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End-user Location in Digital Mobile Networks

Mika Keski-Heikkilä

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Abstract

There are several different techniques that can be used for network-based mobile location. Positioning based on the serving base station (BTS) is widely used around the world. This technique can be improved with Round Trip Time (RTT) measurement or in GSM by reporting Mobile Station (MS) Timing Advance (TA) value. Also received signal level (RxLevel) can be reported, reporting to the network can be done e.g. via Short Message Service (SMS).

Other network-based positioning methods are Time Difference Of Arrival (TDOA) or Angle of Arrival (AOA) methods. Also a combination of these can be used, but they will of course need some investments to the mobile network.

For the end-user location needs GPS and Assisted GPS offers very accurate location information, but has some coverage drawbacks and suffers high battery usage in mobile station (MS). Network assisted positioning uses network-based positioning and delivers the co-ordinates to the MS with e.g. SMSs. For continuous location information there are capacity limitations due to excessive signalling between the network and the user.

A new mobile-based location system, that does not suffer the coverage or signalling capacity problems, is presented in this paper. The system uses network database, broadcast channels of digital networks and any MS measurement method available to offer continuous location service. System is called as Simple Mobile Positioning System (SMPS) that will provide the means to offer self-positioning [1] or mobile-based [5] location service in mobile networks and allow the charging of the service.

Contents

1. Introduction

The need to location has been divided for two purposes, either the ”system” or the service needs to know the location of the users (fleet management, emergency services like E911, etc.) or the users want to locate themselves.

In the similar manner the positioning architectures can be either system-based (i.e. network-based) or user-based (i.e. mobile-based) positioning with maps or Global Positioning Service (GPS). Also hybrid positioning exits (e.g. network assisted location).

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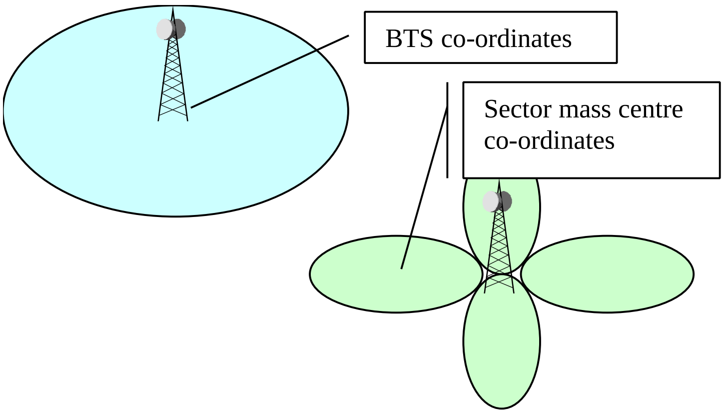
A new mobile-based location system, that does not suffer the coverage or signalling capacity problems, is presented in this paper. The system uses network database, broadcast channels of digital networks and any MS measurement method available. The charging of the service can be done with encrypted broadcast information and SMS encryption key delivery. In its simplest form the system is called as Simple Mobile Positioning System (SMPS), where the MS uses RxLevel measurements. With that no hardware modifications to the MS or to the network are required.

2. Mobile Location Techniques

2.1. Cell ID

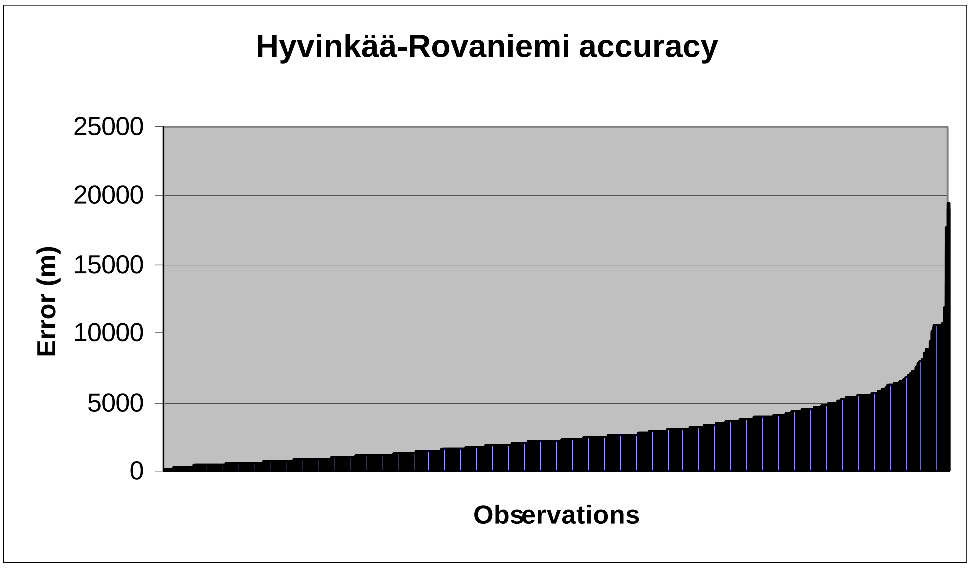
The mobile can be located using it's serving cell co-ordinates. The co-ordinates can either be the BTS co-ordinates or the co-ordinates of e.g. the mass centre of the cell coverage area as in next figure.

Figure 1. Positioning based on cell co-ordinates.



The accuracy of this method depends on the serving cell radius that can vary between 50 m (indoor) to 30 km in rural areas. Mean error for the location when driving a highway from Hyvinkää to Rovaniemi (mostly rural area in Finland) is calculated to be 2774 m.

Figure 2. Mean error for location with Cell ID in Finland.



The accuracy for the location in suburban or in urban environment will be better than in rural area.

2.2. Received Signal Level

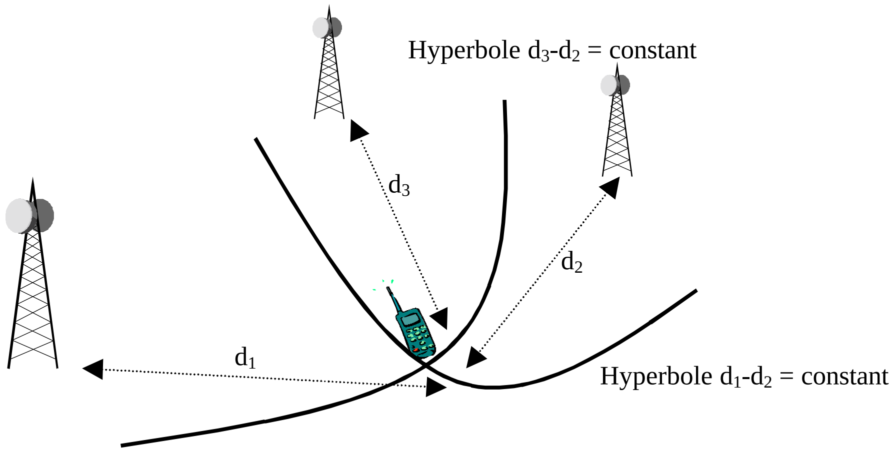
All mobile networks have procedures, where the mobile station measures the serving and the neighbouring cell received signal level (RxLevel) in order to select the best cell. This information and a simple propagation model can be used to estimate the distances between the MS and the serving and neighbouring BTSs.

The accuracy of the location with RxLevel based measurements is 243-248 m (suburban mean) and 755-785 m (rural mean) according to the measurements in Finland [5].

2.3. Time Difference Of Arrival (TDOA)

A receiver can measure the time difference between each pair of received signals and calculate the location from the intersection of two hyperbolas assuming the signals are synchronised (time synchronised BSS).

Figure 3. Time difference of arrival.

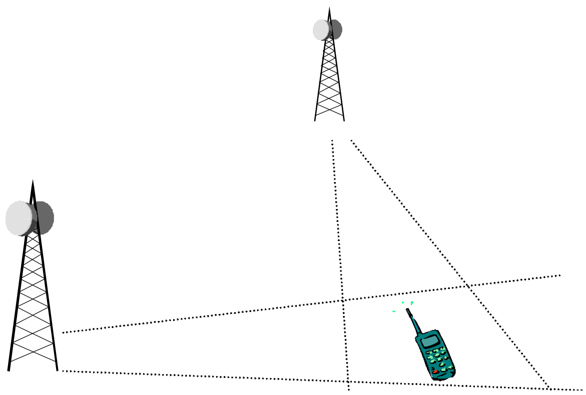


The accuracy of the location with TDOA based method is reported to be 125 m in suburban and 141 m in urban environment with 67% of the samples [5].

2.4. Angle Of Arrival (AOA)

This method involves measuring the Angle Of Arrival (AOA) of a signal either from a BTS or a MS using e.g. antenna patterns.

Figure 4. Estimation of the arrival angle of the signal from a MS at a BTS.



The accuracy of location with AOA based method is reported to be 45 m in suburban environment with 67% of the samples [5].

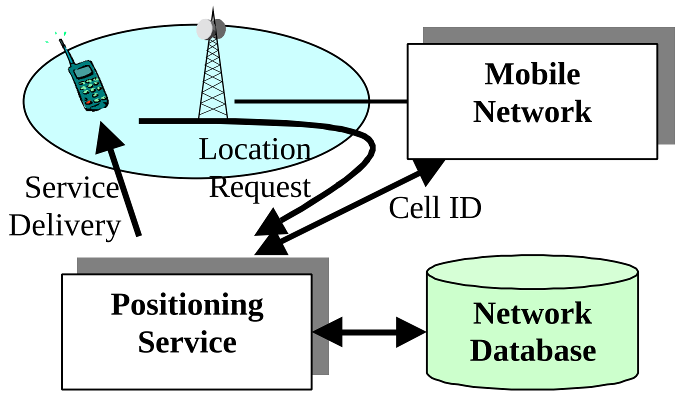
3. Network-Based Positioning Systems

With network-based systems the MS will at first initiate the location request to the Positioning Service e.g. in a WAP session. Sometimes the MS will also send some network data from its cellular environment. After that the Positioning Service will determine the location of the MS with the Mobile Network and the Network Database. Finally the MS will receive the requested location based service it was asking (e.g. the address of the nearest sushi restaurant).

3.1. Cell Coverage Area Co-ordinate (Cell ID)

Positioning Service will receive a request for location. After this the serving BTS ID is resolved from the Mobile Network and the service will look for the corresponding co-ordinates from the Network Database. When the correct co-ordinates have been found the location service is delivered to the MS. The system block diagram is presented in the next figure.

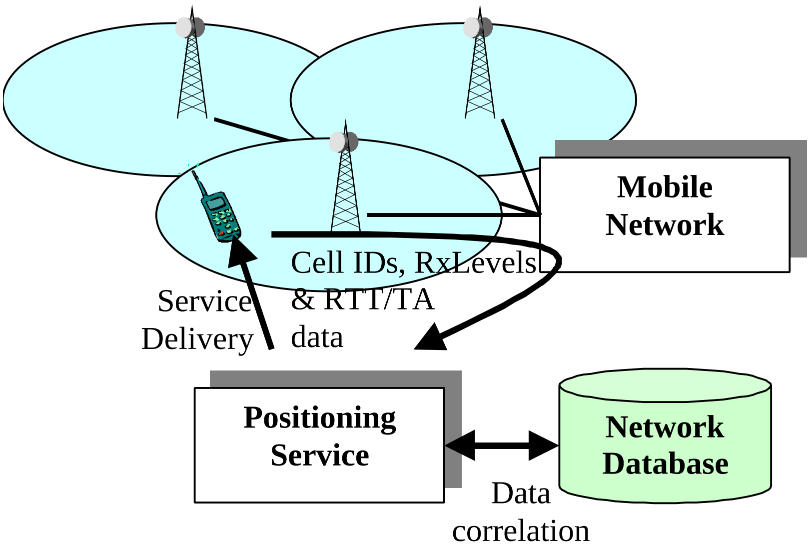
Figure 5. A block diagram of the Cell ID based location service.



3.2. RxLevel and RTT/Timing Advance

With location service request the MS can deliver the measurements (RxLevel, RTT/TA) and needed cell identification data (cell ID, frequencies, BSIC, etc.) from the serving cell and the neighbouring cells to the Positioning Service. The Positioning Service will then correlate the measurements with the Network Database and estimate the MS location.

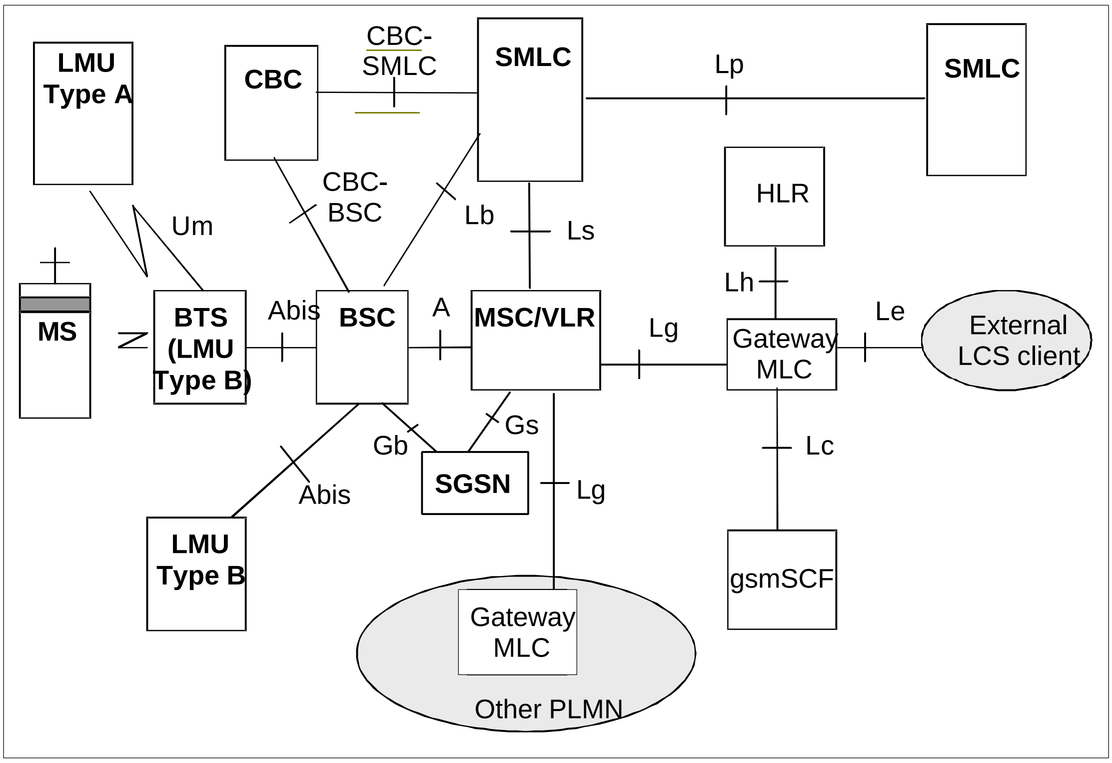
Figure 6. A block diagram of the RxLevel and RTT/TA based location service.



3.3. *Enhanced-Observed Time Difference (E-OTD)*

Enhanced-Observed Time Difference (E-OTD) in one of the standardised location methods, that was designed to fulfil the FCC emergency call requirements (E911) in GSM based systems. Similar method for UMTS is called as OTDOA and for IS-95 as AFLT.

Figure 7. Generic Location Service (LCS) Logical Architecture [7].



Location Service (LCS) is logically implemented on the GSM structure through the addition of one network node, the Mobile Location Center (MLC). A generic LCS logical architecture is shown in Figure 7.

4. Mobile-Based Positioning Systems

4.1. Global Positioning Service (GPS)

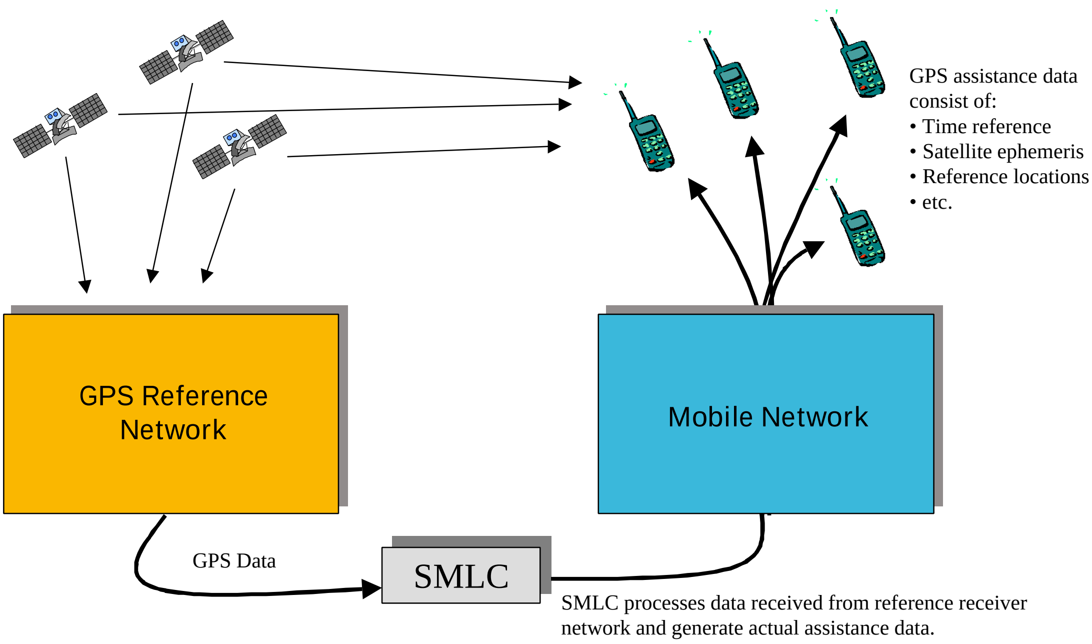
GPS is a satellite based location system, where the GPS receiver measures the distances to the GPS satellites using spread spectrum signals. The position can be calculated if the position of each satellite and the distance from the satellite (pseudorange) is known. There are 24 satellites in 6 orbital planes and connection with four satellites enables the 3D co-ordinates to be defined.

GPS offers very accurate positioning. Currently there are mobiles equipped with a GPS receiver in the market, but they suffer high battery usage and lacking indoor and street canyon coverage. Also the long signal acquisition time (more than 30 s) prevents the usage in obstructed environment (e.g. in cities).

4.2. Assisted-GPS (A-GPS)

Network assisted GPS positioning uses cellular network to speed up the location and reduce the power consumption. Also the indoor coverage can be offered by broadcasting the GPS signal through cellular network.

Figure 8. Assisted GPS Network architecture.

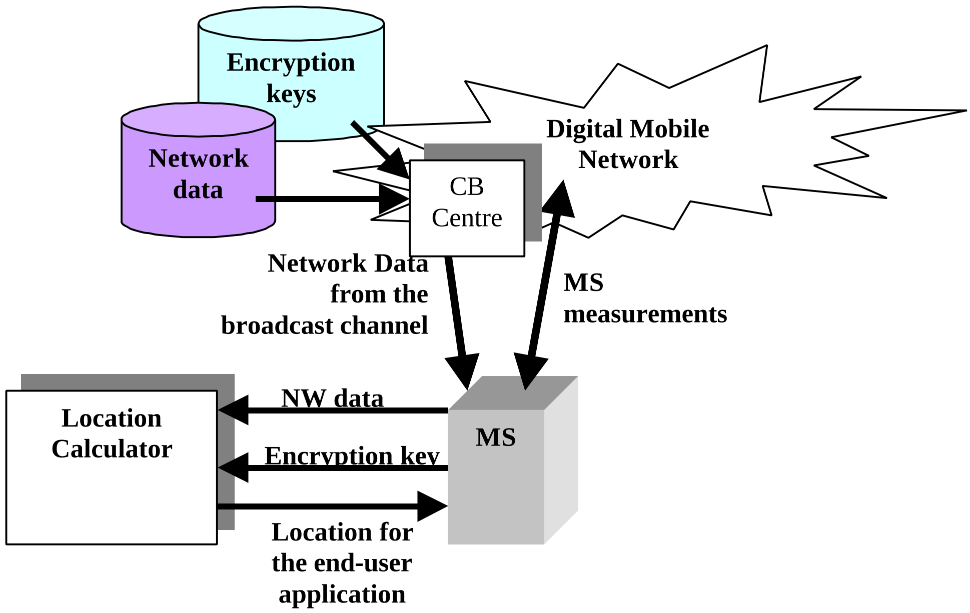


Using mobile network to assist GPS the most drawbacks of GPS location can be minimised without major changes to the accuracy. A GPS receiver is still needed in the MS and that has a major implication to the MS cost. If there is market for the service in the future the cost of A-GPS chips will be greatly reduced.

4.3. Simple Mobile Positioning System (SMPS)

By using broadcasted information to deliver the data needed for location calculation, the mobile measurements from the surrounding network and software in intelligent cards or in the MS itself the location can be calculated in the continuous manner with high enough accuracy to the most mobile user applications. [6]

Figure 9. A block diagram from the SMPS.



4.3.1. Charging Functionality with Encryption

For billing and other purposes the network information broadcasted to the users can be encrypted. After purchasing of the location service, the customer will get the encryption key to the Location Calculator e.g. via SMS.

4.3.2. The Network Database and the Broadcast Centre

The data broadcasted by the network can include the information from the serving cell and from the needed neighbouring cells. From each cell there can be data like:

- the date and time,
- the cell identity for MS measurements,
- area information: country, city, name of the coverage area of the cell, name of the base station (BTS), type of the BTS (macro, micro, pico, indoor),
- co-ordinates: the base station co-ordinates, the cell coverage area co-ordinates (e.g. the mass centre of the sector),
- antenna information: the antenna gains, directions and widths of the sector.

The broadcast centre will deliver the encrypted network data to the physical broadcast channels of the corresponding BTS. In GSM these network elements are called as Cell Broadcast Centres (CBC).

4.3.3. The Repetition Rate of the Broadcast Messages

The repetition rate of the broadcasted message depends from the capacity of the broadcast channel. In GSM the maximum capacity of normal Cell Broadcast CHannel (CBCH) is one message of about 800 characters in every two seconds.

For fast information delivery after cell reselections the rate should be in order of seconds rather than tens of seconds.

4.3.4. Serving Cell Signal Strength and Distance Measurement

In the idle mode the mobiles continuously measure the radio environment (e.g. signal strength and/or quality) in order to select the best serving base station. In active mode they both measure and report this information to the network in order to network to select the serving cell. In addition the distance to the serving cell is measured in order to adjust the timing advance of the signalling bursts with the network.

4.3.5. Neighbouring cell signal strength measurement and distance estimation

This information can be used to determine the estimated distances to the serving and the neighbouring base stations.

In order to improve the distance measurements the MS can change the serving cell and initiate a signalling connection for more accurate timing advance information. Also some methods to improve the usability of the signal strength measurements can be used [1].

4.3.6. Calculation of the Location in the MS/SIM

If the BTS co-ordinates and the distances of at least three base stations are known the 2D co-ordinates (x0, y0) can be calculated with circle equations.

Equation 1. Circle Equations.

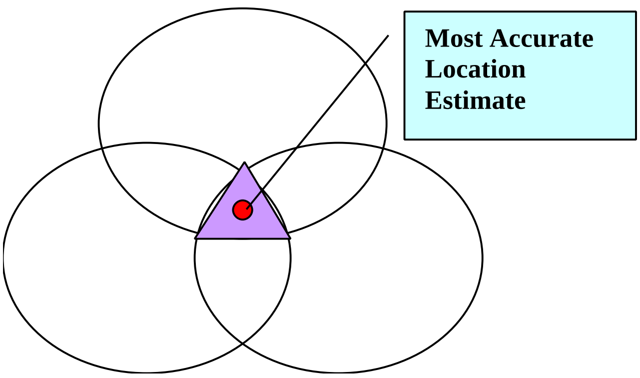
$(x1-x0)2+(y1-y0)2=d12$

$(x2-x0)2+(y2-y0)2=d22$

$(x3-x0)2+(y3-y0)2=d32$

Solving these equations will optimally give one common point to all circles, but most probably six points as in next figure. A most accurate location estimate is presented in the Figure 2.

Figure 10. Most Accurate Location Estimate of Three Circles Crossing.



If the mobile is in the urban environment, it can also estimate the location to be the serving cell base station or sector mass centre co-ordinates. This estimation could be made in e.g. micro cellular environment, when the e.g. TA or the RTT to the serving and/or some neighbouring cells is measured to be small enough.

5. A Brief Comparison Between Presented Positioning Systems

A brief comparison between the different systems can be done using the accuracy, needed network modifications and needed MS modifications as an argument.

Also the signalling load could be an argument, but that demands some knowledge from the location services used, which has not been covered in this paper. The used service has a great impact to the signalling of the network-based or the mobile-based positioning, if the used method does not support it by the nature. However, mobile-based location suffers the signalling less when used with network-base location service than vice versa. That can be explained with an example: if mobile-based location is used for the network-based location service (e.g. find the address of nearest sushi restaurant) the co-ordinates have to be signalled to the network only once. That signalling can also be combined with the service request. In comparison if network-based location is used with mobile-based location service (e.g. area map display), there might be several messages between the MS and the network. If the location need is continuous, the signalling will increase dramatically.

An introduction to the location services can be found from [1].

Table 1. Comparison Between Presented Positioning Systems.

Positioning System	Method	Network Modifications	MS Modifications	Environment	Accuracy [m]
Network-based					
Cell Coverage Area Co-ordinate	Cell ID	SW	-	rural	2774 (mean)
RxLevel and RTT/Timing Advance	RxLev	SW	SW	suburban / rural	243-281 / 755-785 (mean)
E-OTD	TDOA	HW: LMUs to every third BTS, etc.	SW	urban / suburban	141 / 125 (67%)
Mobile-Based					
GPS	GPS	-	HW: GPS reveiver	outdoor	30
A-GPS	GPS	HW: GPS reveivers to BTS, etc.	HW: GPS reveiver	outdoor	30
SMPS	RxLevel	SW	SW	suburban / rural	243-281 / 755-785 (mean)

With accuracy in mind by far the most accurate location is offered by the GPS based systems. The drawbacks of mobile-based GPS location is greatly reduced with Assisted-GPS, only limitation is the GPS receiver needed in the MS (HW modifications).

In addition to GPS based methods the positioning that also fulfil the FCC E911 requirement (125 meters for 67% of the samples) in U.S. are the standardised TDOA based systems. They however require major hardware investments to the network. Without the regulatory actions in Europe it is not easy to see the location service operator, who is willing to cover these expenses.

The minimal network or MS modifications needed is offered by the Cell ID based location methods. There are many products in the market, which use this information in location specific network services around the world.

Only software modifications are needed in the RxLevel based location methods. There are many existing implementations in the network-based location. The only system that can offer the same in the mobile-based location is SMPS using RxLevel MS measurements. The accuracy is still acceptable for most MS and WAP applications, where the MS display is often small.

6. Summary

The mobile location technologies have drawn a lot of attention in the past few years and the need for the services is growing in the advent of the new mobile generation. Depending from the need, there are clearly two types of positioning systems, either network-based or mobile-based.

The accuracy between different location techniques and the cost of implementation between the different positioning systems varies a lot. For high accuracy the GPS based location seems to offer the best solution. The standardised TDOA based location methods fulfil the regulatory needs for the emergency services, but suffer high implementation costs.

The only system to offer mobile-based location with minimal modifications needed seems to be the presented SMPS with RxLevel MS measurements. The accuracy is still acceptable for most MS and WAP applications, where the MS display is often small.

7. References

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