Positioning Technologies and Mechanisms for mobile Devices

Andreas Schmidt-Dannert
Seminar Master Module SNET2
TU-Berlin

Abstract—**Services for which it is necessary to know the position of a mobile phone and a mobile user are commonly known as location-based services (LBS). These services become more and more popular and telecommunication companies (telcos) hope for big revenues through them. In the US, telecommunication companies are obligated by law to localize a mobile station (MS) with a certain accuracy due to the E911 mandate. The hope for big revenues and the law are the reasons for telcos to invest in research in this area since many years. In the European Union the counterpart is called E112 but it does not give the telecommunication companies any guidelines for the accuracy with which they have to localize an MS in case of an emergency. The goal of this paper is to look at the different approaches no matter if the are based on the GSM, UMTS or even other infrastructures. The goal of this work is to look at the different localization approaches that exsits nowadays for GSM, UMTS and other relevant wireless infrastructures.**

I. Introduction

The location of an MS is necessary to give a user certain services that are connected with the position of a person. An typical example could be that after an accident a person calls an emergency number but cannot give any information about the accident location. In these cases the rescue coordination center must be able to localize the injured person fast and with a high accuracy. This is the idea behind the E911 mandate.
Typical commercial usage would be navigation from one point to another, finding the next gas station with the best prices, advertisements from shops in the vicinity of the MS user and information about a historical point in a city. There are many possibilities but they must be fulfilled with the privacy of the user in mind. An LBS can only become a success when the user can be sure that her privacy is protected. GPS, for example, does not reveal the actual position of the user to someone else but the person who carries the device.
One thing to keep in mind is that there are many different techniques to obtain the position of an MS. These techniques are mostly divided in network-based, terminal-assisted, terminal-based and network-assisted approaches. In Network-based approaches the network does all the work i.e. it measures the necessary values and uses them to calculate the position of the MS. The MS is not involved and no changes have to be made to the MSs to use these techniques. The counterpart are terminal-based approaches[1]. Here the MS does all the calculation and no changes to the network are required. Terminal-assisted and network-assisted are the hybrid forms of these techniques [1].
This work first describes the basic principles behind the positioning mechanisms we know today (section 2). After that, it deals with some important technologies with focus on mobile-based technologies in UMTS and GSM networks (section 3). Section 4 will introduce Secure User Plane Location as a secure way to transmit positioning related data over the network. Finally the accuracy and the precision of the individual techniques in urban, suburban and rural areas will be discussed and compared.

II. Fundamentals of Positioning

This section introduces the basic principles of positioning, covering proximity sensing, angle of arrival (AoA), lateration and fingerprinting respectively.

A. Proximity Sensing

Proximity sensing, also known as Cell ID and Cell of Origin (COO), is one of the easiest ways to get the position of an MS but it suffers from accuracy. Both GSM and UMTS networks consist of many transceivers that cover the area the telephone company wants to give service to. The position of these transceivers can be distinguished very precisely and each of them covers a certain area, called cell. Theoretically, a cell can cover an area up to 35 km in GSM, but it is often smaller due to buildings or other obstacles. In rural areas a transceiver with an omnidirectional antenna normally covers an area of 20-30 km while in urban areas this value drops to 100 meters to a few kilometers. For UMTS in urban areas, the accuracy is around 500m - 5 km (macro-cells) and 50 m - 500m (micro-cells) [2]. The denser the transceivers are installed the better is the accuracy. The base stations (BSs) in GSM and in UMTS are called Base Transceiver Station (BTS) and NodeB, respectively, and are equipped with sectorized antennas[2] which can also be identified. This means that the position of an MS can be reduced to the coverage area of one of the sectorized antennas called sector. Figure 1 shows two GSM BTSs, each with three antennas resulting in 6 sectors.

If an MS is located in a cell, Cell ID will return the coordinates of the BS as position for the MS. On the other hand if sectorized antennas are used, Cell ID will return the center of the sector as position. In figure 2, the blue area

[1] also known as mobile-based

[2] in rural areas they sometimes use omnidirectional antennas

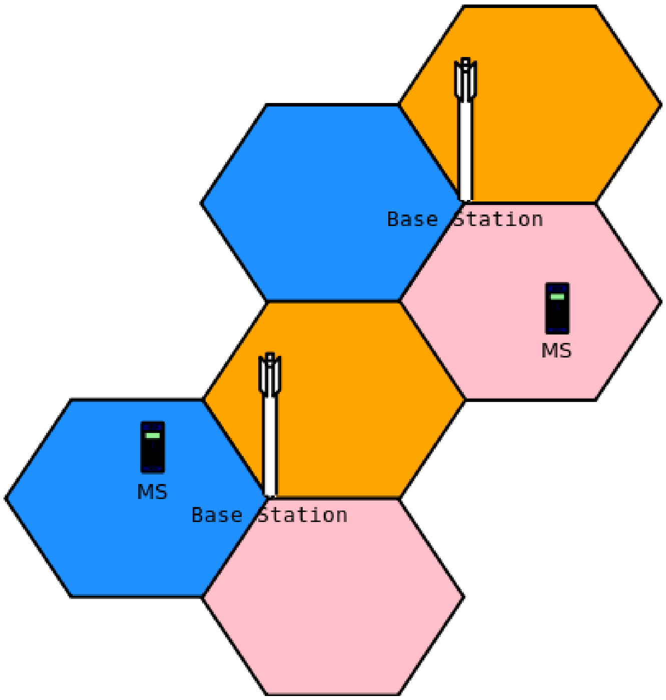

Fig. 1. CellID - Two Base Tranceiver Stations (BTS) with sectorized antennas

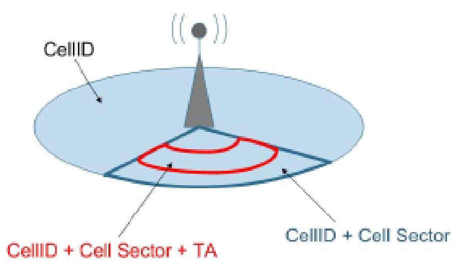

Fig. 2. The principle of Cell ID [4]

represents a whole cell while the dark blue bounded part represents a sector within a cell.
To improve accuracy, mobile providers use enhancements to Cell ID that are discussed in the following.
Transmitted signals from an MS to a BTS must arrive at the appropriate time to inhibit overlapping signals of multiple MSs. To handle this problem a technique called timing advance (TA) is used. In TA the MS advances its transmissions by a certain value - the TA value. The TA value corresponds to the range between an MS and the serving BTS [3] and can be used to narrow down the possible positions of an MS to a band within a sector (see in figure 2 the red part). If an omnidirectional antenna is used, the position of the MS can be narrowed down to a band around the BS in a cell.

Another approach to improve accuracy is based on the received signal strength (RSS). An MS permanently measures the RSS from all surrounding BTSs and this value be used to locate an MS. RSS can be employed additionally to Cell-ID+TA.

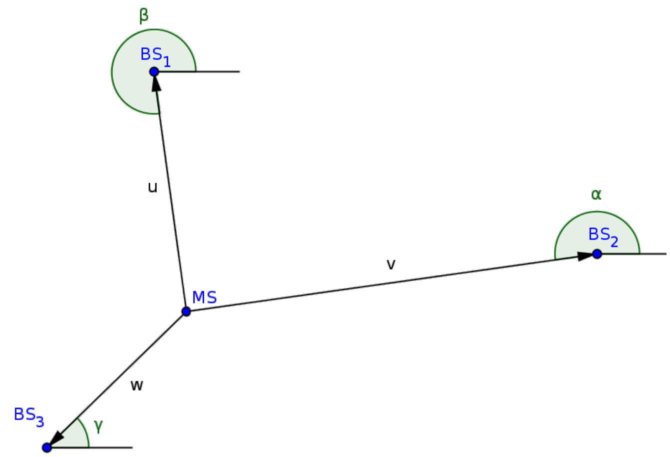

Fig. 3. AoA - The MS sends out a signal that is received by the antenna arrays from the BS

RTT (Round Trip Time) is a similar technique to TA and is used in UMTS to enhance the positioning process. The achieved accuracy can be even higher when compared to GSM. The RTT value is the time difference between the start of a down-link frame and the reception of the corresponding up-link frame. To improve the accuracy, the RTT from other reachable NodeBs can be taken into account and/or a value called the Reference Signal Power Budget (RSPB) can be used in a similar way to the RSS in GSM. The position can always be obtained mobile-based but only network-based if the MS is in an ongoing connection.

B. Angulation - Angle of Arrival (AoA)

AoA uses the angle under which signals arrive at the BSs to calculate the position of an MS and is called triangulation as soon as three BSs are involved to obtain the position. It can be used in both GSM and UMTS networks but the BSs need to be upgraded with antennas (antenna array) that are able to measure the angle under which they receive a signal from an MS (see figure 3). Hence it is an expensive approach for the telecommunication companies.
Theoretically, only two base stations are necessary to obtain a 2D position but the accuracy is too low. Thus, in actual implementations three or more base stations are taken into account to obtain the position of an MS. This approach is purely network-based, since the MS does not take part neither in the measuring nor in the calculation. The MS is only participating by emitting a signal. The positions of the involved BSs are known and imaginary lines can be drawn with the help of the measured angle. The intersection of the lines represents the assumed position of the MS as showed in figure 4.

The position is not as accurate as shown on figure 4 since the measured angle by the antennas is often afflicted with an error. To obtain good results with this technique the MS should have a clear line-of-sight[3] (LOS) to the antenna and

[3]Line-Of-Sight: A straight line along which an observer has a clear view [Wikipedia]

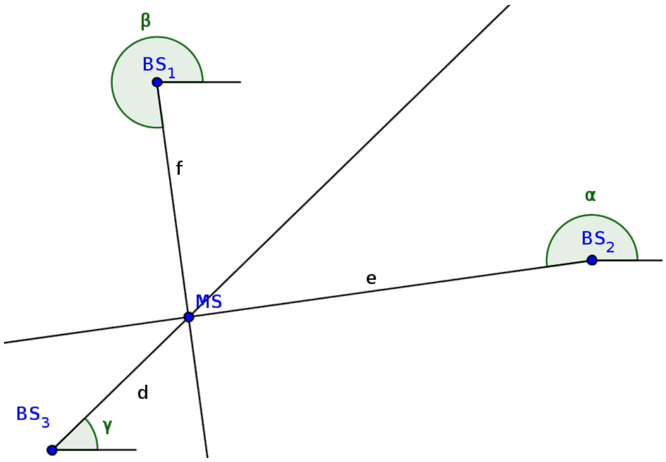

Fig. 4. AoA- The intersection of the lines from the BS in direction of the Angle of Arrival is the assumed position of the MS

the distance between these components should not be too great. Unfortunately in urban areas there is often no clear LOS and in rural areas the distance is mostly too great. Multipath propagation is another problem of this technique, i.e. signals that are reflected from different subjects leading to false positioning data because they arrive at the BTS under a false angle. This is another reason why AoA works poorly in urban area.

C. Hyperbolic and Circular Lateration

In opposition to Angulation, where the angle is the important value, Lateration utilizes the range (Circular Lateration) or the range difference (Hyperbolic Lateration) to calculate the position of an MS. Before a person can make use of these techniques it is necessary to know either the range or the range difference. This can be achieved through different range measurement techniques. Time measurement methods are popular but the range can also be obtained by Received Signal Strength (RSS). In the following discussion it is assumed that either the range or the range difference is known.
If the range (Circular Lateration) between a BS and an MS is known, the possible position of the MS is reduced to an undetermined point on the surface of a sphere around the BS. The distance between the BS and the MS is the radius of this sphere. As this is an ambiguous position a second BS is necessary to reduce the amount of possible positions by providing two spheres with different radii. Both spheres will overlap at some point, which ends in a circle. This circle now represents the possible positions of the MS. Still the position is not clear, which means a third BS has to be taken into account. This will lead to two possible positions for the MS. However one of these positions often can be discarded since it presents a rather unrealistic place. Circular Lateration is also known as Time of Arrival (ToA) and is utilized by GPS, where each GPS receiver is synchronized to the atomic clocks in the satellites for a very precise range measurement. Anyway the mobile network is normally not synchronized with the MS [2], which leads to rather poor accuracy for approaches that

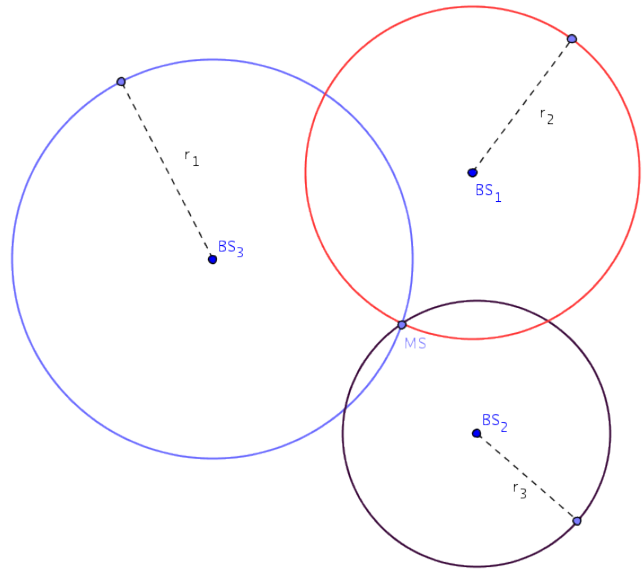

Fig. 5. ToA for the 2D case. Here 3 BS are enough to get an unambigous position for the MS

utilize this technique. To accomplish synchonization so called Location Measurements Units (LMU) have to be installed in the network and this is expensive for the tellecommunication companies. See figure 5 for an example where two dimensions are considered.

The next approach uses range differences (Hyperbolic Lateration) instead of the pure range. It is called hyperbolic lateration because it uses hyperbolas and no spheres or circles. In hyperbolic lateration in 2D at least three BSs are necessary to get a clear position of an MS. Figure 6 shows three BSs (BS_1, BS_2, BS_3) and two hyperbolas that are denoted c and f. The intersection point of these hyperbolas is the assumed position of the MS.

To understand how these hyperbolas are constructed consider figure 7. G and F are two randomly chose positions for the MS on the hyperbola f. In fact every point on f represents a possible position for the MS and they all have one thing in common: the differences in distance between the MS and BS_1 (denoted j or g in figure 7) and between the MS and BS_3 (denoted i or h in figure 7) is constant for every point on hyperbola f that is $|j - i| = |g - h|$. Hyperbola c is constructed in the same way.

Since we have three BSs here, we also have two hyperbolas which intersect at one point on which j and a have the same value and where the assumed position of the MS is (see figure 6). In 3D a forth BS has to be taken into account for an unambiguous position. Hyperbolic lateration is also called TDoA (Time Difference of Arrival) and Uplink Time Difference Of Arrival (U-TDoA) and Enhanced Observed Time Difference (E-OTD) utilizes this approach (see chapter 3).

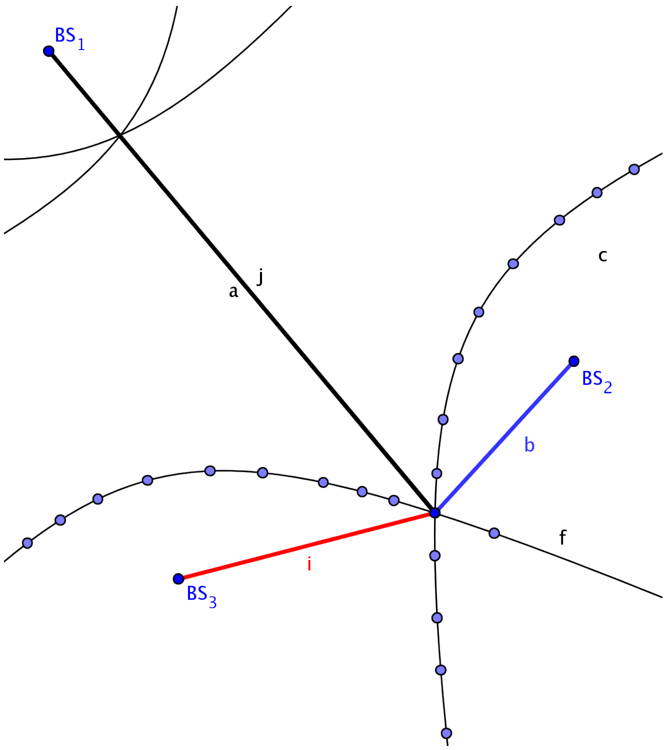

Fig. 6. TDoA - The intersection of the hyperbola c with the hyperbola f is the assumed position of the MS

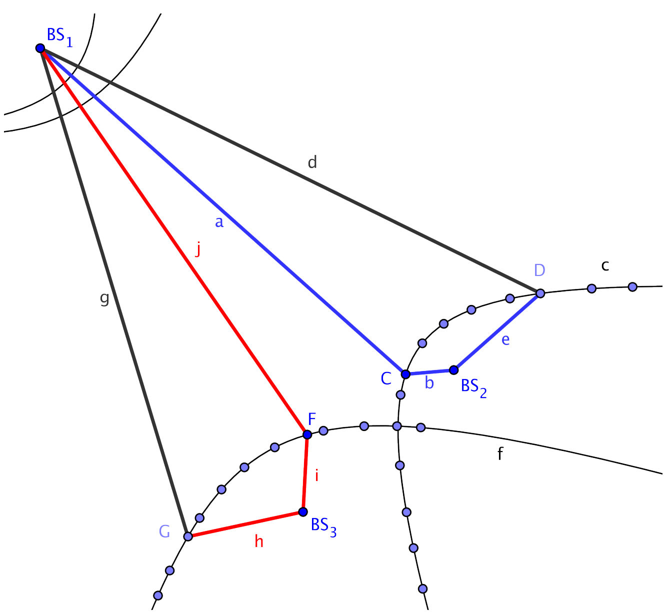

Fig. 7. TDoA - Two hyperbolas which represent possible points of residence for the MS. D,C,F,G are four such points with the correspond distances from the BS.

D. Fingerprinting

Fingerprinting, also known as Pattern Matching or Database Correlation, is another approach to localize an MS and is divided in two phases: training and the positioning. In the training phase, the goal is to build up a database with fingerprints of reference points in the desired area where localization should take place. At this reference points the signal strengths of the surrounding BSs should be measured and stored in a vector. This vector is the fingerprint for one certain point and is stored in a database within the network. The closer these reference points are to each other, the better is the accuracy but the higher is the computing time.

In the positioning phase, the MS measures the signal strength from the location where it is and transmits this vector to the database in the network. There, the vector is compared to the entries with an appropriate search algorithm and the database returns the location which best correlates with the vector. Therefore the returned location is likely to be the position where the MS is [5]. Since both the MS and the network are used, this approach is called mobile-assisted. It can be used in GSM, UMTS and WiFi networks.

III. POSITIONING MECHANISM

In the previous section base technologies for positioning have been introduced while this section discusses concrete mechanisms to localize an MS. It is divided in three subsections, the first and the second subsection explain different network-based and terminal-based approaches and the last subsection is about technologies that neither use the mobile network nor a satellite network for positioning.

A. Network-based approaches

This subsection gives an overview of different network-based localization approaches. Network-based means that the network computes the position of the MS and that the MS only plays a passive role in the positioning process.

1) ***U-TDoA - Uplink Time Difference of Arrival****:* This approach utilizes hyperbolic lateration (TDoA) and is standardized by 3GPP (3rd Generation Partnership Project) for UMTS and GSM.

For U-TDoA at least 3 BSs are necessary to obtain a unambiguous position and LMUs (Location Measurement Units) have to be deployed in the network to gain synchronization. Another prerequisite is that the MS is in busy mode (whether it is a real call or stimulated by the network to transmit for a short time). A transmitted signal from the MS is received from one BS and two LMUs, the time difference is calculated and the two hyperbolas are constructed that intersect at the assumed position of the MS [3]. It is called Uplink-TDoA because the frames in the uplink, from the MS to the BS and the LMUs, are used to determine the position of the MS. The best results can be obtained in urban areas or areas with dense BS coverage [6]. EOTD is very similar to U-TDoA but uses the downlink signals and hence belongs to the terminal-based approaches.

*2) **PCM - Pilot Correlation Method**:* PCM utilizes fingerprinting and was developed at the Tampere University of Technology in Finland. The approach is purely network-based and applicable only for UMTS networks [7]. It works as follows:
First the area of service is divided into small regions. The smaller these regions, the better the accuracy. The UE measures the RSCP (Received Signal Code Power) over the CPICH (Common Pilot Channel) and reports the value back to the network. The value is used among other things for handover decisions and hence is already present and can be used for PCM. In the offline phase the CPICH levels of the regions of the desired area are measured and stored in a database.
If the UE is in an ongoing connection it transmits the RSCP value to the network. If a location request appears, the most recent value is compared with the entries in the database and the estimated position is returned.
If the UE is in idle mode the network has to page the UE in order to get the RSCP measurement. To get a better accuracy it is possible to take the RTT in account or even values from the existing GSM network [8].

*3) **DCM - Database Correlation Method**:* This fingerprinting method for GSM is used in many research or commercial implementations today [9]. The network needs certain information from the MS in order to make handover decisions (called Network-Measurements Reports - NMR). Therefore the MS measures the signal strength of the serving cell and the six strongest neighbors. The MS sends this seven elements vector to the BTS where it is checked against the entries in the database that was obtained in the offline phase. In the offline phase the position of these fingerprints were determined by GPS or some other accurate localization technique. It uses the GSM standard and neither changes to the MS nor changes to the network have to be made [9].
The problem is that the mentioned seven element vector hardly ever is the same for one position. This is among other things due to weather conditions or changes in the area (new buildings or the like). It is also very time consuming and expensive to make all these measurements for a whole city [9].

B. Terminal-based approaches

Terminal-based or also called MS-based approaches have in common that the position is calculated on the MS. The advantage is that the mobile phone user can decide whether she wants to reveal her position or not. In the network-based approaches where the localization is done by the network an MS can also be located without the knowledge of the user. A disadvantage is that these approaches mostly consume much power. This is valid especially for GPS receivers. Anyway the next generation of mobile phone chips will support low power GPS [10] and batteries will last longer.

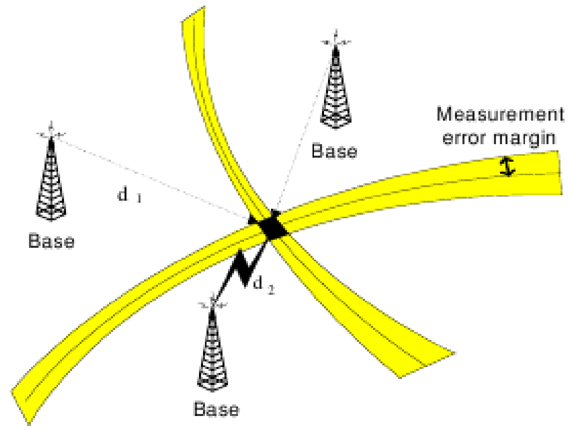

Fig. 8. The principle of E-OTD [13]

*1) **E-OTD Enhanced Observed Time Difference**:* E-OTD belongs to the TDoA family and uses time differences to find the position. Important is here that a position is calculated in relation to BSs and therefore the positions of the BSs must be known. Accuracy of this approach can be as good as 50-150 meters in GSM (and GPRS) and even better in 3G networks (there it is called OTDoA). Since here the calculation is done in the MS, the MS must come with sufficiently memory and processing power and it must be upgraded with a piece of software that does the calculation. This approach can be used either when the MS is idle or in busy mode.
A big advantage of E-OTD over simple GPS is that it works indoors or in urban canyons but a disadvantage is that it works poorly in rural areas where the BS density is rather low [2].
Since GSM phase 2 support for pseudo-synchronous handover is compulsory. For that the Observed Time Difference (OTD) is necessary. A MS kind of pre-synchronized itself to the surrounding BSs to be prepared for a handover to another BS. To make that synchronization possible the MS must calculate the Observed Time Difference between the serving BS and the neighboring BSs i.e. the OTD value is used for handover but can also be used for localization of an MS [11]. E-OTD is the OTD measurement for positioning purposes [12] and the position of the MS is calculated via lateration (figure 8).

The E-OTD value represents a sum of two components: Real-Time-Difference (RTD) and Geometric-Time-Difference (GTD). The former is the synchronization difference between two BSs and the latter is the propagation time difference between two BSs. The MS can measure OTD and RTD can be measured by a location measurement unit (LMU) that has to be installed in the network infrastructure. With the help of these values it is possible to calculate GTD. A constant GTD value between two BTSs defines a hyperbola the intersection of two hyperbolas give the position of a MS [13] (see section 2).
E-OTD has the disadvantages that the MSs have to be

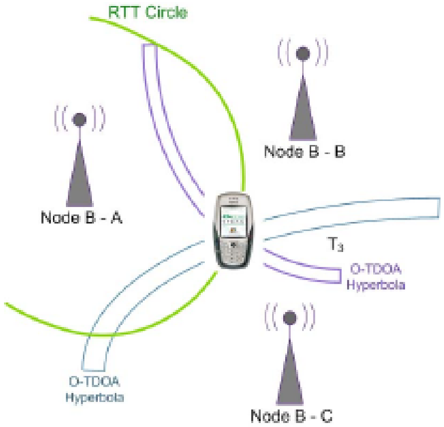

Fig. 9. The principle of OTDOA

upgraded with software and that LMUs have to be deployed in the network. It is also vulnerable to accuracy degradation due to multipath and signal reflections [4].

*2) **OTDoA - Observed Time Difference of Arrival**:* OTDoA is the counterpart of E-OTD in UMTS. The primary standard OTDOA measurement is the "SFN-SFN[4] observed time difference" observed at the UE. Additionally to these measurements the position of the NodeBs and the RTD of the actual transmissions of the down link signals are needed to find the position of the user equipment (UE) [14]. The UE calculates the position with the help of the difference in the arrival times of the pilot signals from at least three NodeBs. Again the UE can be found at the intersection of at least (more are better) two hyperbolas (see figure 9).

There exists two approaches: UE-assisted and UE-based. The former uses the network for calculation and in the latter everything is done in the UE. As mentioned earlier the exact position of the NodeBs is necessary for a good result. These positions for example can be obtained by GPS and transferred to the network (UE-assisted) or to the UE (UE-based). The accuracy depends on different factors: the position of the NodeBs and the precision of the timing measurement. The accuracy can also degrade due to multipath radio propagation. It also has to deal with the near-far problem that is if the UE is to near to the serving NodeB it cannot hear the other NodeBs because of the strong signal coming from the serving NodeB [15].
All these problems led to enhancements that try to overcome the disadvantages. OTDOA with IPDL (Idle period down-link) is one solution where idle periods of the serving NodeB are used to hear the pilot signal from other NodeBs. The UE knows when the idle periods occur so that it can measure the pilot signal from another NodeB. This maximizes the hearability of distant NodeBs [15].
An enhancement of this technique is called OTDOA with TA-IPDL (Time-aligned idle periods down-link). Here the idle period is used from all NodeBs to send a signal that can only be used for location estimation. The UE measures this signal for the different NodeBs. This helps to enlarge the accuracy but it also brings more complexity to the network. It also reduces the communication efficiency since for a certain amount of time all the NodeBs are busy sending the signal for the UE that needs to be located.
IPDL has one major problem and that is that the network suffers from down-link capacity loss since all the down-link traffic from a NodeB is blocked during the idle periods. An alternative to IPDL is called cumulative virtual blanking (CVB). Here the Serving Mobile Location Center (SMLC) is used to do some digital signal processing to the transmitted signals to remove stronger signals consecutively. This helps to extract the timing signal from the weaker signals without the capacity loss of pure IPDL. The result is similar to IPDL [16].

*3) **GPS - Global Positioning System**:* The Global Positioning System (GPS) was developed and installed between 1978 and 1995 by the United States Department of Defense. GPS satellites transmit two carrier frequencies of which one is used for military purposes and the other for civilian receivers [15]. When the work on GPS first started it was intended for military use only but president Reagan announced that it should also be available for public after a plane crash with many deaths due to bad navigation [17]. After that GPS was available for civilian use but the accuracy was artificially degraded by the US military. This degradation was known under the term Selective Availability (SA) and was deactivated in the year 2000. After the deactivation the accuracy improved from about 100 m to 20 m.
The following content of this section is oriented on www.kowoma.de.
GPS can be divided into three segments:

- Space segment with the satellites
- Control segment with the control stations
- User segment that is the civilian and military users

The space segment consist of at least 24 satellites[5] that orbit the earth on predefined paths in a height of 20200 km (from earth surface). The constellation of the satellites guarantees that the signal of at least 4 satellites can be received from every point on earth.

The control segment consists of one master control station and 10 additional monitoring stations that are distributed over the world so that every satellite can be seen from at least two monitoring stations. The advantage is that more accurate orbits and ephemeris data can be calculated. The master control station computes new ephemeris data and three transmitting stations sends the data once to twice a day to the satellites via the S-band signal (S-band: 2000 - 4000 MHz).

[4]System Frame Number

[5]right now 31 are in the orbit in case one of the 24 breaks down

The user segment consists of the GPS receiver on earth. Both civilian and military receiver belong to the user segment. They have no possibility to upload any data to the satellites. Nowadays most GPS receivers are able to connect to 12 satellites in parallel that is they have 12 channels.

Simplified spoken a satellite transmits with a signal its identifier, the position and a time stamp. It also transmits the position of other satellites (ephemeris and almanac data). The almanac is a approximation of the orbit of the satellites and it also gives information about the health of the satellites. The almanac is broadcasted by every satellite and the content is the same until the almanac gets updated. To download the almanac from the satellites takes around 12.5 min[6]. Fortunately the almanac only has to be downloaded under special circumstances for example for a device fresh out of the factory, if it has been switched off for several days or has been moved switched off for more than 300 km. The problem is that the satellites always move and after a while the constellation has changed that much that a fresh download becomes necessary. The MS also needs the ephemeris data from the satellites which are more precise orbital path of the satellites and they are valid for around 4 hours. They are broadcasted every 30 seconds and the download takes 30 seconds as well. That means if a GPS device has been switched off for more than 4 hours this data has to be downloaded again which takes at least 30 seconds.

A GPS receiver stores the almanac and ephemeris data for later calculations. Important for the calculation of the position is the time on which the signal left the satellite and the time to which it was received from the GPS receiver. This time difference can be used to calculate the distance between the satellite and the GPS receiver. If the distance is obtained we know that the GPS receiver must be somewhere on a sphere around the satellite. Of course this is an ambiguous position and that is why more than one satellite is necessary to obtain a position.

GPS uses ToA and hence it is necessary that the clocks are synchronized. The clocks in the satellites are atomic clocks and really accurate but the clocks in the GPS receivers are not. Assume that the clock in the GPS receiver is 0.5 seconds early compared to the atomic clock in the satellite. The GPS receiver will now calculate the position with a time that is 0.5 sec longer than it actually is. This will end up in wrong distances from the satellites to the receiver. In figure 10 we see three satellites and one GPS receiver. The circles that intersect in the points B are called pseudoranges since no synchronization between GPS receiver and satellites has taken place. The positions B in figure 10 give the wrong positions and point A stand for the accurate position after synchronization. A clock error of 1/100 second already leads to a mistake in position of

[6]The full almanac has a size of 37500 bit and with a bit rate of 50bit/s this adds up to 12.5 min

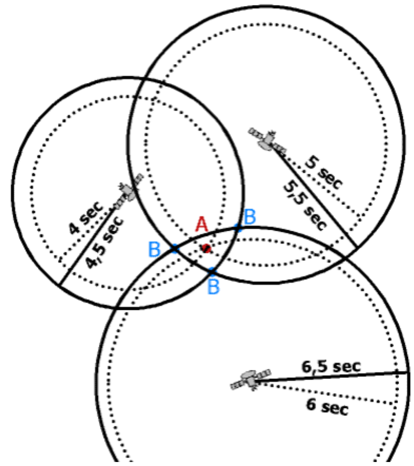

Fig. 10. 2D positioning with 3 satellites and adjustment of the clock error [19]

about 3000 km. To synchronize the GPS receiver clock with the atomic clocks in the satellites we just have to shift the clock in the receiver until they all meet at one point which is point A in figure 10. Now the clocks in the GPS receiver and in the satellites are synchronized and the pseudoranges become the actual ranges and the position is accurate. Figure 10 is an 2D example and here 3 satellites are enough but in the 3D world at least four satellites are necessary [18], [19].

GPS is so far the location technology with the best accuracy. A problem is that it can take a while to obtain the position after turning an MS on. This time is is also called time to first fix (TTFF). Another drawback is that the signal from the satellites is quite weak because of the great distance they have to travel and because they are broadcasted. It is not possible to obtain the position indoors or between tall buildings even leafs of trees or bad weather conditions can weaken the signal . GPS works best with a clear LOS (Line-Of-Sight) to at least 4 of the 24 satellites. To use GPS also under difficult conditions and to improve the TTFF A-GPS was developed.

*4) **A-GPS (Assisted - GPS)**:* GPS was invented to localize a GPS device outdoors where a clear LOS to the satellites exist. The TTFF is related to the usage behavior of the GPS device and the actuality of the almanac that is stored on the device. To get a fix on its position a MS needs to obtain certain data from the satellites as explained in the previous section and this can take some time in GPS. In case of an emergency or in LBS in general it is not sufficient to wait a certain amount of time till the position is obtained. A user wants the position as fast as possible and without limitations of the surrounding area i.e urban, suburban or rural. To overcome these drawbacks of GPS A-GPS was developed. In A-GPS not only the satellites but also the terrestrial cellular network (GSM, UMTS or the internet) are used to gain the position [20]. If the MS is not able to receive the needed data from the satellites it can request the cellular network

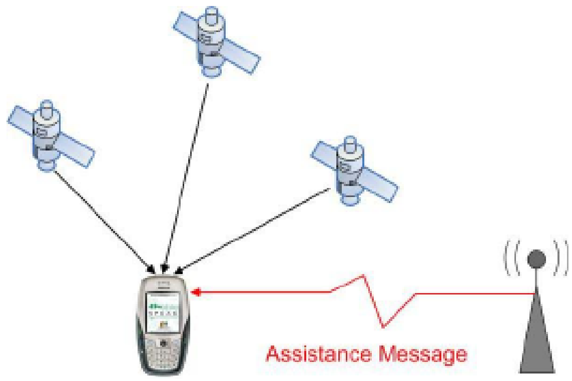

Fig. 11. A-GPS principle[4]

to provide the data and disburden the MS by doing so [21]. The cellular network needs to be upgraded with assisted-GPS servers (also called reference stations) that can deliver the required data e.g. ephemeris or/and almanac. These reference stations monitor the same satellites as the MS via its reference GPS receiver. The network needs to know a rough initial position of the user i.e. via Cell ID. With this information the network can support the MS with the positions of the satellites that should be visible for the MS. The better the network can localize the MS in the beginning the better and faster will be the overall result [22]. The computation of the position can either be done by the MS itself or the MS can send its measured ranges to the satellites to the network where the position is being calculated. Figure 11 shows the procedure.

*5) **Galileo**:* GALILEO uses the same technique as GPS but delivers more features than GPS. Once installed and in operation it will deliver five services:

1) Open Service
2) Public Regulated Service
3) Search and Rescue Service
4) Safety-of-Life Service
5) Commercial Service

According to the official website of the GALILEO project [23] the first three services will be available from 2014 on while the last both will go in operation as soon as all 30 satellites are orbiting the earth. The Open Service is basically the same like GPS but offers a better accuracy. It can be used free of charge everywhere in the world. The Safety-Of-Life Service is not for public but for the safety critical transport like aviation. The enhancement is that it includes an integrity function that will warn the user in case of a malfunction. The Commercial Service is an enhancement to the Open Service. It is not for free and this service uses two encrypted signals for higher data throughput and even better accuracy. The Public Regulated Service uses also two encrypted signals and can only be accessed by governmental bodies. The Search and Rescue Service maybe is the biggest step forward if compared to GPS. Each of the satellites is equipped with an transponder and can therefore forward a distress signal to the nearest rescue unit. It is also possible to send an answer back to inform the person that the distress signal has been received and that help is on the way [23]. This was not possible with GPS. The accuracy will be for the Open Service around 4m, for the Commercial Service and the Public Regulated Service the accuracy will be around 10 cm at best. For the other 2 services it will be also around 10 cm [24].
Another advantage is that Galileo will be compatible with GPS and GLONASS (the Global Navigation Satellite System (GNSS) of the Russians). This means the availability in cities will improve significantly since more satellites are in space and so from one point on earth it is more likely to have a LOS to more than 4 satellites. In rural areas the accuracy will improve since more then 4 satellites can be used for the calculation of the position.
One of the main reasons for Galileo was to be independent from GPS which is controlled by the government of the USA. Galileo can be used by the military but it is not in their hands but in the hands of the European Union.

C. Non-conventional approaches

There also exist many alternatives to the mentioned positioning mechanisms but this work will just deal with the more common ones like Bluetooth and positioning via WLAN. There are also approaches using the RFID or NFC technique. Skyhook is a famous company utilizing positioning via WLAN and also Google is categorizing Access Points for their own positioning service.

*1) **Bluetooth**:* Positioning via Bluetooth utilizes lateration to obtain the position of an MS. Bluetooth transceivers have to be installed in the desired area of localization (stationary at known positions) and an MS should be able to receive at least 3 Bluetooth transceivers to get a position fix. The positions of the transceivers need to be known to calculate the position of the MS. The accuracy is rather high since the cover range of a Bluetooth device is 100 meters at most. Unfortunately this approach is time and cost intensive since many Bluetooth transceivers have to be installed to cover a large area. Hence this technology is manly used in indoor scenarios i.e. at fairs where a MS can be localized with an accuracy of up to 1.7 meters [25].

*2) **Positioning via WLAN**:* This positioning technology becomes more and more popular and is used by Skyhook and Google. Lately Google attracted attention by storing WiFi related data of private (and open) Access Points in the course of taking the pictures for GoogleStreetView.
It is a technique that can be used in cities where many WiFi access points exist. To use this technique on an MS it must have a WiFi device available. Two approaches exists: Trilateration and fingerprinting.
For trilateration the propagation of three (or more) access points and their positions are used to find the MS. The

technique works as explained in the beginning of this work. The difference is only that here the base stations are replaced by wireless access points. The needed distance between the access points and the MS is gained through the signal strength measurement.
Fingerprinting works as explained earlier: Any wireless access point transmits certain data like the SSID and its MAC address. In a city it is very likely that at one point an MS can see more than one WiFi access point. All the data at one certain point are stored in a vector which than acts as the fingerprint for that position. The fingerprints are stored in a database that has to be queried to get the position. The more fingerprints stored in the database, the higher the computing time to find the associated entry in the database. It became evident that it is enough to determine one fingerprint per room (indoors) and then measure the next fingerprint in a distance of 5-10 meters. Outdoors a distance of 15-25 meters ought to be enough [26].

*3) **MyLocation by Google** :* MyLocation is a service that exists for an MS but also for the desktop PC. While the service for the mobile phones utilizes the cell towers, GPS or WiFi access points to get a fix on the position, the version for the desktop only uses the WiFi access points. For a GPS enabled phone a Google Location server can help to speed up the localization process by supporting the MS with positioning related data. MyLocation makes it also possible to get a fix on the position while indoors or in an urban canyon through A-GPS. Not only the GPS related data being sent to the Google servers but also the Cell ID from which the MS uses the service. This helps Google to build up a database in which lat/long coordinates are being mapped to a certain Cell ID. If GPS is not enabled or not built-in MyLocation sends the Cell ID to the Google Location server which returns the coordinates of the center of that BS cell. Figure 12 shows the architecture of MyLocation.
On a desktop where the mobile network cannot be used, Google uses the internet access points of the users around the world. The system works like the one from Skyhook Wireless. Per war-driving the SSID and MAC addresses from access points in the big cities were captured and stored in a database. Probably also the RSS for each AP was stored and all this data together are a fingerprint for a certain position in that city. Google also uses crowdsourcing to gather useful data. A user that uses MyLocation on a desktop sends his own SSID and all it sees plus the RSS to the Google Location Server where a database look-up takes place. If the values of a transmitted vector are similar to a stored one, the coordinates of the stored vector are returned and the position is displayed in Google Maps. This technique works for many users around the world but does not necessarily return the correct position. A test was conducted on a laptop that was connected to a WiFi network in Berlin. Instead of Berlin MyLocation localized the laptop in Brooklyn/New York. At other points in Berlin, MyLocation returned the correct position with a good accuracy.

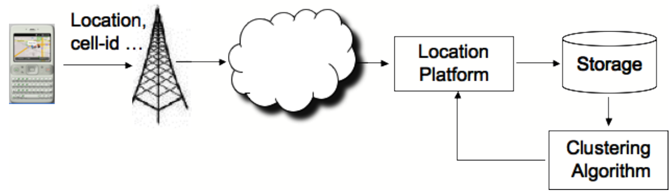

Fig. 12. MyLocation architecture

IV. SUPL - SECURE USER PLANE LOCALIZATION

SUPL is not a positioning mechanism but a secure way to transmit positioning related data over a network. It is mentioned here to give an idea of how these data are exchanged between different nodes.
SUPL was developed by the OMA (Open Mobile Alliance) with the idea in mind to use User Plane data bearers such as IP for exchanging location information and for carrying positioning technology-related protocols, like RRLP, between a SET (SUPL enabled terminal) and the network. The advantage of utilizing the user plane (e.g. IP) instead of the control plane is that the core and radio network can stay unchanged since the infrastructure already exists. SUPL exists in the second version by now and supports A-GPS, Autonomous GPS, E-OTD, OTDoA and enhanced Cell ID (UMTS and GSM) and is applicable in LTE, UMB, I-WLAN and WiMAX networks. It can handle emergency positioning procedures, can deliver the position to a third party and retrieve the location of another SET [27]. Figure 13 shows a simple SUPL architecture.
A network based SUPL session works as follows: Assume an LBS that needs the position of an MS. To retrieve it the network sends a push message to the SET which establishes a secure connection to a SUPL server. This connection is used to exchange all positioning related data until the position is calculated and exchanged [27].
A terminal-based SUPL session works as follows: A SET wants to calculate its position and assumedly needs additional data from the network e.g. it could contact an A-GPS server that speaks SUPL. Afterwards the calculated position can be send to a service using the SUPL architecture.
SUPL uses the MLP (Mobile Location Protocol) to exchange LBS data between two SUPL servers or between a GMLC (Gateway Mobile Location Center) and a SUPL server (also called SLP - SUPL Location platform). Additionally it uses ULP (User Plane Location Protocol) to exchange LBS data between a SET and a SLP [28].

V. ACCURACY AND PRECISION

In the field of LBS it is necessary to distinguish the terms accuracy and precision. Accuracy describes how much the measured value differs from the true value while precision is the degree of repeatability under unchanged conditions that show the same results (see figure 14) [29].

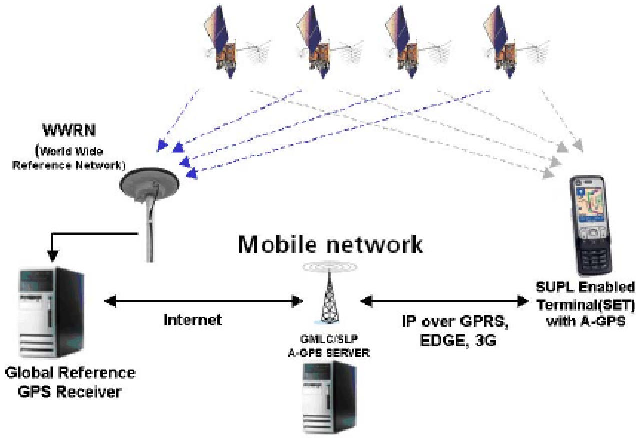

Fig. 13. SUPL architecture[28]

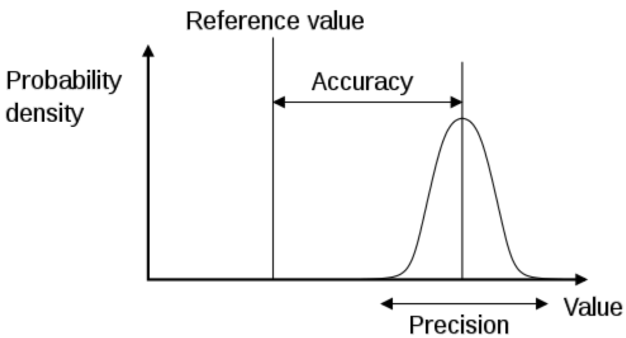

Fig. 14. Difference between accuracy and precision [wikipedia]

This is well known from the FCC mandate for E911 public safety applications in the USA. The FCC has specified different goals that telephone companies have to achieve and if they do not accomplish these goals have to pay a penalty fee. Different accuracy and precision values have been specified for E911 e.g. the service provider must be able to locate a caller within an accuracy of 100m and a precision of 67% or within 300m and a precision of 95%. This means that if a person calls 911 with her MS, the service provider returns the location to the Public Safety Access Point (PSAP) that differs maximum 100m from the actual position on 67% of the calls.

Tables I, II and III give a rough overview of the accuracy and precision of some important positioning techniques in rural, suburban and urban areas, respectively. The minuses in the tables mean that it was not possible to find reliable values to fill in. It must be mentioned that the values of the tables represent measurements under specific circumstances. They cannot be taken as valid for every situation since they depend on the environment and the environment is not stable but they can be used as a guideline. The precision represents the reliability of the techniques.
The best option for positioning in rural areas are GPS and A-GPS and also in suburban areas these techniques achieve the best results. In urban areas A-GPS is a good solution but if the MS is not equipped with a GPS device U-TDoA is a good alternative. DCM is also possible but would be a challenge to build-up and maintain the database due to multipropagation and changing environment.

	Accuracy	Precision
CellID	1746m[30]	95%[30]
CellID+TA	500m-10km[31]	-
CellID+TA+RSS	250m-35km	50-550m
Time Difference of Arrival	8609m[30]	95%[30]
Database Correlation Method	812m[30]	95%[30]
Observed TDoA	27m[32]	95% [32]
Enhanced Observed TD	80m-110m[31]	-
GPS	5m	-
Assisted GPS	10m-15m [31]	-

TABLE I
ACCURACY AND PRECISION FOR RURAL AREAS

	Accuracy	Precision
CellID	1870m[30]	95%[30]
CellID+TA	500m-1.5km[31]	-
Time Difference of Arrival	1956m[30]	95%[30]
Database Correlation Method	849m[30]	95%[30]
Enhanced Observed TD	80m-120m[31]	-
GPS	5m-15m	-
Assisted GPS	10m-15m[31]	-

TABLE II
ACCURACY AND PRECISION FOR SUBURBAN AREAS

	Accuracy	Precision
CellID	526m[30]	95%[30]
CellID+TA	80m-800m[31]	-
Angle of Arrival	100m-200m[12]	-
Time Difference of Arrival	624m[30]	95%[30]
Uplink TDoA	<50m[12]	-
Pilot Correlation Method	80m [8]	67%[8]
Database Correlation Method	25m[8]	67%[8]
Observed TDoA	97m[8]	67%[8]
Enhanced Observed TD	80m-110m[31]	-
GPS	5m-30m[12]	-
Assisted GPS	15m-100m[31]	-

TABLE III
ACCURACY AND PRECISION FOR URBAN AREAS

VI. CONCLUSION AND OUTLOOK

This work discussed different basic positioning mechanims and some of their concrete approaches with a focus on accuracy and costs. It was explained why AoA is expensive to deploy and why it is difficult to use in rural areas. The mentioned disadvantages are the reason why telecommunication companies do not invest in this technology.

Fingerprinting is already used by MyLocation and it works to some extent. While tested on several locations in Berlin, MyLocation tracked the test device once in New York and the rest of the time at the correct position. In cellular networks fingerprinting is not reliable enough due to multipropagation and changing environment.

Cell ID with enhancements is used by many telcos in the US. Accuracy is reasonable in urban areas with high density of BSs but approaches that utilize lateration show better results. EOTD is working very well in urban areas with high density of BSs but it is expensive since LMUs have to be installed in the network. The counterpart of EOTD, OTDoA gives good results which can be improved by using the uplink version U-TDoA.

The best accuracy can be accomplished by GPS and to make GPS also usable under difficult circumstances A-GPS was introduced. Since the A-GPS/GPS chips get smaller and consume less power from year to year it is very likely that these technologies will dominate positioning on MSs in the future. The next MS generation will not only support GPS but also GALILEO to achieve better accuracy and availability. The successor of UMTS, LTE, has been developed with MS localization on mind and will support A-GNSS/GNSS methods, down-link positioning and enhanced Cell ID. In summary it can be said that there is no positioning technology that is applicable in every situation and area. Some techniques do not work indoors or have problems in urban areas while other work well in urban areas but give poor results in rural areas. The technology that best fits most situations is A-GPS and will dominate the positioning market in the future.

References

[1] N. Deblauwe, *GSM-based Positioning: Techniques and Applications*. ASP/VUBPRESS Brussels, 2008.

[2] T. Kos, M. Grgic, and G. Sisul, "Mobile user positioning in GSM/UMTS cellular networks," in *Multimedia Signal Processing and Communications, 48th International Symposium ELMAR-2006*, 2006, pp. 185–188.

[3] A. Küpper, *Location-based Services : Fundamentals and Operation*. John Wiley & Sons Ltd., 2005.

[4] A. Roxin, J. Gaber, M. Wack, and A. Nait-Sidi-Moh, "Survey of Wireless Geolocation Techniques," in *IEEE Globecom Workshops*, 2007, pp. 1–9.

[5] B. Li, J. Salter, A. Dempster, C. Rizos *et al.*, "Indoor positioning techniques based on wireless LAN," in *First IEEE International Conference on Wireless Broadband and Ultra Wideband Communications, Sydney, Australia*, 2006, pp. 13–16.

[6] J. Warrior, E. McHenry, and K. McGee, "They know where you are [location detection]," *IEEE Spectrum*, vol. 40, no. 7, pp. 20–25, 2003.

[7] J. Borkowski and J. Lempiäinen, "Pilot correlation positioning method for urban UMTS networks," *Proceedings-European Wireless 2005*, 2005.

[8] B. Jakub *et al.*, "Practical Network-Based Techniques for Mobile Positioning in UMTS," *EURASIP Journal on Advances in Signal Processing*, vol. 2006, 2006.

[9] B. Denby, Y. OUSSAR, and I. AHRIZ, "Geolocalisation in Cellular Telephone Networks," *Mining Massive Data Sets for Security: Advances in Data Mining, Search, Social Networks and Text Mining, and Their Applications to Security*, p. 357, 2008.

[10] G. Beavis, "Dual-core qualcomm 1.2ghz smartphone chips now shipping," 2010. [Online]. Available: http://www.techradar.com/news/phone-and-communications/mobile-phones/dual-core-qualcomm-1-2ghz-smartphone-chips-now-shipping-693429

[11] Svein Yngvar Willassen , "Implementing Mobile Station Location in GSM," 1998, http://www.willassen.no/msl/node7.html.

[12] S. Wang, J. Min, and B. Yi, "Location Based Services for Mobiles: Technologies and Standards," *IEEE ICC Beijing*, 2008.

[13] I. Motorola, "Overview of 2G LCS Technologies and Standards," in *3GPP TSG SA2 LCS Workshop, London. www.3gpp.org/ftp/workshop/Archive/0101LCS/Docs/PDF/LCS-010019.pdf*, 2001.

[14] UMTS , "Stage 2 functional specification of User Equipment (UE) positioning in UTRAN (Release 9)," 3GPP TS 25.305 V9.0.0 (2009-12), 3rd Generation Partnership Project.

[15] Y. Zhao and M. Inc, "Standardization of mobile phone positioning for 3G systems," *IEEE Communications Magazine*, vol. 40, no. 7, pp. 108–116, 2002.

[16] Y. Guo, *Advances in mobile radio access networks*. Artech House Publishers, 2004.

[17] D. Ralph and S. Searby, *Location and personalisation: delivering online and mobility services*. The Institution of Engineering and Technology, 2003.

[18] not mentioned, "Global positioning system - serving the world," 2010. [Online]. Available: http://www.gps.gov/

[19] kowoma.de, "Gps-system," 2010. [Online]. Available: http://www.kowoma.de/gps/

[20] C. Ratti, D. Frenchman, R. Pulselli, and S. Williams, "Mobile Landscapes: using location data from cell phones for urban analysis," *Environment and Planning B: Planning and Design*, vol. 33, pp. 727–748, 2006.

[21] ACA, "Location, location, location - the future use of location information to enhance the handling of emergency mobile phone calls," *Australian Communications Authority, now Australian Communications and Media Authority, Level 44 Melbourne Central Tower, 360 Elizabeth Street, Melbourne,Victoria 3000*, 2004.

[22] S. Tekinay, *Next generation wireless networks*. Kluwer Academic Publishers Norwell, MA, USA, 2001.

[23] E. C. - Enterprise and I. - Space, "Galileo - what do we want to achieve?" 2010. [Online]. Available: http://ec.europa.eu/enterprise/policies/space/galileo/index_en.htm

[24] kowoma.de, "Übersicht über das galileo-system," 2010. [Online]. Available: http://www.kowoma.de/gps/galileo/Uebersicht.htm

[25] F. Giannotti and D. Pedreschi, "Mobility, Data Mining and Privacy: Geographic Knowledge Discovery," 2008.

[26] S. Meyer, "Bodenständig - positionsbestimmung per wlan statt gps," May 2010. [Online]. Available: http://www.heise.de/mobil/artikel/Positionsbestimmung-per-WLAN-statt-GPS-222253.html

[27] I. Guzey and E. Ucar, "Impacts of SUPL Capabilities on Location Based Services in Next Generation Mobile Networks."

[28] G. Tolga and B. Ozgun, "Secure user-plane location (SUPL) architecture for assisted GPS (A-GPS)," *ASMS2008. Bologna: IEEE Express Publishing*, pp. 229–234, 2008.

[29] J. Taylor, *An introduction to error analysis: the study of uncertainties in physical measurements*. Univ Science Books, 1997.

[30] B. Lakmali and D. Dias, "Database Correlation for GSM Location in Outdoor & Indoor Environments," in *Information and Automation for Sustainability, 2008. ICIAFS 2008. 4th International Conference on*, 2008, pp. 42–47.

[31] M. Grigat, "Innovative lokalisierungsverfahren in mobilfunknetzen zur mobilitätsunterstützung im bereich des öffentlichen personenverkehrs," in *Vortrag, FIV-Symposium Neue Kommunikationstechnologien für den Personenverkehr*, 2002.

[32] D. Porcino, "Performance of a OTDOA-IPDL positioning receiver for 3GPP-FDD mode," in *3G Mobile Communication Technologies, 2001. Second International Conference on (Conf. Publ. No. 477)*, 2001, pp. 221–225.