Current approches of Wifi Positioning

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***Abstract*—WiFi positioning plays an increasingly important role in improving performance because good positioning can improve performance in indoor environments without additional devices. It will make use of existing WiFi infrastructure, although this was never designed to do so. Methods that were used for other positioning technologies can be adopted for WiFi. Whether or not these other methods work with WiFi will be explained and examined. This paper also discusses the accuracy of the methods and the optimal area of application.**

***Index Terms*—Wifi, WLAN, Positioning, Location, Position determination, localization, Fingerprinting**

Fig. 1. Illustration of Indoorpositioning Use Cases
(source: http://www.gpsworld.com/wireless/indoor-positioning/)

I. Introduction

IN 1978 the first GPS satellite was launched[14] and in 1995 GPS worked with its full capability for the first time.[1] Unfortunately, the satellite signals were not strong enough to work indoors. In 1997 IEEE Standard 802.11 was set and the first version of Wireless LAN was born.

Nowadays Wireless Local Area Network technology can be found in almost every building. This widespread infrastructure offers the possibility to locate mobile devices in an economical way. Position determination using WiFi technology has the advantage that it can perform indoors and outdoors, in a different way to GPS. And, although WiFi was never made for positioning, it is more accurate than a GSM indoor positioning[20] and, in some cases, it is also more accurate in regards to outdoors. By using WiFi Positioning Systems it is possible to locate the position of almost every WiFi compatible device without installing extra software or manipulating the hardware. In the course of time many methods that were initially used with other positioning technologies were applied to WiFi positioning. WiFi Positioning also allows the use of location-based services (LBS) indoors, which is interesting for the industry. Useful applications of this technology are, for example, for indoor navigation at shopping malls or for finding a lost child in an indoor area. Lost devices or items can also be found with this technology. Additionally, this technology is especially interesting for hospitals because sometimes when staff move certain pieces of equipment it can be hard to find them again straight away. Big corporate companies like Google have already seen the potential of this system called WiFi Positioning. As we all know, Google captures photos, GPS positions and WiFi measurements, while collecting data for the Google Street View project[4].[5] This data was the basis for the hybrid outdoors positioning system that they use today. If a smartphone user turns on WiFi and Google Maps, he also collects new WiFi positioning data for Google. The device scans for stations (in this case access points) and, at the same time, it determines the position with GPS, GSM or known WiFi stations. In November 2011, Google published Google Indoors which enables navigation in buildings. It is also based on WiFi technology.[16] Even in large train stations or airports, a WiFi positioning system could help people to find out when their next train or plane leaves. The programming of autonomous robots often has the problem that the robot does not always know where they are. WiFi positioning could support the mechanisms that are already in place. The second chapter is about the basic Theory of WiFi Technology. 802.11 is introduced and physical problems are discussed. The third chapter is about the Positioning Theory. The three topologies are explained and the different environment of Indoors and Outdoors are discussed in terms of positioning. The fourth chapter deals with the methods that are available for positioning. Each method is examined to find out whether it advertises itself to the topologies and whether it is suitable for indoor WiFi positioning systems. This paper is about the methods that can be used to build a WiFi Positioning System.

II. WiFi Technology

A. WLAN, Wi-Fi and IEEE 802.11

WLAN, WiFi and IEEE 802.11 all mean the same: they determine the industrial standard for wireless data transmission. The latter is the most used expression.

WiFi uses electromagnetic waves to transmit data over the airwaves. In figure 2 (p. 2) the whole frequency spectrum is shown, starting with radio signals and ending with gamma-rays. Looking at the illustration one can see that it operates in broadband, on about 2,4 GHz and 5 GHz.[10] Other longer distance technologies also use frequencies in between these figures. The frequency is the number of wave occurrences per unit of time.

In the best case, the radio waves spread out evenly and lose more and more of their signal strength with increasing radius.

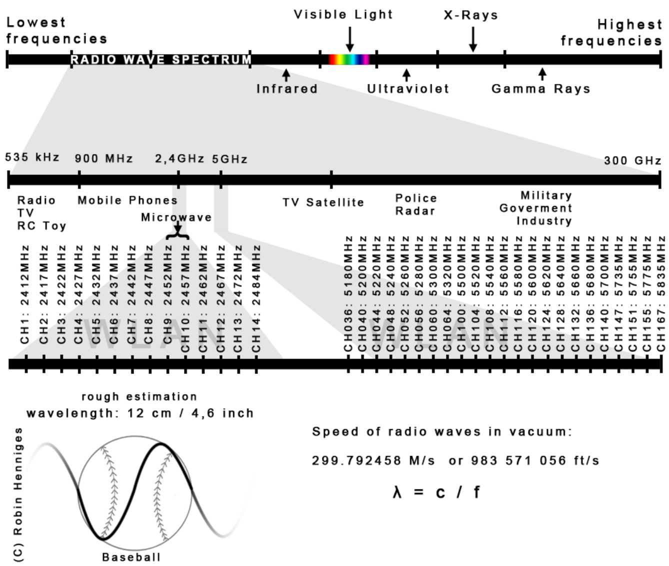

Fig. 2. frequency overview - A Wifi wave matches into a baseball.

This loss of signal strength is due to the energy transformation because, in physics, energy is never lost, but instead converted. Consequently the amplitude of the signal becomes smaller and smaller. In an outdoor station the radius ratio of distance to signal strength is inversely proportional, because the decrease of the signal is log-normal.[12] In conclusion, if the distance to the station is increased in any direction, the signal strength will decrease steadily. However, indoors we encounter a different problem, because the waves bump into walls, windows, doors and so on. If a wave bumps into a different material, it converts more energy than in the air. During this process, the signal strength is decreased more strongly, because the energy is transferred to the material (e.g.: in heat). Furthermore the signal is also reflected from the material. More about this problem is following in the section entitled Problems and interferences.[22]

1) Fundamentals for Wifi measuring: the distance between the transmitter and the receiver has an important role in determining the position. In contrast to GPS, WiFi, at a time measurement method, does not come into question, since such an exact time is difficult to achieve synchronization. Finally, the path from space to the ground is much farther than from one access point to a mobile device. The received signal strength (RSS) and the signal noise ratio (SNR) are the most suitable. These values can be calculated from the incoming signals.

2) Signal Strength: the signal strength is measured in dBm (decibel in milliwatt). A Wifi station has a EIRP (Equivalent isotropically radiated power) of 100mW - 1000mW (20dBm - 30dBm). This is how to calculate:

$$Lp(dBm) = 10 * \log \frac{P}{1mW} \quad (1)$$

For Example:

$$Lp(dBm) = 10 * \log \frac{100mW}{1mW} = 20dBm \quad (2)$$

A WiFi connection gives us information about signal strength and interference.
For example: signal strength: -52 dBm (0,00001 mW) interference: -90 dBm

Because of the path loss, the signal becomes weaker and weaker the farther it is away from its origin. Barriers may attenuate the signal (more about that later). The property to the path loss can be used to determine the distance.

B. Problems and disruptive factors

In general, wireless radio transmission is subject to many confounding factors. Even the sun or rain drops have an effect on the signal strength, actually even if this disruptive factor is very low, it would still be measured. Another problem is the electromagnetic radiation inside buildings. Additionally, many walls, doors and floors have to be penetrated. The result of this is attenuation. An additional problem is the wireless overlay. In an office or apartment building, there are several dozen wireless stations that provide much interference.

1) Signal attenuation of static environment: usually hits an electromagnetic wave on a wall or another barrier it passes through. However, the wave becomes weaker, due to reflection that originates while striking the barrier. Another part is absorbed and converted into heat, the factor of which is so small that it would not be noticeable for a human. The size of the loss is related to the material, specifically its thickness. For example, glass has a higher attenuation effect than brick walls.[21] These factors are critical, especially with methods which determine a distance by the measuring of the signal strength.

2) Signal attenuation by user: As we can see in the experiment,[13] the presence of a user changes the signal strength. This is especially important for the Fingerprinting-based location method, because the mean values would be influenced by the presence of a user. ”When the positioning system is supposed to cater to real users, it is essential to have the user present while collecting the RSS values for the fingerprint and to take into account the effect of the humans body.[13] As already mentioned, WiFi uses the frequencies of about 2,4 GHz, just like microwaves. The effect that is used to heat up food with a microwave is a disruptive effect with WiFi. This is because the radiation is partially absorbed by the water in the human body and the signal is attenuated.

III. Positioning Theory

A. Topologien

There are three topologies that can be used for positioning.[18] This first one is called network-based, here the position is determined by the stations (which build a network) and a central server. The next is called terminal-based and identifies the position over the terminal (or mobile device). The last topology is a hybrid form of the two. An illustration can be seen in figure 3

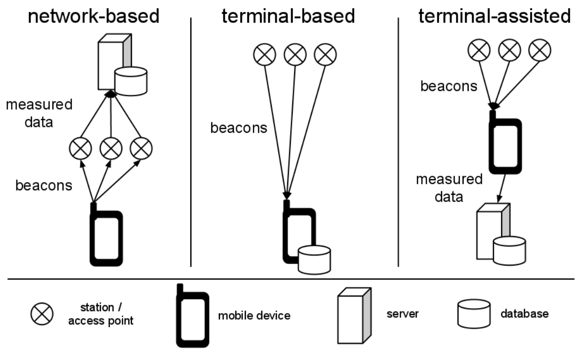

Fig. 3. network-based, terminal-based and terminal-assisted topologie

1) network-based: The network-based approach works on WiFi, only when the station software is modified because the station must be able to redirect its measurement data (mostly RSS and IDs) beside the normal network data. The sequence looks like this: beacons of the mobile devices are received by the stations and are redirected to a central server. This server has a database and can use it to calculate the position. For almost all of the positioning methods, preparations must be made, for example: the positions of all stations with their BSSIDs must be stored.

The mobile devices do not need any software installed, instead they must just send beacons. Indeed, the mobile devices do not take note of if they are located.

2) terminal-based: The terminal-based approach functions exactly in the opposite way to the network-based approach. The mobile devices receive the beacons of the stations. With this, and with the information from the database, the position can be calculated. A WiFi device is able, in a so-called passive mode, to wait in the background for beacons from WiFi stations, and can even be connected to a station. The interval for sending beacons from a station lies at less than 10m. Another possibility is the active mode, and for this the WiFi device sends out beacons, and with it the station sends a reply back to the beacon. An important feature is that the mobile device (or terminal) carries the database with it.

3) terminal-assisted: The terminal-assisted approach is a mix of both of the above. The beacons are received by the mobile device and the information is transferred to the central server so the database can calculate the position.

B. Indoor and Outdoor Positioning

The indoors and outdoors have different requirements for a WiFi positioning system. The indoor environment has man disruptive factors like walls, windows, doors, and so on. A positioning system must be able to handle these problems and deliver good results. A higher accuracy is also required for the indoors because it is important to locate a user at least in the right room. A few meters can make a big difference. WiFi is especially interesting for indoors because there are no other positioning services running. Outdoor positioning has fewer requirements. The accuracy is not as important outdoors as it is indoors, but there are fewer environmental barriers. Coverage is another problem in outdoor positioning because only in urban surroundings is a WiFi infrastructure guaranteed. In rural surroundings the chance for an outdoor WiFi positioning system are not as good.

IV. MEASUREMENT THEORY

There are many different approaches for locating a mobile device using WiFi technology. In the following, the method to estimate the sought position is described. In general, the methods need to know the position of the WiFi stations (=access points) as a reference point that are used for the approximate position of the mobile device.[7] A prerequisite for a good-working WiFi positioning system is an adequate coverage of the access points. This coverage is called Basic Service Area (BSA). The expression of the BSA determines which positioning method is the most suitable. The methods differ in the minimum required number of stations and its accuracy. This varies between building part accuracy and room accuracy to an accuracy of a few meters difference.

A. Based on Proximity sensing

Methods based on proximity sensing are among the simplest and fastest, but they are also imprecise. A position calculation can be done with just a single station. It is hardly possible, for example, to perform an indoor positioning that delivers the right floors in a multi-storey building. As result, one gets only the part of the building in which the mobile device is located. On the other hand, this kind of positioning is popular for outdoor positioning.

1) Cell Identity: A relatively simple method is called ”Cell of Origin or ”Cell Identity and is based on ideas coming from a GSM positioning method. To run a positioning system using this method, some preparations must be made. A database of station IDs and the geolocation is necessary. The position is determined by measuring the signal strength. It is assumed that the closest station is the station from which the strongest incoming signal on the device is received. Depending on which topology is used, a request to the database is performed for the ID of the station with the strongest received signal. The database returns the position of the desired station and thus the position of the device. This is because a device within range of the station has the approximate location of the station. So this method is good for short-range technologies like WiFi.

If this method is used with WiFi as ID, the BSSID (basic service set identification) is used, which is a unique hardware address given to every WiFi device. In this case, the MAC address is used as BSSID, as explained in IEEE 802.11 BSSID.[3] By using a network-based topology, the station collects tuple from the mobile device IDs and its received signal strength, and commits this information to a server that has access to the database of station locations. The server now chooses the station with the strongest signal as the position for the mobile device. By using a terminal-based or terminal-assisted topology, the mobile device can use the ”passive mode to scan for active WiFi stations. After choosing the station with the strongest signal, a simple search in the database will return the position coordinates. However, unfortunately this information is very inaccurate.

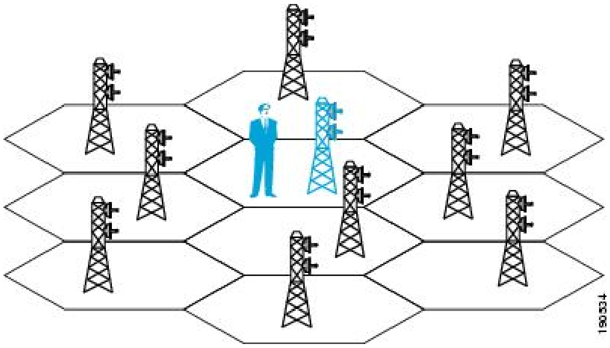

Fig. 4. Cell of Origin illustration (source: cisco.com)

The disadvantage of this measuring method it that the size of range is variable between 25 and 200 Meters, depending on the measuring occurs indoors or outdoors.[2] That makes indoor positioning with this method not very attractive. Indeed one could run the stations with low power, so the radius is smaller and the positioning would therefore be accurate. However, it also negatively affects the data transmission and possibly the WiFi coverage. It is also an important requirement, as with many positioning methods, that the stations are fixed. If changes are made to the location of the station, the database entry needs to be corrected. This is a big problem for companies that use CI in their positioning system, because they themselves must find out if a stations location has been changed. The advantage of the method is that it is very simple and therefore a position determination is very fast. It works with at least one station

Summary:

- Positioning is based on the position of the station with the stongest signal that can be received.
- (+) Can utilize existing wifi infrastructure without modifications
- (+) Allows network- and terminal-based positioning
- (-) Positioning is inaccurate
- (+) Allows real-time positioning
- Better for outdoor positioning.

B. Based on Trilateration

Lateration or trilateration is the determination of absolute or relative locations of points by measurement of distances, using geometry. The ”tri in trilateration reveals that at least three fixed points are necessary to determine a position.

The idea behind the geometry is that all trilateration methods start with calculating the distance from a station to a device. The distance then is used as the radius from the station. Somewhere on the edge of the resulting circuit, the position of the device is assumed. To lessen the possibilities, a second group of results is also used from the measurements of another station. Of course the second station has to be in the range of the device.

With the radius of the second station one receives two points. If one imagines this in a geometrical way, one keeps two circles and two intersection points. One of the two points is the position of the devices. To find out which point is the right point a third station is used. An illustration of this geometry can be seen in figure 5. In the following the methods of distance determination are explained.

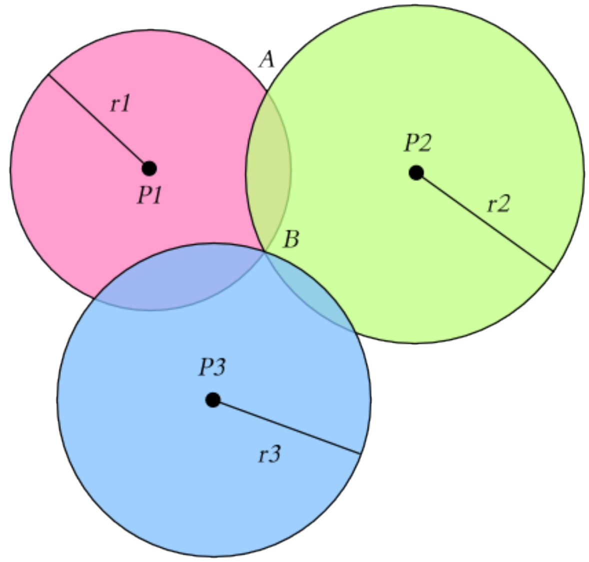

Fig. 5. Trilateration (source: wikipedia.org)

Should the localisation deliver three dimensional results which make sense, e.g., in multi-storey buildings, the additional fourth station is required to receive an unequivocal position.

Because the distance measurements are not very accurate it is recommended to use an ”Error range in the circles. This compensates the measuring errors otherwise it is possible that one does not get any intersection points.

The challenge for a Trilateration method lies in the best possible determination of the distance between the station and the device. Methods that are based on time measurements have to guarantee a good synchronisation on the stations or mobile devices. On the other hand, methods that are based on the signal strength have problems with interferences and reflection. Therefore, they are probably better suitable for outdoors than for indoors.

1) Time of Arrival (ToA): With this method time is measured, which needs a signal from a station to mobile device and back again, and in this instance it is called the ”Round trip time (RTT). A requirement for this method is synchronically running clocks. According to which topology is used, only the clocks of the stations or also the clocks of the mobile devices must run synchronically. With the measured data of the station and the given speed of the signal, it can be calculated how far away the mobile device is. Indeed, no time may pass with the receiving and sending back of the signal because this would influence the measured data. As this is not possible without modification in mobile devices, this method does not function with WiFi.

- Positioning is based ontrilateration with measurements of time
- (-) At least three station in range of the device are necessary.
- (-) Position coordinates of station must be exact.

- (-) Does not work with Wifi

2) Time Difference of Arrival (TDoA): Like ToA, TDoA also needs exact clock synchronisation. Indeed according to,[6] TDoA is more popular with commercial detection systems than ToA. With this method, the difference is used between the arrival times of the signals to determine the position. Because WiFi was never planned, nevertheless, to make such exact time measurements, is also not possible to use TDoA on WiFi.

- Positioning is based ontrilateration with measurements of time difference
- (-) At least three station in range of the device are necessary.
- (-) Position coordinates of station must be exact.
- (-) Does not work with Wifi

3) Received Signal Strength (RSS): This method uses propagation-loss of the WiFi signals to compute the distance.[8] The decibel version of free space path loss equation is $10\log(\frac{s}{0.001})$ (s is the signal strength in watts). By using these measurements, which distance matches which signal power can be found out. This method functions relatively well outdoors, but in buildings it can come to strong divergences, because the walls reflect and attenuate the WiFi signals. These methods work with the WiFi technology and can be used for the localisation. One can even use all three topologies with this method, however, software must be modified with the routers network-based topology.

- Positioning is based ontrilateration with measurements of signal strength
- (-) At least three stations in range of the device are necessary.
- (-) Position coordinates of station must be exact.
- (+) Does work with Wifi
- (+) Works well outdoors
- (-) Works indoors but doesnt deliver accurate values
- (+) supports all topologies

The method Signal to Noise Ratio (SNR) is neglected here because it usually provides poorer results than RSS. Only the fact that it exists should be mentioned. It works on the same principle, but instead of transmitting power, the measured interference is used.

C. Based on Triangulation

1) Angle of Arrival - AoA: In this method, the angle of the arriving signals is determined and, using geometry, the position can be determined. At least two stations in reach of the mobile devices are a requirement for AoA. It is suitable for indoor and outdoor positioning and it can measure in real time. The estimation of the angle has an inaccuracy of only 2 degrees.[17]

AoA is not applicable without modification of the hardware, but it returns good results. Special antennas are mandatory for the determination of the location with the ”Angle of Arrival method. These antennas must be able to measure the phase-shift of incoming signals. Therefore it is best to use directional antennas or a multiple antenna array. The direction can be determined with the TDoA (Time Difference of Arrival.) This refers to the array antennas. When a signal hits the antenna at

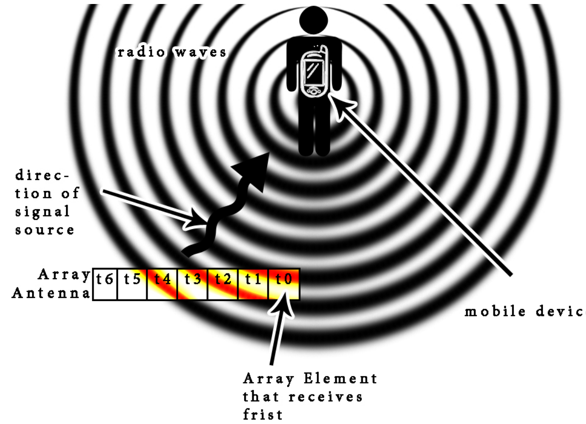

Fig. 6. Illustation of a single Array Antenna that receives a signal.

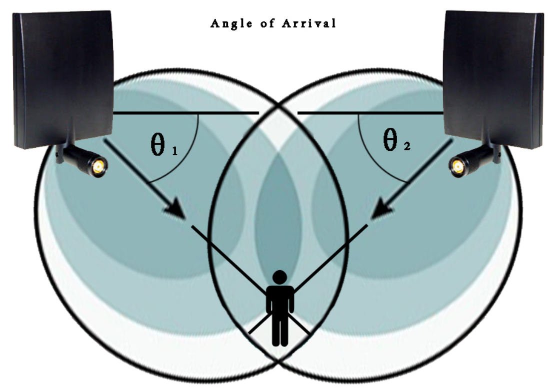

Fig. 7. A special directional Wifi antenna determine the position with AoA.

the right angle, the TDoA is equal to zero. In all other cases the signal hits the part of the antenna first that has the smallest distance to the source of the signal. The time difference of the receiving on the next part of the antenna is measured, and thus the angle can be calculated.

With the triangulation technique it is possible to calculate the position of the mobile device, due to the determination of the incident angle on the receiving sensor of the station. From the geometrical view, a line goes out in the calculated angle from the antenna. If this is made with all the stations standing at possession, an intersection originates. This is shown in figure 8. As a reference value, the position, like with all methods, must be confessed[2] . This approach works well with WiFi, but, as already mentioned, the hardware must be modified. As it would be extremely complicated to equip mobile devices afterwards with an array of antennas, unfortunately one cannot measure from which direction the signal from the station comes. Therefore two topologies are omitted: terminal-assisted and terminal based. Now the network-based topology is the only one remaining. In practice it would be in such a way that the stations tuple with mobile device ID, and that the angle (or the TDoA data) is sent to a central server and this calculates the positions.

Summary:

- Position determination with the intersection point of two

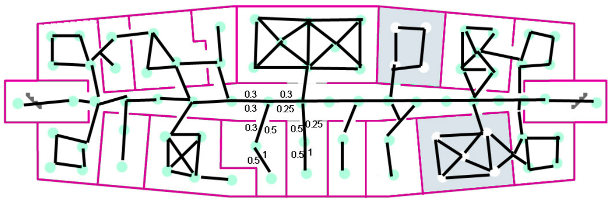

Fig. 8. Illustation of Fingerprint Positioning

lines.
- (-) needs hardware modifications / special antennas
- (+) Allows Real-Time positioning
- (+) indoor + outdoor
- (-) only network-based

D. Based on Pattern recognition

1) Fingerprint Positioning: Fingerprinting, also called Location Patterning, uses a previously created database of signal patterns, which need to be matched for positioning only. Fingerprinting doesnt need modification of the hardware like, for example, AoA. Furthermore, no time synchronisation is necessary between the stations. Before a position can be determined, the entire area in which the positioning is supposed to work must be recorded. This happens in **Phase 1**, the so-called calibration-phase, offline-phase or training-phase: The area in which the positioning should later run, must be covered with a pattern of recording points, called fingerprints. Step by step, for every fingerprint there must be a measurement, that includes the information about all stations and their Received Signal Strength (RSS). Each fingerprint is a vector **R** , associated with each element of a station.

The number of stations must be known and may be changed only if the measurement is repeated from phase 1. The collected data is stored in a database, called a radio map, so that it can be retrieved later in **phase 2**.

That is the actual position determination phase. If a mobile device should be located in the recorded area, then it measures the signal strengths of all the current stations in range. It is the actual position determination phase. If a mobile device should be located in the recorded area, then it measures the RSS of all the current stations in range. This data will be stored in the comparative vector P. Now the euclidean distance between P and the Rs on the radio map is calculated. The chance to have chosen the right place is greatest where the Euclidean distance is smallest. The disadvantage of this method is that there must be a lot of complex preparation before the system works.[15]

As we read in[18] RSS strongly depends on line-of- sight, so to improve the system every measurement should add additional information about the direction. This takes longer in phase 1 but delivers better results in phase 2. The table shows an example of such a radio map.

Fingerprinting can be used with all three topologies. With a network-based system every position is sent to the station with mobile device beacons. As usual, with network-based attempts, the software of the station must be customised, so that the signal information can be extracted. If the information

TABLE I
EXAMPLE OF A RADIO MAP (SOURCE:[18])

Position	Direction	BSSID 1	BSSID 2	BSSID 3
p1	0	-59 dBm	-75 dBm	-71 dBm
p1	90	-54 dBm	-73 dBm	-67 dBm
p1	180	-49 dBm	-72 dBm	-69 dBm
p1	270	-55 dBm	-74 dBm	-65 dBm
p2	0	-35 dBm	-64 dBm	-50 dBm
p2	90	-27 dBm	-64 dBm	-43 dBm
p2	180	-40 dBm	-65 dBm	-52 dBm
p2	270	-30 dBm	-60 dBm	-46 dBm
p3	0	-69 dBm	-66 dBm	-73 dBm
p3	90	-65 dBm	-60 dBm	-68 dBm
p3	180	-63 dBm	-66 dBm	-70 dBm
p3	270	-68 dBm	-62 dBm	-76 dBm

is in the central server this can calculate the position. The advantage with this topology is that devices that dont usually have WiFi can also be located, for example: a wheelchair. When a WiFi badge or a WiFi tag device, without any real function except sending beacons, can be attached to this device, this enables it to be found in the building anytime. Later we will to talk about a company, called ekahau, that uses this strategy. On the terminal-based approaches, there are no great characteristics, so this topic is not taken up here again. The functionality has already been explained in the preceding chapter.

It is also interesting that the position of the station does not need to be known. Only the position of the fingerprints must be known, so that the type of coordinates used can be chosen. It would, for example, be possible to use the geographic coordinate system or our own coordinates of the building area.

Finger printing can be used indoors as well as outdoors like this experiment shows.[19]

- Position determination with RSS Pattern.
- (+) needs no hardware modifications
- (+) indoor and outdoor
- (-) only network-based
- (+) very good accuracy
- (-) creating a radio map is consuming

V. IMPROVING OF POSITIONING DETERMINATION

A. Hidden Markov Model

The hidden Markov model is a statistical model in which a system can be modelled. It allows the system to integrate the likelihood of a movement or positional change. To integrate a hidden Markov model in a positioning system, a pattern of nodes must be laid over the area, just like in fingerprinting. A node corresponds to a position and is connected bi-directionally to the edges of other nodes. At each of these edges the likelihood for the transition to the next node is attached. Mistakes like jumping through walls or floors can therefore be reduced. We can see this used in a patent of Ekahau.

Fig. 9. Bages and Tags that use Ekahau for positioning (source: apply-wifi.com)

B. Dead Reckoning

Dead Reckoning is the process of calculating the current position through a predetermined position based on estimated speeds and the direction.

VI. Commercial soluions

A. Skyhook Wireless

Skyhook Wireless is a Company from Boston (USA) that collect WiFi and Location Data. Their most famous customer is Apple, who use the WiFi Location data to determine positions without real GPS on the iPhone. They also offer a SDK for WiFi Positioning that is available for free and is especially valuable for mobile software developers. Like Google, Skyhook Wireless has a collection of WiFi Stations and positions them by using cars that go through the cities and streets, which is called WarDrivering.[9] Skyhook give an accuracy of 10-20 meters, according to their website. To get the best results they use XPS, the Hybrid Positioning System. It uses GPS-, Cell Towers- and WiFi-measurements for position determination. Due to this architecture, they are able to provide a time to fix under 1 second. The database of Skyhook Wireless includes the locations of over 250 million WiFi access points and cellular towers.

B. Ekahau

2000 Ekahau was founded in Helsinki as a spin-off from the University of Helsinki. Now the headquarters is in the USA. Ekahau offers real time WiFi positioning systems for companies, especially for hospitals. The system works both indoors and outdoors. A whole range of WiFi enabled devices are available. For example, small WiFi devices, like a watch, for locating patients or others to send a help signal or to call a nurse. The advantage of this WiFi positioning system is that it can use the existing infrastructure of 802.11 a/b/g/n stations. The Tracking algorithms is patented with 7 patents for positioning. It uses the hidden markov model, signal strength and signal value bit error rate.[11] That allows Ekahau to offer a good working positioning solution.

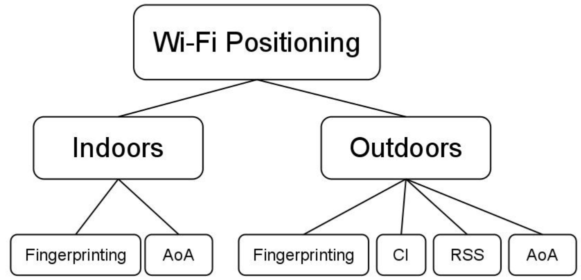

Fig. 10. Use Case hierarchy of WiFi Positioning

C. Navizon

In January 2005, Navizon was founded. Just like Skyhook, they collect data of WiFi access points, GSM Cells and the associated GPS positions.

D. Others

Nokia Indoor Positioning, WIPS, Nokia Indoor Positioning, Walkbase, RADAR, Horus, Nibble, WhereMops, LIV, AeroScout

VII. Conclusion

WiFi has become a widespreading technology, a technology that has never been designed for localization. Nevertheless, WiFi positioning performs well in comparison to other positioning technologies, and has the favourable advantage that it is based on an existing infrastructure. First, it can be said that all WiFi agreed methods are based on signal strength (except AoA). Methods that are based on timing can not be realized with WiFi. So the techniques ToA and TDoA were not agreed by WiFi.

The technique best suited for each individual WiFi positioning is dependant on the environment. When indoors, positioning fingerprinting delivers the best results. However, it is also associated with a lot of effort. With a hidden markov model the accuracy can be increased even further. The Angle of Arrival is also a good opportunity. Unfortunately, this requires special hardware and the localizations can only be network-based. For indoor positioning CI or RSS gives inaccurate values.

Outdoor WiFi has a smaller benefit, mostly because GPS provides better results. However, there are outdoors areas, where GPS can not perform. Then WiFi Positioning is a good alternative. A further advantage is that WiFi is faster than GPS at the beginning with finding the position. The GPS module used in mobile devices usually needs a lot of power, and by switching onto WiFi positioning it can use the already switched on WiFi to determine its position. A system based on CI is fast and easy to build up. RSS is also well suited for outdoors and delivers even better results. AoA systems are probably not profitable for larger areas, but they do give good results. Fingerprinting can also be used outdoors. In this case, the use of directional data will improve the accuracy of the results.

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