Positioning within the GSM Network

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Key words: Positioning, Mobile Phone, GSM Network, Positioning Infrastructure

SUMMARY

Within FIG Commission 5 Working Group 5.3 the new special study group “New Positioning Techniques and Infrastructure” has been established. This study group will deal with infrastructure relevant for positioning. An infrastructure of this kind is the mobile phone network. This paper gives an insight into one type of mobile phone network, the GSM network.

To understand the general possibilities available for positioning using mobile phones one has to distinguish between different locations and modes of positioning. The location may be at the mobile phone (handset-based) or within the mobile phone network (net-based). The latter case has to be divided into positioning actively pursued by the mobile phone user or positioning using the GSM system intrinsic information. The second uses the mobile data without the knowledge of the mobile user in an anonymous way. An overview about the positioning methods, their assignment to the different positioning modes and to different accuracy levels is given in this paper. The structure of the GSM network as well as the requirements, that have to be available for the different positioning methods, are outlined. Special focus is given on the GSM system intrinsic positioning information.

Additionally the paper gives an example for the anonymous positioning approach. The measurements available within the GSM network used for this purpose are the signal strength values from the mobile phone to up to seven antennas and the so-called timing-advance value to one antenna. The information are e.g. transformed to distances, thus allowing positioning methods based on arc sections or alternatively reference data are used for signal strength matching methods. The accuracy of individual positions is determined to approximately 400 m. An enormous accuracy jump is made using time series of positions and filtering algorithms.

ZUSAMMENFASSUNG

Die FIG Commission 5 hat eine neue Special Study Group mit dem Aufgabenbereich “New Positioning Techniques and Infrastructure” eingerichtet, die sich mit der für die Positionsbestimmung relevanten Infrastruktur beschäftigen wird. Eine typische Infrastruktur, die für Positionsbestimmungszwecke genutzt werden kann, ist das Mobilfunknetz. Dieser Beitrag beschäftigt sich mit einem ausgewählten Mobilfunknetz: dem GSM Netz.

Um ganz allgemein die Möglichkeiten der Positionsbestimmung zu verstehen, muss man zwischen einerseits Positionsbestimmungsmethoden und andererseits Ort der Positionsbestimmung unterscheiden. Dieser Ort kann am Mobilfunkgerät (handset-based) oder innerhalb des Mobilfunknetzes (net-based) sein. Die zweite Variante muss wiederum unterteilt werden hinsichtlich des Engriffs des Nutzers. Entweder kann der Nutzer seine Position anfordern oder sie wird anonym ohne sein Wissen berechnet. Einen Überblick bezüglich Positionsbestimmungsmethoden und deren Zuordnung zu den angesprochenen Möglichkeiten und zu verschiedenen Genauigkeitsniveaus wird in diesem Beitrag geliefert. Der Aufbau des GSM Netzes und der für die Positionsbestimmung relevanten Infrastruktur werden dargestellt. Ein Schwerpunkt wird dabei auf die im GSM System vorhandenen nutzbaren Informationen gelegt.

Zusätzlich beschreibt der Beitrag ein Beispiel für einen anonymen Positionsbestimmungsansatz. Die genutzten Messgrößen sind bei diesem Ansatz die gemessenen Signalstärken von bis zu sieben Antennen sowie der so genannte TA-Wert zu einer Antenne. Diese Informationen werden entweder in Strecken umgerechnet um Bogenschnittlösungen zu ermöglichen oder Referenzdaten werden genutzt um Signalstärken-Matching-Methoden einzusetzen. Die Genauigkeit der Einzelpositionen bestimmt sich zu ca. 400 m. Eine deutliche Verbesserung wird durch die Verwendung der Zeitreihen in Filteralgorithmen erreicht.

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1. MOTIVATION FOR THE SURVEYING PROFESSION

Within the surveying community the knowledge regarding two or three dimensional positioning techniques, methods, and systems is standard. Each surveyor learns about intersection or arc section in the first years of his study. Later on, when dealing with navigation, the hyperbola section is treated too. These methods are typical positioning methods too, if mobile phones are used. Of course the surveyors should have the competence to develop and implement these methods using mobile phone networks too. The possibility to infiltrate this positioning market that is related to Location Based Services or traffic applications like traffic state and forecast.

In contradiction to the standard measurement quantities of the surveyors the measured respectively derived measured quantities are less accurate; approximately some hundred meter. Logically the determined positions may not be used for surveying tasks. But the technologies used may be adopted. To understand the possibilities the structure of the GSM network and the available quantities have to be known for the surveying profession. This will be accomplished by this paper. The idea to use known geodetic techniques and methods, further develop and adapt them to the respective problem is outlined in this paper too.

2. CHARCTERISTCS OF THE GSM NETWORK

2.1 Structure of the GSM Network

Any cellular network consists of many base stations including the respective antennas that serve the nearby cell phones respectively mobile phones. A cell phone shall be called mobile station within this paper, therefore the abbreviation MS is comfortable. For the GSM network the base stations are called Base Transceiver Stations (BTS). Some BTS are pooled and are controlled by a Base Station Controller (BSC). The next higher hierarchy is the Mobile Switching Centre (MSC) that routes calls between MSs and between MSs and fixed-line network phones. The region controlled by an MSC is frequently identical to the so-called location area (LA) that plays an important role for positioning techniques, as may be seen later on. The number of BSC controlled by one MSC as well as the number of BTS controlled by one BSC may vary from provider to provider as well as from region to region. Data, and not only positioning relevant data, may be acquired at different interfaces. Between the BTS and the BSC the so-called Abis-interface is defined. The data available at one of these interfaces are restricted to all BTS assigned to this one BSC; but it is more detailed than on the higher level interfaces. The next hierarchy is the A-interface that is defined between the BSC and the MSC. All data of the BSC assigned to one MSC may be acquired at one of these interfaces. Figure 1 gives an overview about the GSM network structure and the respective interfaces relevant for the positioning task.

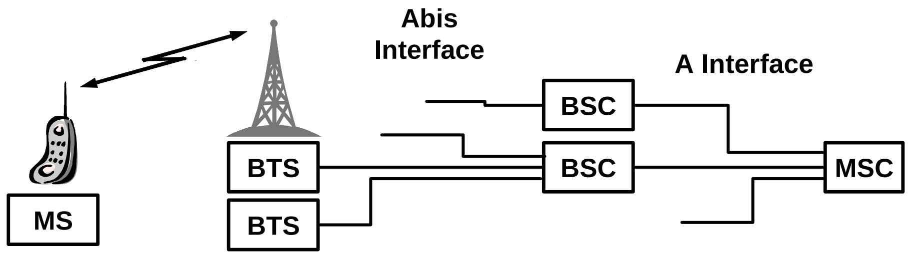

Fig. 1: Structure of GSM network including interfaces

2.2 Measurements within the GSM Network

At the A-interface as well as at the Abis-interface a lot of data is available. A typical example for one MSC are about 6 GB for A- and Abis-interface for one day. These values are empirically determined and already reduced including the positioning relevant information only. They may differ with respect to the number of BSC controlled as well as to the communication load.

One information available in the GSM network is the cell ID (unique number assigned to one cell respectively BTS). It is the basic information for all information tasks, because it indicates the provider, if and where a MS is located within the network. In the point of time when a MS changes from one cell (BTS) to another one, both IDs are available. One talks about a handover.

Each LA is defined by an unique LA ID. If a MS changes its position from one location area to another one, this information is available within the network too. In this case the cell ID of the LA which the MS enters is given additionally to the two LA IDs. The LA ID may be obtained in the GSM network in defined time intervals too. The provider defines this time interval in dependence of the general communication load.

To establish communication between BTS and MS, time slots are used. These time slots have to be synchronised. To achieve this synchronisation, the signal propagation delay has to be taken into account (Roth 2002). This is ensured by the timing advance (TA) value, that is an approximation of the distance between MS and the serving cell. The TA value indicates the time delay for the MS to send one data packet and is given with a resolution of approx. 550 m. The accuracy for determination of the distance is limited to approx. 1100 m and depends on the distance between MS and BTS. It increases with approach to the BTS (Wiesmann 2000). The measurement of the TA value is system-intrinsic, thus it enabling network-based positioning (Reed et al. 1998).

The received signal strength (Reception Level / RXLEV-value) at the mobile station is an important information for e.g. handover decisions. Therefore the MS can measure the signal strength of the serving cell and up to six neighbouring BTS. The MS transmits these measurements to the network during communication (Walke 2001). The accuracy of the signal strength is subject to fluctuations, since it depends on metrology, multipath propagation, shadowing effects (moving and fixed objects) and short-term-/fast fading (Wiesmann 2000). The signal strength is measured between - 110 dBm and - 48 dBm. The unit dBm is transmission power related to 1 mW (Detlefsen & Siart 2005). The difference of two transmission levels given in dBm results in a dimensionless relation given in decibel (db). The theoretical accuracy for the signal strength is given with 4 dB (up to -70 dBm) respectively 6 dB (Walke 2001). The accuracy decreases, in other words the standard deviation gets higher, with increasing distance.

3. POSITIONG METHODS

3.1 Classification and Overview of Positioning Methods

In general different geometric ways to determine positions are possible using mobile phones. All of these methods base on geometric principles well-known to the surveyor. The denomination differs with respect to the geodetic vocabulary. Table 1 gives an overview about the methods of mobile positioning and their geodetic analogy, if available, as well as restrictions that limit the spread of the respective methods. Figures 2 to 6 show the geometric principles. Some explanations are intermediately given.

Tab. 1: Geometric principles of mobile phone positioning

denomination within cellular positioning	geodetic analogy	measurements	restrictions
Cell Global Identity (CGI)	-	cell ID	none
Handover / Location Area Update	-	two cell IDs / two LA-IDs + one cell ID	available at special events
Time-of-Arrival / TOA	arc section	distances	none
Time-Difference-of-Arrival / TDOA	hyperbola section	distance differences	BTSs have to be synchronised
Angle-of-Arrival / AOA	intersection	angles	need for 2 antennas at a BTS
Signal Strength Matching	-	RXLEV (signal strength)	reference data has to be available

The most simple positioning method is the Cell Global Identity (CGI) that results in a location region as large as the cell itself. In city areas this may be below 250 m^2. In rural areas the cells are larger than some km^2 by the way decreasing the respective accuracy. As shown in figure 2 this positioning method may be extended to sectoral cell positioning or even combined with TA-based distances determined. For GSM networks realized in Germany three antennas are mounted at most of the BTS locations, so that sectoral cell positioning is realized automatically.

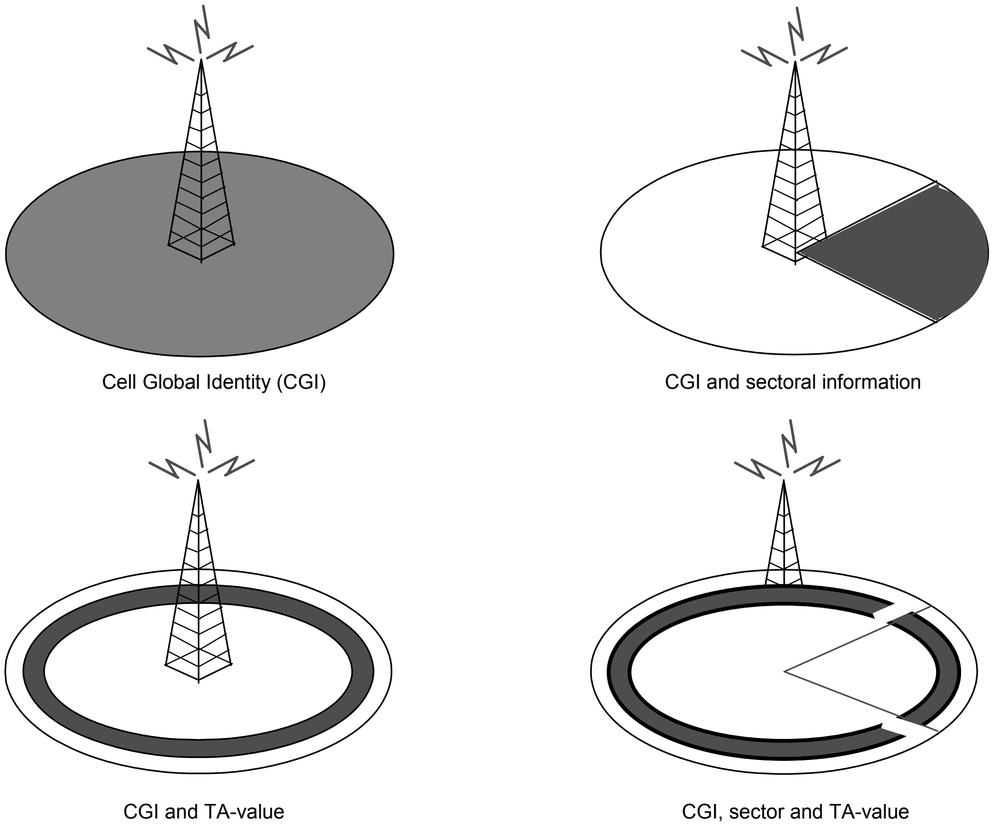

Fig. 2: Cell Global Identity and extended cell positioning (Czommer at al. 2006)

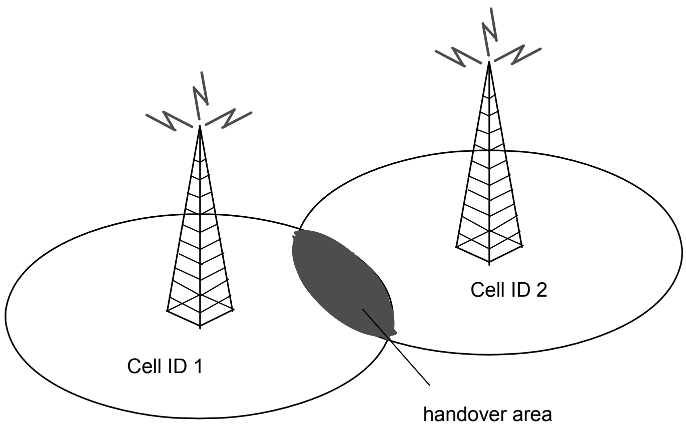

Fig. 3: Positioning during handover event (Czommer at al. 2006)

The next possibility to position mobile phones is the handover event. This occurs, if a mobile phone switches from one BTS to the next one due to low quality communication e.g.

indicated by a low RXLEV value. The advantage of this method is the availability of two cell IDs in the moment of handover, thus defining the borderline of the two cells as position. The restriction is that this increased accuracy is not available all the time. Again the accuracy depends on the size of the cell areas. Figure 3 presents an exemplary geometry for a handover event. The same principle may be used, if a mobile switches from one LA to the next one. In this case the accuracy is decreased, because the LAs are larger than the cells. For the new LA the respective cell ID is delivered too, thus compensating the decrease of accuracy partly.

GSM system intrinsic measurement quantities are the TA-value, and RXLEV values for the measurement of the signal strength at the MS with respect to the serving BTS and up to six neighboring BTS (compare 2.2). Both may be converted into distances that may be used for positioning using arc sections. In general this method is called Time-of-Arrival (TOA). Due to the fact that more than three distances are available the solution is not unique and may be solved by e.g. least square adjustment. If the position may be determined intentionally by the user or with respect to the user, an adequate number of TA values or even run-time measurements may be generated allowing a more accurate positioning. In this case the positional accuracy may reach approximately 500 m for a 2D position according to Heinrichs & Eissfeller (2002) respectively 50 to 300 m according to Wunnava et al. (2007). For arc sections determined by RXLEV-values the position is determined with an accuracy of 800 to 1000 m (see e.g. Ramm et al. 2006).

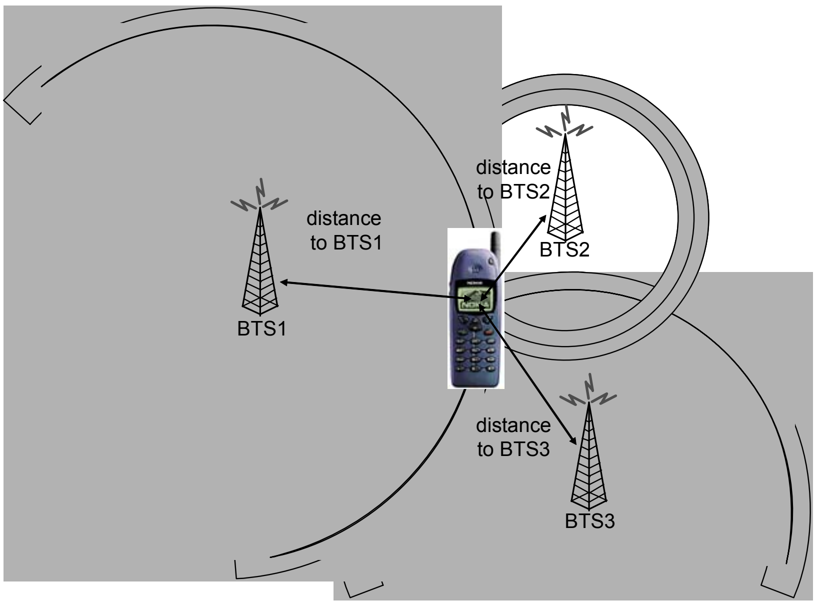

Fig. 4: Time-of-Arrival – arc section (Ramm at al. 2006)

Due to the fact that distances derived from TA or RXLEV values are of low accuracy, but the decrease in accuracy is similar to different distances, one may use distance differences, by the way eliminating the clock error of the MS. The geometric method used is called hyperbola section well known from other positioning applications like e.g. Loran C (Heinrichs & Eissfeller 2001). In the context of mobile phone positioning one talks about Time-Difference-of-Arrival (TDOA). To get an increase in accuracy the BTS used for differencing have to be synchronized precisely using so-called Local Measurement Units (LMU). In this case the method is called Enhanced Observed Time Difference (EOTD), whereby EOTD may be seen as acronym to TDOA. The method may be realised handset-based or handset-assisted. The first measures the TA values and determines the position at the MS, the latter evacuates the positioning task to the GSM network. This is not realized in most of the GSM networks. The position accuracy determined at the MS may reach approximately 500 m for a 2D position too (Heinrichs & Eissfeller 2002).

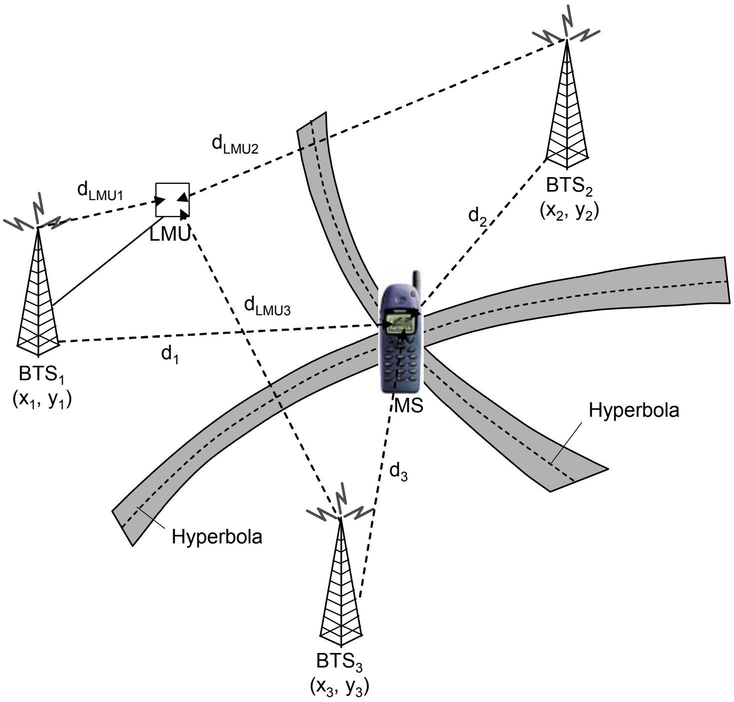

Fig. 5: Time-Difference-of-Arrival – hyperbola section (Czommer at al. 2006)

If the antenna of a BTS is equipped with a two-antenna-array, the angle of attack of the propagated wave may be determined following figure 6, if the positions of the two antennas are known:

$$\cos(100 - \delta) = \frac{c \cdot dt}{d}$$

with

c – velocity of light

d – known coordinate difference between antennas

δ – angle of attack

dt – measured time difference between antannas

The geodetic solution of the problem is the use of angles of attack from minimum two BTS to solve for an intersection. This method is called Angle-of-Arrival (AOA). Figure 6 presents the geometry of an intersection. The required angles α and β may be calculated without problems using the respective angles of attack. If more than two BTS are available adjustment methods may be used again. Synchronisation and two-antenna-arrays are required for this method leading to its rare use. The accuracy corresponds to the methods described before. Wunnava (2007) presents accuracy values of 50 to 200 m.

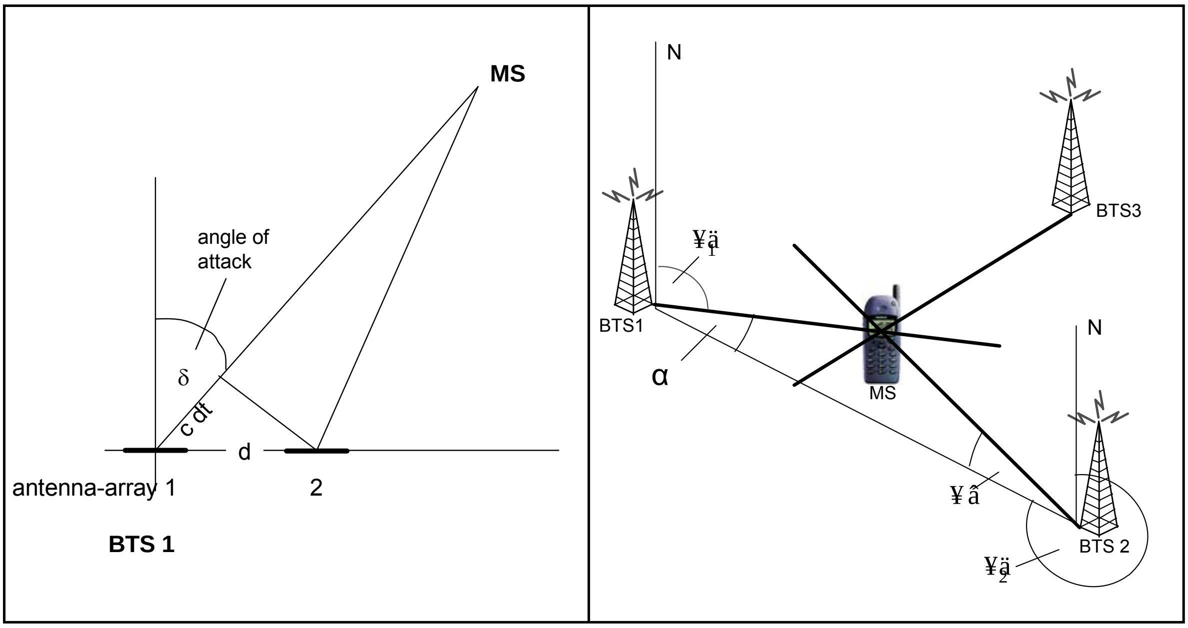

Fig. 6: Angle-of-Arrival – angle of attack and intersection

The last method that should be mentioned within this paper is the signal strength matching method. It is called multipath matching or pattern matching too. Here the measured signal strengths to up to seven BTS is compared to reference data. The reference data may be given through calibration measurements using mobile phones or special measurement equipment. This possibility is time and cost intensive and the matching result still depends on current environmental issues. An alternative is the use of signal strength maps that are available in a given raster for planning purpose of the network provider. The positioning task is solved via least-square adjustment again (e.g. Hellebrandt et al. 1997, Ramm & Schwieger 2007). For further details it is referred to chapter 4.

3.2 Focus on Net-based Methods

As elaborated in 3.1 not all of the methods may be executed, if net-based anonymous positioning methods are the only ones that may be used e.g. in case of mass acquisition of mobile phone data for traffic state acquisition. Therefore only methods that use GSM intrinsic information could be used. For this reason AOA and ADOA including all enhancing possibilities have to be excluded. Now we must distinguish between data acquisition using the A- and the Abis-interface. Using the A-interface LA updates are available only, if no communication is realized. In the case of communication the handover information is generated additionally leading to a higher resolution of positioning areas as shown in figure 3.

During communication additionally on the Abis-interface RXLEV and TA-value measured to the serving cell, as well as RXLEV-values measured to up to six neighbouring cells are available enabling arc section as well as signal strength matching. Table 2 summarises the different positioning methods and their dependences on the status of the MS (active communication or no communication = passive) as well as the availability regarding the interfaces.

Tab. 2: Availability of net-based positioning methods

measurement	mobile station	interface	positioning method
Location Area Update	passive	A / Abis	location area update
Handover	active	A / Abis	handover area
Cell ID	active	Abis	cell global identity
TA-value	active	Abis	arc section
RXLEV-values	active	Abis	arc section / signal strength matching

4. EXEMPLARY REALISATION FOR TRAFFIC APPLICATION

4.1 Project and Procedure

The following positioning method and the measurements carried through are realised within the project Do-iT (Datenoptimierung für integrierte Telematik) granted by the German ministry of economics and technology. The project deals with traffic state application and forecast using the information of active mobile phone users. The participants of the project as well as the background is described more in detail e.g. in Fastenrath 2007. An overview with respect to the positioning tasks and the identification of active traffic participants may be found e.g. in Wiltschko et al. 2006.

Within the project the A-interface and the Abis-interface will be used for data acquisition. Currently the Abis-interface is used for positioning only due to logistical reasons. Since active communication meaning calls generated from the MS let expect an increased accuracy, only these data is taken into account. Considering chapters 2 and 3 the TA-value to the serving cell, and the RXLEV-values to the serving cell and up to six neighbouring cells are available for the positioning task every 0.5 seconds. Consequently arc section as well as signal strength matching are possible for positioning. In Schwieger et al. 2007 the two approaches as well as the results are presented. This paper is restricted to the signal strength matching approach, since it is superior with respect to arc section approach (compare Schwieger et al. 2007).

4.2 Realisation and First Results

At the first stage of the project Do-iT the net-based positioning approach was simulated by acquiring the respective positioning relevant data at a computer connected to the mobile phone, and at the same time to a GPS receiver to evaluate the positioning results. The evaluation of the measurements was reported in Ramm et al. 2006. In a next step the data was acquired at the mobile phone and via the GSM network at the same time. It could be shown that the two data sources are identical for the same point of time. The net-based sampling rate is 0.5 seconds, against what the sampling-rate at the MS was 2 seconds due to logistical reasons. The results presented in the following are based on the data acquired through the GSM net, so real net-based positioning is realised. For evaluation the GPS data are available again. Since some problems during the data acquisition have occurred, only four test drives are at our disposal. The results and the detailed evaluation is described in Ramm & Schwieger 2007 and Schwieger et al. 2007. Here we present the positioning solution based on signal strength matching (RX-matching) as well as a filter approach using a moving average filter in figure 8 and a Kalman filter approach in figure 9. We restrict the presentation to one test drive. The results are similar to ones of the other test drives. In both figures the mobile phone positions respectively trajectories are compared to the GPS trajectories. The RMS of the mobile phone positioning with respect to the GPS trajectory is between 300 and 400 m for the adjusted RX-matched positions and below 300 m for the two filtered solutions. The Kalman filter result is slightly better (see Schwieger et al. 2007).

The figures show that the processing taking into account the moving character of the MS obviously improves the positioning results. Further investigations are required with regard to the algorithms as well as to the reference to the digital road map not discussed within this paper. One further challenge is the realtime capability of the traffic state acquisition, respectively a faster processing for the future.

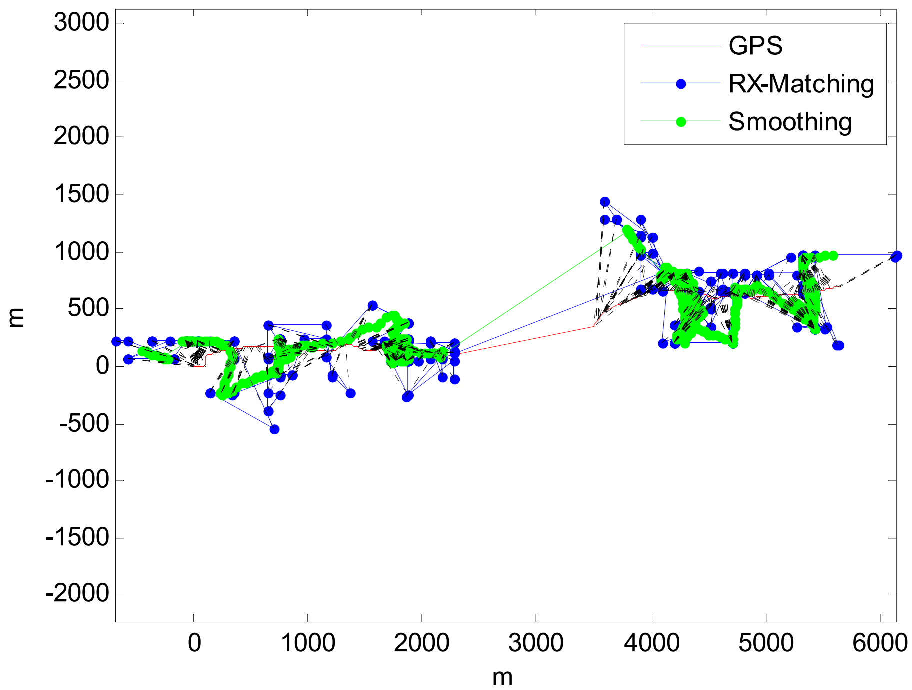

Fig. 8: RX-matching, moving-average filter (smoothing), GPS reference (Schwieger et al. 2007)

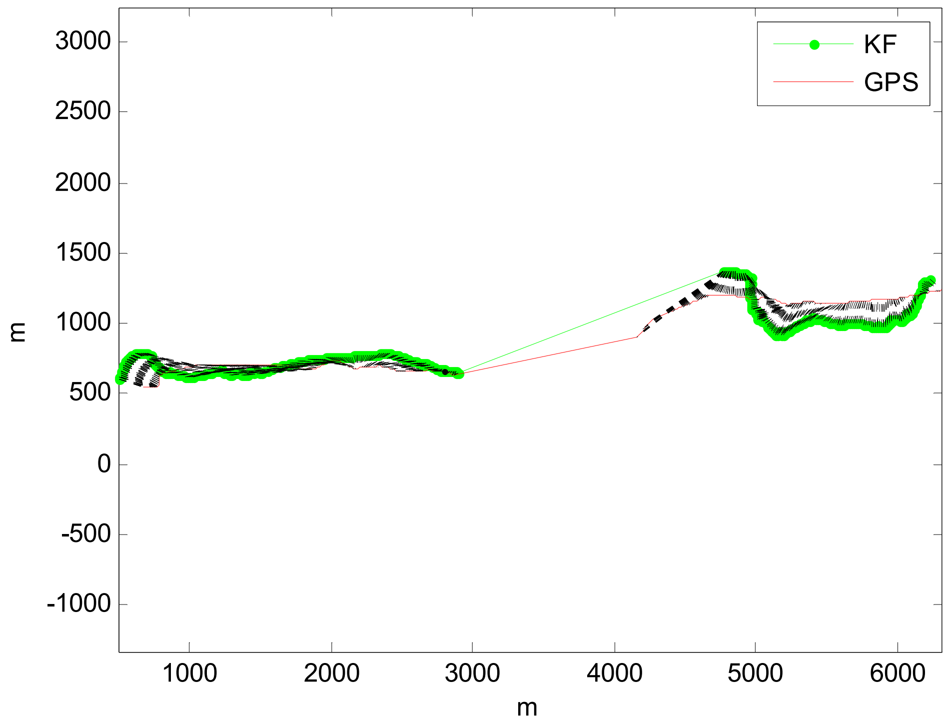

Fig. 9: RX-matching Kalman filter (KF), GPS reference (Schwieger et al. 2007)

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