for indoor positioning and the techniques that are needed to use them for positioning. Also, the basics of RF-technology are introduced and what kinds of factors, mainly physical affect the signal propagation. The thesis is a summary that gives the reader a basic knowledge of the radio-based indoor positioning technology.

When choosing a system for indoor positioning usage, there should be done a good evaluation what are the needs and requirements for the system. Environmental factors need to be considered when using radio based technologies. The premises where the system is built need to be explored for factors that can effect negatively to the systems operation. The system designer has to plan and measure how the system would work in the desired environment. There are many tools for measuring e.g. a WLAN signal and it could be done for instance with access points that are sending a signal. It is not necessary to configure the access points all that is needed is an access point device that has a radio on and it is sending its SSID. What is the technology that will be used? Is there a WLAN that could be used for this purpose? What kind of accuracy will be needed?

There is a reason to believe that in future indoor positioning systems, location based-services and all this kinds of systems will have growing markets. All these systems are designed to help our everyday life. Smart phones and other mobile devices will also develop in future and they can be used for the positioning or location services. Combining different solutions e.g. a satellite positioning, WLAN, a cellular network and mobile device properties, e.g. an accelerometer and a gyroscope, will result more accurate and precise systems.

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LIST OF FIGURES