SATELLITE POSITIONING AS THE FOUNDATION OF LBS DEVELOPMENT

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Location-based services (LBS) form the group of particularly advantageous telecommunications services. Installation of proper positioning process is mandatory first step in any LBS development. After years spent in comprehensive research and analysis, satellite positioning systems emerged as the most promising candidate for LBS-related positioning system development. In this lecture, we examine positioning performance of both basic and advanced satellite positioning systems with the aim to reveal difficulties and discuss solutions to the problem of satellite positioning implementation as the foundation of LBS development.

After brief introduction to satellite positioning, and existing LBS requirements for positioning performance, the influence of both basic and augmented satellite positioning on the LBS development will be addressed. Several assisted satellite positioning methods will be analysed, that improve the positioning performance in targeted environments particularly specific for the LBS. Finally, several topics related to integration between satellite positioning and telecommunications network will be presented. All topics will be supported with comprehensive list of references, most of them freely available on the Internet.

After presentation, a number of particularities are to be discussed, including:

- *positioning performance for LBS;*
- *environmental issues in effect of positioning performance;*
- *choosing the approach in assisted satellite positioning;*
- *distributed positioning;*
- *integration with telecommunications systems.*

1. INTRODUCTION. Location-based services (LBS) are among the most prosperous telecommunications services expected for implementation in the nearest future. LBS are based on the well-known human need to be connected with surrounding environment in intelligent way, which will allow orientation and navigation. So far, location awareness has been more or less hidden in other telecommunication services. However, recent studies have shown an important business case in exploring location awareness and that fact has started a huge activity in LBS development.

Crucial step in any LBS development is deployment of proper positioning service. Accurate, reliable and confident positioning process forms a foundation on which diverse location-based services are or will be developed. However, lack of proper positioning process cannot provide successful LBS with appropriate quality of service (QoS). While the QoS clearly establish feasibility of the LBS, it relies upon the proper positioning performance provided by positioning service deployed.

In this lecture, we discuss satellite positioning and its applicability as the foundation for LBS development. It will be shown that only satellite positioning could provide basis for this foundation and it still needs a proper augmentation in order to reach proposed requirements. After brief review of LBS requirements for positioning performance, a comprehensive description of basic satellite positioning process will be given. Advanced satellite positioning methods will be discussed in order to increase satellite positioning performance towards LBS requirements. Finally, the capabilities of telecommunications networks in increasing the LBS positioning performance will be discussed, with particular emphasis given to integration topics.

2. LBS POSITIONING PERFORMANCE REQUIREMENTS. Location-based services are telecommunication services that explore and contribute to the location awareness. In order to explore the added value of location awareness, LBS should rely on proper identification of position of all objects involved in the service: users, and related moving and static objects. At the same time, being telecommunications services, LBS should provide the appropriate quality of service (QoS). This means that service should provide a set of guarantees for both the content delivered and the way for content delivery. The LBS user should be offered a certain level of confidence in service and this quality is the criterion for (business) success of the service.

LBS QoS is firmly based on the appropriate positioning performance. Location service must be supported by proper positioning method, providing a certain level of confidence in position obtained. While exactly this position constitutes the foundation of LBS, LBS QoS can be established only in case of deploying the positioning method with suitable positioning performance.

Through the history of LBS development, different positioning methods were proposed and LBS positioning requirements were tailored according the positioning performance available on the market. This usually led to unsatisfyingly low-level LBS QoS, which blocked successful business-case development. With increasing popularity of satellite navigation and its intrinsically well-established positioning performance, LBS developers started to explore satellite positioning as the framework for LBS development. In due course, a debate has started in order to establish a proper satellite positioning performance definition for LBS. In our recent work at Ericsson Nikola Tesla, Zagreb, we have identified four main positioning parameters for LBS satellite positioning performance development. Based on that, we have developed a set of case studies and developed hierarchical structure of LBS services with the appropriate positioning performance requirements. Parameter definitions and LBS services structures are presented in **Tables 1** and **2**, respectively.

Parameter	**Definition**
Positioning service availability	Positioning service availability for LBS is defined as a percentage of the telecommunications network coverage area and percentage of the time during which the required number of position signals are provided to the mobile user, allowing him/her to locate the position with certified performance.
Positioning service integrity	Positioning integrity for LBS is the ability of the telecommunication network to detect the temporal inability to provide the position service and inform the users about. It is to be expressed as the time difference between the start of denial of service and the time of sending the appropriate message to the users.
Positioning accuracy	Positioning accuracy for LBS is defined as the largest acceptable horizontal position error, obtained in given percentage of the telecommunications network coverage area and in given percentage of the time.
Continuity of positioning service	Continuity of positioning service is defined as ability to provide two neighbouring position estimates in specified time interval. Although at the first sight it refers to the positioning receiver only, this parameter is usually related to the communication environment (terrain configuration, positioning signal coverage, etc.).

Table 1 Basic positioning performance parameters

Parameter	**Low-level positioning performance**	**Standard-level positioning performance**	**High-level positioning performance**
Positioning service availability	Network coverage area	Network coverage area	Network coverage area
Positioning service integrity	No	On demand (20 s)	Yes (10 s)
Positioning accuracy	> 100 m	30 m – 50 m	< 10 m
Continuity of service	< 10 s	< 10 s	< 10 s

Table 2 Proposal for hierarchy of LBS services and their positioning performance

Using positioning performance definition as summarised in **Table 1**, direct and effective comparison between different positioning methods and procedures is available. Additionally, LBS services hierarchy proposed in **Table 2** enables comprehensive grouping of location services according to their QoS.

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Kitching, I. D. (2000). GPS and Cellular Radio Measurement Integration, *J. of Navigation*, **53**, pp 451-463.
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3. SATELLITE POSITIONING. Basic satellite positioning procedure relies upon reception of straight-line travelling satellites signal and measurement of its travelling time, as shown on **Fig 1**.

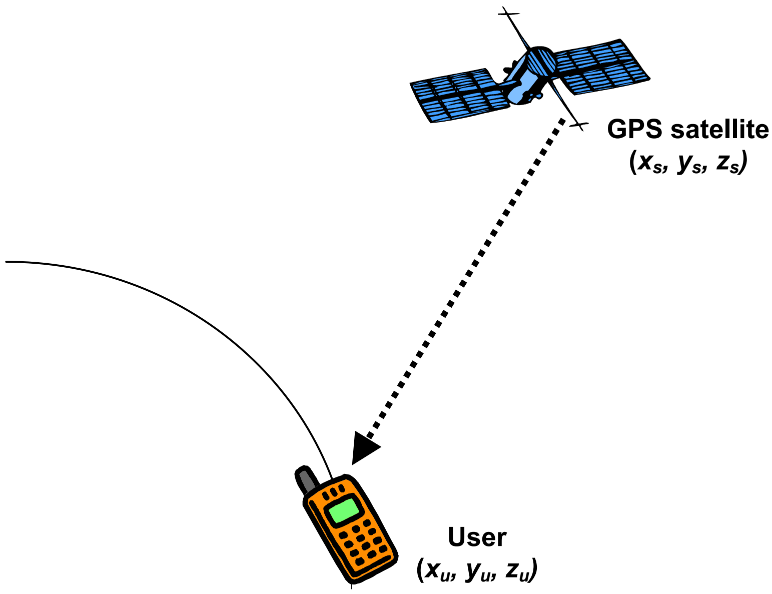

Fig 1 Basic satellite positioning

Although several satellite positioning systems have already been developed or are to be deployed in the nearest future, the US Global Positioning System (GPS) is so far the only one commercially available. In this chapter, the general discussion of satellite positioning system will be often illustrated with actual GPS information.

3.1. Components of satellite positioning system. A satellite positioning system usually consists of four main components:

- space segment
- control segment
- user segment
- propagation media

Space segment consists of a set of positioning satellites put into stable orbit(s) that should provide good signal coverage and ability to precisely determine exact position of every satellite at given instance of time. Satellites broadcast a range of signals that includes positioning signals and navigation message.

GPS satellite constellation currently consists of 28 satellites in six orbital planes, equally spaced (60°) and inclined approx. 55° in respect to the equatorial plane. Satellites are approx. 20180 km above the Earth's sea level. Satellites are usually equipped with micro-motors for small orbit corrections. GPS satellites broadcast complex signals that contain positioning signals and navigation message. There are two GPS positioning signals:

- commercial, transmitted on L1 = 1575.42 MHz carrier and modulated by so-called C/A (Coarse Acquisition) code (for commercial use) – for Standard Positioning Service (SPS)
- military, transmitted both on L1 = 1575.42 and L2 = 1227.60 MHz carriers and modulated by so-called P (Precise) code (for military and authorised users) – for Precise Positioning Service (PPS).

Every satellite transmission is characterised with its own pseudo-random code sequence used for modulation. Every code has its own pseudo-random code number (PRN), which is usually used for differentiation of GPS satellites.

Control segment controls and maintains the system. This segment usually consists of one master control and several monitoring stations. Monitoring stations continuously monitor different parameters of space segment (satellite orbits aberration, malfunctioning, satellite clock bias, etc.) and its environment (space weather

conditions, ionospheric and tropospheric disturbances, etc.) and transfer the observations to the master control station. There, they form the satellite positioning system status. From this status, several correction model parameters are calculated (for instance, to compensate the orbital drift, or error due to increased ionospheric activity) and delivered to users in a form of additional, so-called navigation message transmitted by satellites.
In case of GPS, the master control station is situated at the Schriever Air Force Base, Colorado Springs, with four monitoring stations distributed all over the world (Hawaii in eastern Pacific Ocean, Ascension Island in Atlantic Ocean, Diego Garcia in Indian Ocean, Kwajalein Island in western Pacific Ocean).
User segment consists of suitably designed GPS receiver with appropriately designed aerial and optional equipment (personal computer, DGPS receiver,, etc.) Specially designed processing unit in GPS receiver separates GPS signals from different satellites, and enables measurement of so-called pseudoranges (GPS signal travelling time times the velocity of propagation) using advanced digital signal processing procedures.

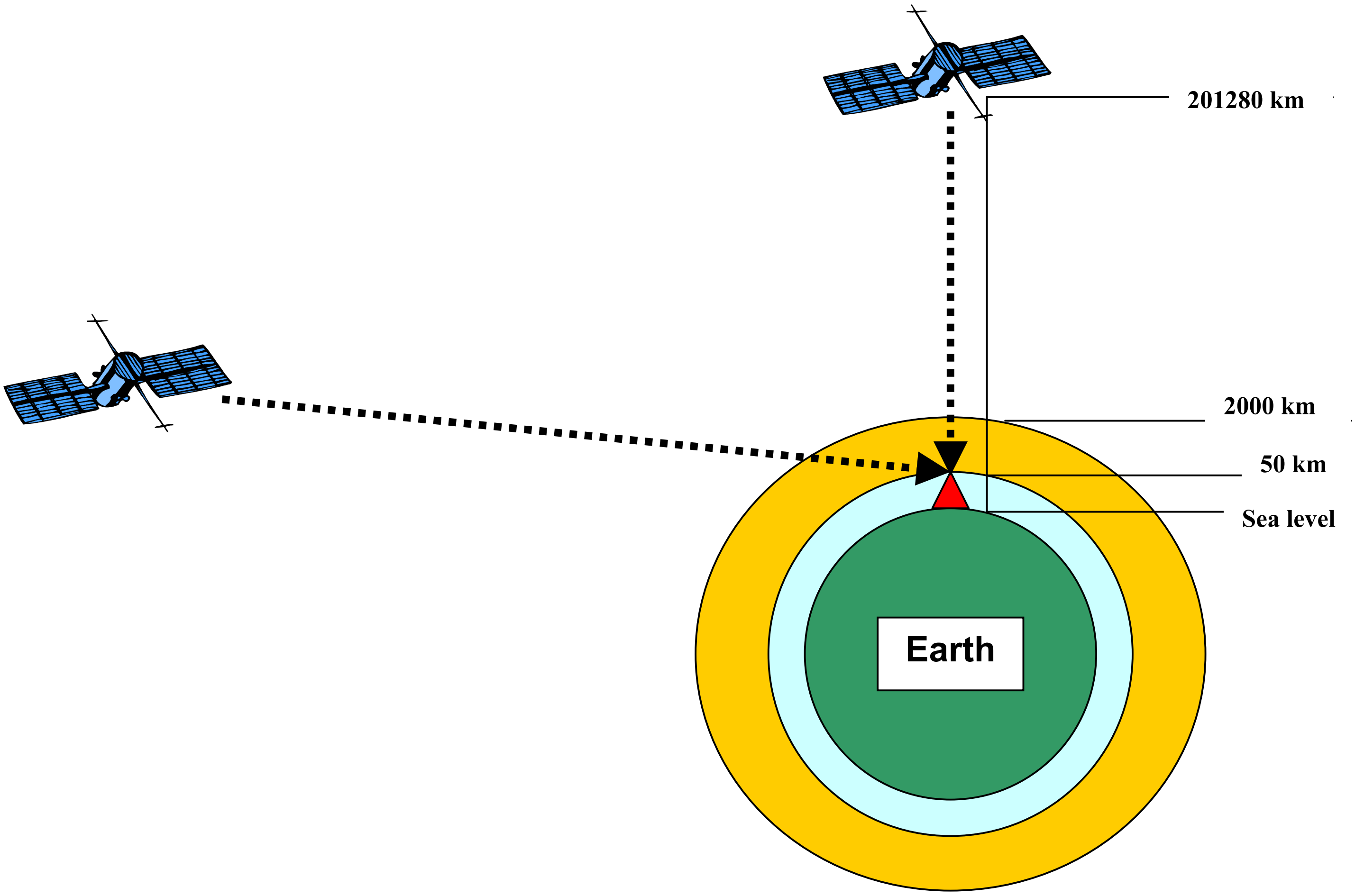

Fig 2 Propagation media impact on satellite positioning performance. Ionospheric and tropospheric influence is considerably amplified by low satellite elevation angle

Propagation media affects the positioning performance of satellite positioning by changing the radio wave propagation velocity. Although satellite positioning signals travel mostly through near-vacuum conditions (as shown on **Fig 2**), ionospheric layers regularly make a significant impact on GPS signal propagation by unexpected and unpredictable changes in ionisation levels and concentration of ionised particles on GPS signal path. The effect is more pronounced by low elevation signals, which path through the ionosphere is up to three times larger then in satellite-in-zenith case. Significant impact is particularly emphasised during the intervals of high solar activity and significantly disturbed space weather. Recent studies show a considerable effect of geomagnetic disturbances on satellite positioning performance. Additionally, non-ionising processes in lower atmosphere affects satellite positioning performance by variable levels of temperature, humidity and atmospheric pressure. However, low atmosphere impact is of greater importance for high precision (geodetic, for instance) satellite positioning.
3.2. Satellite positioning model. Referring to the **Fig 1**, travelled signal path can be expressed both as:

$$\sqrt{(x_s - x_u)^2 + (y_s - y_u)^2 + (z_s - z_u)^2} \tag{1}$$

and:

$$c\,(\Delta t + b), \tag{2}$$

where:

(x_s, y_s, z_s) … satellite position co-ordinates
(x_u, y_u, z_u) … user position co-ordinates (unknown)
c … signal propagation velocity (velocity of light)
Δt … signal propagation time between satellite and user receiver, as measured by user equipment
b … user clock offset (i. e. difference from common system time reference, unknown).
It gives the basic satellite positioning equation:

$$\sqrt{(x_s - x_u)^2 + (y_s - y_u)^2 + (z_s - z_u)^2} = c\,(\Delta t + b) \tag{3}$$

Group of errors	Error sources	Level of impact on positioning accuracy
Space and control segment errors	Orbital drift from calculated position, satellite clock errors, selective availability (SA)	Usually minor. Orbital drifts are well monitored and rather quickly corrected. The same is valid for satellite atomic clocks. President William Clinton ceased SA service (intentional disruption of Standard Positioning Signal accuracy) in 2000.
User segment errors	Multipath, receiver noise	Receiver noise is usually kept very low by using the appropriate satellite positioning receiver. However, multipath can cause considerable problems, particularly in urban areas and for mobile users. Different techniques (specially designed aerials, advanced signal processing, etc.) can be applied in order to mitigate multipath effects.
Propagation media errors	Ionospheric activity, tropospheric disturbances, scintillation effect, ionospheric storms, space weather disturbances, increased solar activity	The most influential satellite positioning error source. In GPS, it is usually fought by correction algorithm included in basic GPS positioning. While this method lower the impact of long-term ionospheric disturbance, single-frequency (L1) users are severely affected by sudden and short-term ionospheric processes.
Dilution of precision (DOP)	Adverse space distribution of positioning satellites around the particular user	Optimal distribution is obtained when points of satellite and user positions form the largest-volume frame. Usually, however, the choice of satellites is very limited by obstruction elements (buildings, bridges, mountains, etc.). The effect is particularly accentuated in urban and mountainous areas.

Table 3 Error sources for basic satellite positioning

In order to find the values of four unknowns (user position co-ordinates and user clock offset), it is necessary to establish the four unknowns-four equations system. System formed in this way represents the basic satellite positioning model, which can be solved by standard mathematical procedures.
As any other measurement procedure, satellite positioning is able to give a more or less correct estimate of user position. Sources of measurement errors affecting the accuracy can be grouped into four main categories, as presented in **Table 3**.
In order to combat the error sources, a number of correction algorithms can be deployed in satellite positioning procedure. GPS deploys the following algorithms within its basic single-frequency (L1) Standard Positioning Service:

- corrected satellite ephemeris
- satellite clock correction model
- Klobuchar's ionospheric correction model.

Basic satellite positioning procedure for obtaining user position estimate is comprehensively presented on **Fig 3**.

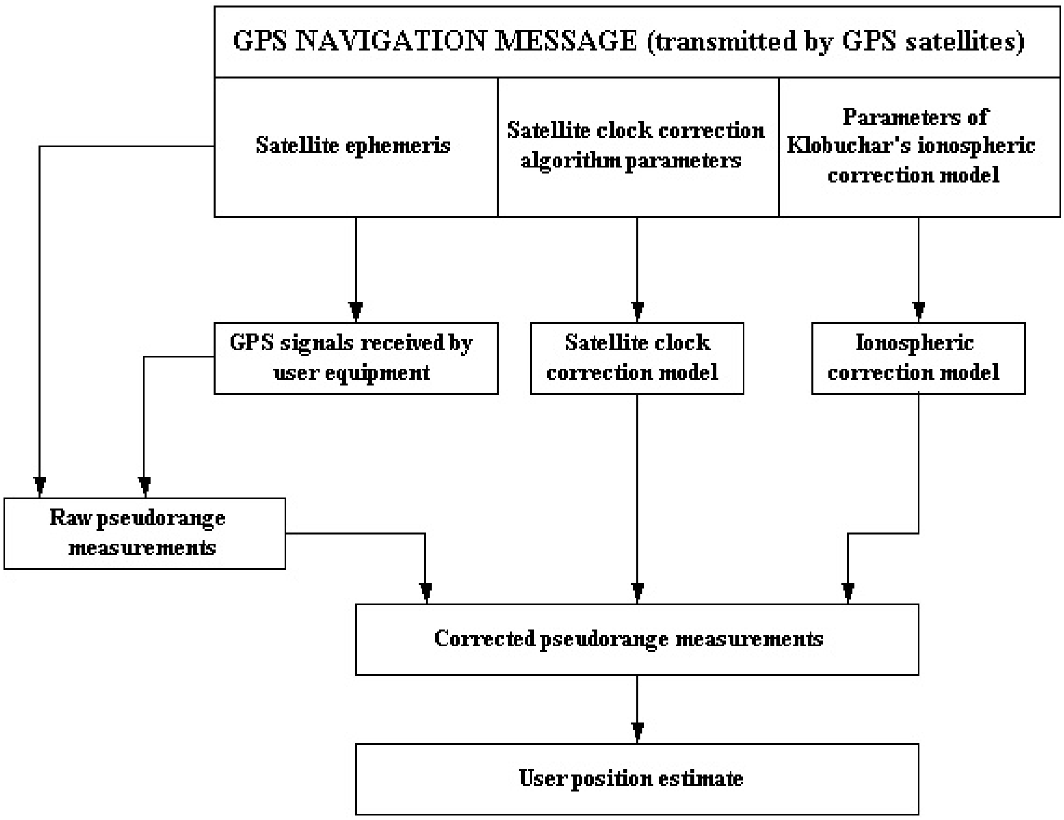

Fig 3 GPS SPS positioning procedure

3.3. GPS positioning performance. GPS is the only fully operational satellite positioning system commercially available at present. While the considerable effort has been made to commercially explore the Russian counterpart called Glonass, lack of reliable financial and operational management deprived Glonass from success. Related commercial develeopment is therefore oriented towards exploration of GPS Standard Positioning Service (SPS).
GPS positioning performance is continuously monitored both by dedicated US agency and numerous users worldwide. Official documents are regularly released in order to inform the users worldwide of GPS positioning performance. Based on these documents, GPS SPS Performance Standard is released, forming the reference for further studies. GPS SPS Performance Standard describes basic GPS positioning process and performance in special case of all theoretically available satellites in view. **Table 4** comprehensively summarises GPS SPS performance in relation to LBS positioning performance requirements (Ch. 2, this paper), with presumption of all theoretically available satellites in view. GPS SPS performance standard deals with the factors under control of the US Government, and those related to space & control segment and propagation media. User segment is not considered and evaluation of positioning accuracy for end user is given only as the estimate. Although the basic GPS service does not meet in full the LBS positioning performance requirements, GPS SPS provides a good foundation for LBS positioning system development.

LBS positioning performance parameter	GPS SPS value (95%)	Compliance with LBS positioning performance requirements
Positioning service availability	At least 6 satellites visible in 95% of time (5 in worst case). Additionally, Position Dilution of Precision (PDOP) maintained below 6 in 95% of time.	Yes, for signals-in-space (SIS) case. No guarantees for particular environment (urban areas, in-doors environment, etc.)
Positioning service integrity	Satellite health information presented in navigation message, but up-dated infrequently.	No
Positioning accuracy	Global horizontal position error for single-frequency (L1) users (95%, conservative estimate): 33 m (signals-in-space position accuracy standard, 95%: 13 m) Global vertical position error for single-frequency (L1) users (95%, conservative estimate): 73 m (signals-in-space position accuracy standard, 95%: 22 m)	In compliance with proposed low- and standard-level LBS services. LBS positioning performance requirements do not specify vertical position accuracy, so far.
Continuity of service	Partly depends on user receiver design, estimate is given based on acquisition time for available products: - warm start (brief loss of GPS signals): 15 s - cold start (with given approx. position): 45 s - auto-locate: up to 5 min	No

Table 4 GPS SPS positioning performance in view of LBS-related requirements, based on (US DoD, 2001)

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4. ADVANCED SATELLITE POSITIONING METHODS. Implementation of satellite positioning systems obviously brings an enormous benefit to any application based on it. However, a designer should bear in mind both advantages and drawbacks of satellite positioning system he/she intends to use. Some of them related to currently available GPS are listed in **Table 5**.

In order to prevail the flaws of GPS SPS service, advanced satellite positioning methods based on GPS are proposed. They act essentially in two separate ways:

- by providing additional positioning signals to sustain positioning performance when GPS signals are prevented to reach the user (augmentation systems)
- by providing positioning-related information when these are not available from GPS SPS service (assisting systems).

Advantages of GPS use	Drawbacks
- service is free of charge to everyone - no maintenance costs both for operators and users - good overall coverage (availability is reduced only at the poles) - recently improved and maintained accuracy (under assumption of all satellites in view) - user satellite receiver available as a chip component (ready for installation in mobile equipment) - standardised means of positioning data interchange between satellite receiver and other microprocessor-based equipment.	- satellite positioning performance is not guaranteed and could be significantly deteriorated in areas densely populated by potential customers of LBS (urban areas, in-doors spaces) - no guarantees regard the system integrity - service is under control of the US Government - continuity of service not guaranteed

Table 5 Advantages and drawbacks of basic GPS implementation in LBS development

Numerous augmentation and assisting systems are developed so far to improve GPS SPS positioning performance locally. A comprehensive review of them is given in this chapter, along with the commentary of their practical implementation in LBS development.

4.1. Differential satellite positioning. Differential satellite positioning has been introduced in order to improve positioning accuracy, under proven presumption that positioning errors stay nearly constant for two nearby satellite receivers. In that case, one receiver can measure the positioning error(s) very precisely, and then transmit their values as corrections to all satellite positioning users in local area, as shown on **Fig 4**. Usually, positioning errors are expressed in terms of error time delay for every satellite in vicinity of differential satellite positioning station. Measured positioning errors for every satellite (i.e., positioning corrections) can be then transmitted to the users in local areas. In case of GPS, a variety of systems are used, including:

- LF and MF radio beacons
- Radio data system (RDS)
- Internet.

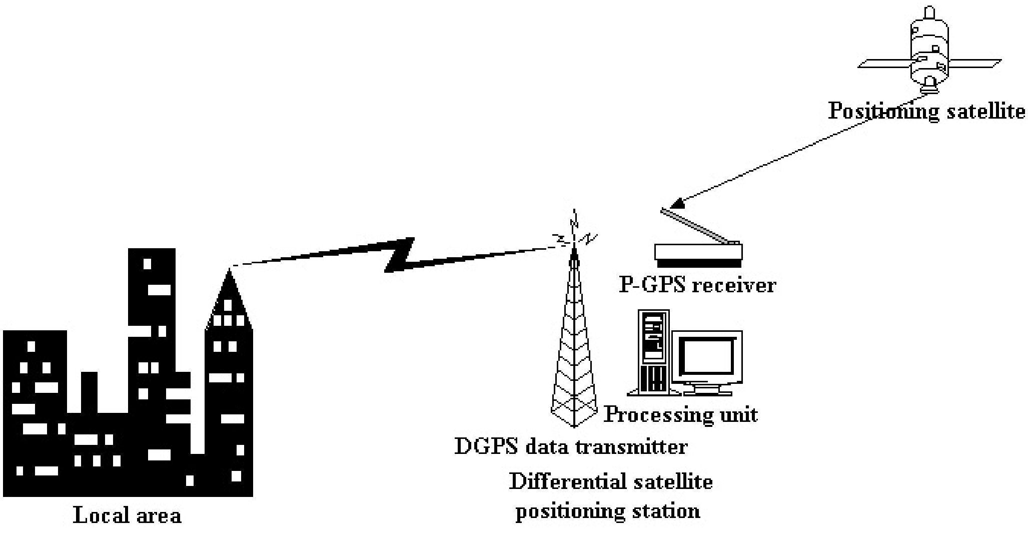

Fig 4 Differential satellite positioning

Users should be equipped with additional piece of hardware (DGPS receiver and aerial).

Differential GPS service is usually provided by dedicated governmental agency. In special cases, private companies can act as service providers on behalf of the government. Subscription is usually mandatory. Although differential satellite positioning offers additional communications channel for submission information missing in GPS SPS (integrity data, for instance), this method does not increase satellite positioning performance in relation to LBS requirements.

4.2. Integration with terrestrial navigation systems. Integrated systems consisting of satellite positioning and terrestrial navigation systems (such as Loran C) have gained considerable attraction among the positioning-related application developers. Loran C is recently modernised, and the chains in Northern and Western Europe (NELS) provide rather good navigation performance. Applications of GPS-Loran C integrated systems gain popularity in marine navigation and even among telematics developers. However, Loran C receivers are still unsuitably large to be included as chip components in rovers to support LBS. Recent projects aimed to develop GPS/Integration Navigation System (INS) synergy present significant improvement in positioning accuracy and continuity of service. However, these improvements do not contribute considerably to satisfying LBS positioning performance requirements.

4.3. EGNOS. European Geostationary Navigation Overlay Service (EGNOS) is joint project of European Commission (EC), European Space Agency (ESA) and the European Organisation for the Safety of Air Navigation (EUROCONTROL). The aim of the project is to establish necessary augmentation of the basic satellite positioning system (GPS and Glonass) as to obtain the improved accuracy and so far unavailable integrity features in Europe and in neighbouring areas. These are to be provided by additional GPS-like satellite positioning signals from three independent satellites in geostationary orbit, and the network of control and monitoring stations. So far, EGNOS capability is deployed on two Inmarsat-3 satellites:

- Inmarsat AOR-E (Atlantic Ocean Region – East), PRN = 120
- Inmarsat IOR (Indian Ocean Region), PRN = 131

It is expected that regular transmissions from the third EGNOS satellite (ESA Artemis satellite, orbiting above Africa) will start in Autumn 2003. Full constellation is to be fully operational in 2004.

EGNOS system test-bed (ESTB) is established as the polygon for EGNOS positioning performance validation and an opportunity for developers to evaluate their applications in relation to the EGNOS deployment. In last three years, ESTB has presented remarkable results in basic satellite positioning performance improvement by providing redundant (additional) satellite positioning signals, more accurate ionospheric corrections (suited for local European environment) and system integrity information. Major flaw of the system is caused by usage of geostationary satellites. All over the Europe, elevation angles of geostationary satellites are usually rather low. This raises the probability for satellite visibility obstructon by local environment (buildings, bridges, mountains). In order to combat the problem, ESA recently offers the possibility to access EGNOS Signal In Space signals over the Internet using so-called SISNet (Signal In Space over Internet) technology. Using SISNet, EGNOS user does not need the clear radio path to satellites at all because the EGNOS signals (and data) are transmitted in real time, so the only requirement is to establish a reliable Internet connection. SISNeT should be considered an assisting system atop an augmented positioning system.

EGNOS/ESTB/SISNeT is not the only augmentation system deployed or developed so far. In the US, a similar system called Wide Area Augmentation System (WAAS). Local Area Augmentation System (LAAS) is currently under development and scheduled to be operational in 2004 in the US, too. Similar systems are under development in other parts of the world, aiming to provide the positioning performance improvement in local area (Japan, India).

4.4 Galileo. A unique satellite navigation system is under development in Europe, aimed to provide navigation (not only positioning) service independent of, but compatible with the existing GPS. The main idea in Galileo development has been to offer independent navigation system controlled not by military but by civil community. With similarities in design, Galileo is to provide better positioning performance and a variety of services for its users. In its full maturity, Galileo is to deploy 30 satellites (27 operational and three spare) in the orbits slightly higher (23 616 km) than GPS, in order to assure larger number of visible satellites. Compared to GPS, Galileo is to provide a complex set of navigation signals and information, with a wide range of availability (some services will be free of charge, some of them available for subscribers, and the rest available for authorised users only). Different levels of integrity-related services will be offered, providing enormous improvement. Positioning accuracy will be improved by advanced signal processing methods and application of customer-shaped correction models.

Along with its technical excellence, Galileo is to provide a unique business model for development and modernisation of the system. Compared with GPS, who is completely developed and owned by the US government, private companies are invited to participate in development and control of the system (by taking part in technical developments and financial support of deployment and maintenance).

4.5 Global Satellite Navigation System. In its full deployment, Galileo is to provide additional 30 positioning satellites to already existing 28 deployed in GPS. Considering their interoperability, many developers suggest integration of the two systems in one, called Global Satellite Navigation System (GNSS). Indeed, under presumption of continued maintenance of both GPS and Galileo, there is no lot work left in development of GNSS. Actually, technical compatibility will be attained with sole implementation of Galileo. However, the ownership and control of the system will remain the crucial issues in practical realisation of GNSS.

Many authors prefer to look at GPS's augmentation by EGNOS as the first phase of GNSS development (GNSS-1). In due course, integration of GPS and Galileo in one system will mark the second phase of GNSS (GNSS-2).

Reference:

General:
Filjar, R., Dešić, S., Huljenić, D. (2002). Distributed Positioning: A Network-supported Method for Satellite Positioning Performance Improvement. *J. of Navigation,* **55**, pp 477-484.
EGNOS:
ESA EGNOS web-site at: http://www.esa.int/export/esaSA/GGG63950NDC_navigation_0.html
ESA EGNOS System Test-bed (ESTB) web-site at: http://www.esa.int/export/esaEG/estb.html
ESA Signal-In-Space through the Internet (SISNET) web-site at: http://esamultimedia.esa.int/docs/egnos/estb/sisnet/sisnet.htm
Galileo:
European Commission Galileo web-site at: http://europa.eu.int/comm/dgs/energy_transport/galileo/partners/private_infoday_en.htm
Galilean Network web-site at: http://www.galilean-network.org/
ESA Galileo web-site at: http://www.esa.int/export/esaSA/GGGMX650NDC_navigation_0.html
Loran C:
International Loran Association web-site at: http://www.loran.org
Northwest European Loran-C Syste web-site at: http://www.nels.org/
EuroFix Internet Pages at: http://www.eurofix.tudelft.nl/indexnopictures.htm

5. ROLE OF TELECOMMUNICATIONS NETWORK IN SATELLITE POSITIONING PERFORMANCE IMPROVEMENT. Telecommunications industry is an interested party in location awareness exploration. Location awareness is inherited in telecommunications as the part of both the system and services. With the advent of mobile communications system, location awareness emerges as the one of few pillars of future development. Optimising the network resources without location awareness becomes almost impossible task. With implemented location awareness, telecommunications industry is able to offer a huge set of attractive and potentially very profitable services. It should not surprise anyone that telecommunications industry has thoroughly investigated implementation of location awareness for some time. In this chapter, achievements in implementation of positioning methods in mobile communications networks are presented and several promising strategies in satellite positioning performance improvement examined.

5.1 Network-supported positioning methods. Telecommunications industry started exploring the field with deploying the existing resources. Several features, already incorporated in mobile communications networks, were used to develop a set of signals generated in network. As the result, network-supported positioning methods were developed, with the most advanced of them briefly outlined below.

Cell global identity(CGI) method is the simplest network-based positioning method. It is based on presumed limited coverage of particular base station (BS; base station is the equipment through which rover connects to the mobile communications network). In that case, rover position is approximated by BS position, which is known exactly. Positioning error is equal to distance between rover and the BS. Although particularly densely distributed in urban areas (giving estimated rover position error of about 100 m), BS is usually deployed with larger area of coverage, and positioning error can reach up to 35 km.

Time of arrival (TOA) method is a simple method for mobile positioning purposes, based on measurement of positioning signal's propagation time between rover and at least three base stations. Every measurement determines one circle around the observed BS as the set of possible rover positions. Exact rover position is obtained as the intersection point of three independent measurements.

Observed time difference (OTD) method is based on differential measurement of observed time difference between arrivals of bursts of nearby pairs of base stations. At least three base station pairs should be used in order to avoid measurement uncertainty and estimate the ranging error. Although the method yields rather acceptable accuracy (60 m – 200 m), the main flaw of the method is a large number of measurements needed which complicate the positioning algorithm. As this method belongs to so-called terminal based methods group, a large consumption of energy should be taken into account.

Network-supported methods generally yield poor to moderate positioning accuracy. Only in best cases, this accuracy can meet the low-level LBS positioning performance requirements, with other positioning parameters having rather acceptable values. However, one should bear in mind that implementation of network-supported methods requests considerable and targeted changes of hardware and software in either rover, network or both of them.

5.2 Satellite positioning methods and mobile communications networks. After the years of research, it became evident that network-supported methods cannot beat satellite positioning if positioning accuracy is considered, despite the fact that other positioning parameters' values presented in some cases even better results than in satellite positioning. Telecommunications network developers have taken a different approach, making network-supported methods available for interested customers, but shifting the focus towards integration of satellite positioning methods in mobile communications networks. Most recent specifications (those related to 3G/UMTS – listed at the end of the chapter) accept satellite positioning as the foundation for future development in location awareness exploration. Moreover, an active role in support to satellite positioning by mobile communications network is examined and several strategies developed, some of them described in the rest of this chapter. In general, mobile communications networks are capable of providing both assistance and augmentation to satellite positioning method inherited in LBS.

5.3 LBS architecture in mobile communications systems. The first step in both satellite positioning assistance/augmentation and LBS implementation in mobile communications network involves determination of LBS architecture in mobile communications systems. The general outlook is presented on **Fig 5**.

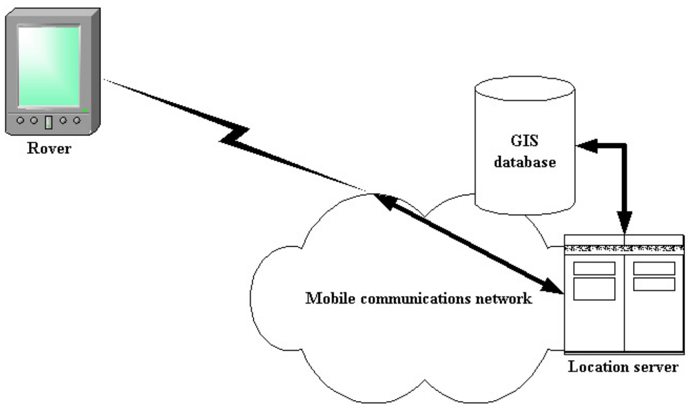

Fig 5 General LBS architecture

Location-based services are usually designed as client-server applications. Mobile communications network provides dedicated path for information exchange between rover (client) and location server. GIS database stores all location-related information, both static (location of buildings, roads, etc.) and dynamic (motorway traffic information, for example). Location server and GIS database are usually a part of mobile communications network. This approach assures more accurate, reliable and faster information exchange, based on usage of dedicated signalling protocols.

Position estimate calculations could be done either on the rover or on location server, being called terminal-based and server based position estimation, respectively. While terminal-based position estimation decreases server load, it causes additional rover energy consumption, which is particularly critical for mobile users. On the other side, a large number of users can overload the server if complete position estimate process is to be performed on location server.

5.4 Strategies for satellite positioning performance improvement have been developed in order:

- to assist satellite positioning
- to augment satellite positioning

both by appropriate involvement of telecommunications (mobile communications) networks. Most promising strategies will be discussed below.

5.4.1 Exploring existing resources. 3GPP specifications declare usage of satellite positioning in different 3G/UMTS features. Protocols for data exchange are well defined, even for advanced positioning methods, like A-GPS. An example of possible solution for A-GPS data exchange is presented on **Fig 6**. Implementation of advanced positioning methods necessarily raises mobile communications network traffic and location server load. However, both levels of traffic and location server load are still pretty low due to exchange of rather small data packages.

5.4.2 Assisted GNSS (A-GNSS) concept is a unique approach in augmentation satellite positioning system. The main idea of A-GNSS is to use all available signals that can be used for positioning in order to sustain the required positioning performance. Possible sources of additional signals are wireless communications networks and terrestrial navigation systems, as shown on **Fig 7**. Additionally, data processed or generated by location server can be delivered to mobile user using the most appropriate communication link.

A-GNSS substantially differs from A-GPS concept, where only GPS SPS assistance data are to be transmitted to the user by mobile communications network. In A-GNSS, all positioning-related assistance data can be transmitted, including integrity information of all available resources (positioning and communications systems) in user's vicinity. A-GNSS incorporates other positioning systems (including EGNOS and future Galileo), allowing assistance for all satellite positioning systems involved. Utility of terrestrial and satellite communications networks in transmitting positioning-related data (navigation message) greatly improves both availability and integrity of positioning systems. Terrestrial navigation systems (such as Loran C and radio beacons) could be deployed in telematics applications as both redundant navigation systems and communications systems for provision of satellite systems integrity data. At the same time, network-supported positioning methods could be applied as redundant positioning systems in cases of temporal satellite navigation outages. A-GNSS implementation considerably affects the basic satellite positioning procedure, described in chapter 3.2. Impact of the A-GNSS is presented on **Fig 8**, with additional features marked in red.

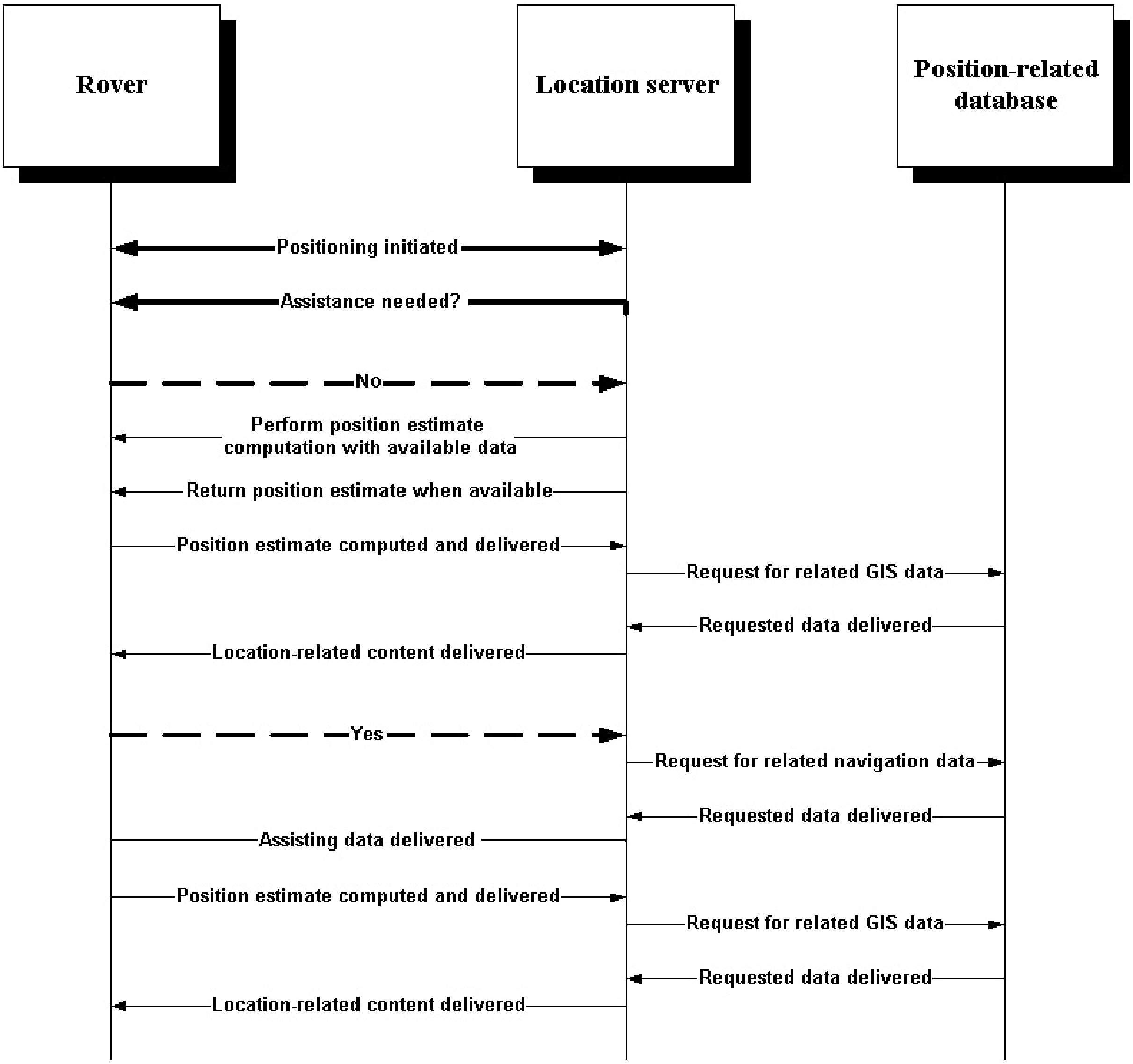

Fig 6 An example of A-GPS data exchange

Implementation of A-GNSS is a challenge for both satellite navigation and telecommunications industry. Most positioning-related data are already available through appropriate interfaces between positioning equipment and personal computers (NMEA-0183, for instance). It is therefore a task for telecommunications developers to include these data into appropriate mobile communications protocols, as has been already done with GPS SPS data.

5.4.3 Distributed positioning concept utilises advanced network computation power in order to achieve positioning performance improvement. The general idea of position estimate computation performed either on rover or location server is changed to position estimate computing to be done on the most appropriate platform. Usually, this means that the position estimation process is distributed over (at least two) machines. Platform selection (rover or location server) is to be based on positioning data availability, having in mind optimisation of data transfer between rover and location server. In case rover has got all necessary data and sufficient amount of energy in its battery, position estimate can be done at rover. Location server could assist with small packets of assisting data, if necessary. On contrary, with critical status of rover battery and/or large amount of navigation data missing, location server can take care of position estimate with rover submitting only essential pseudorange measurement data to the position estimation process. The same can happen when a large amount of processor time at the rover is dedicated to processing other (for instance, multimedia) applications or to processes vital for network contact. In all cases, data transfer between rover and location server is limited to a number of small data packages. Additional increase in traffic will be caused by resource availability data exchange.

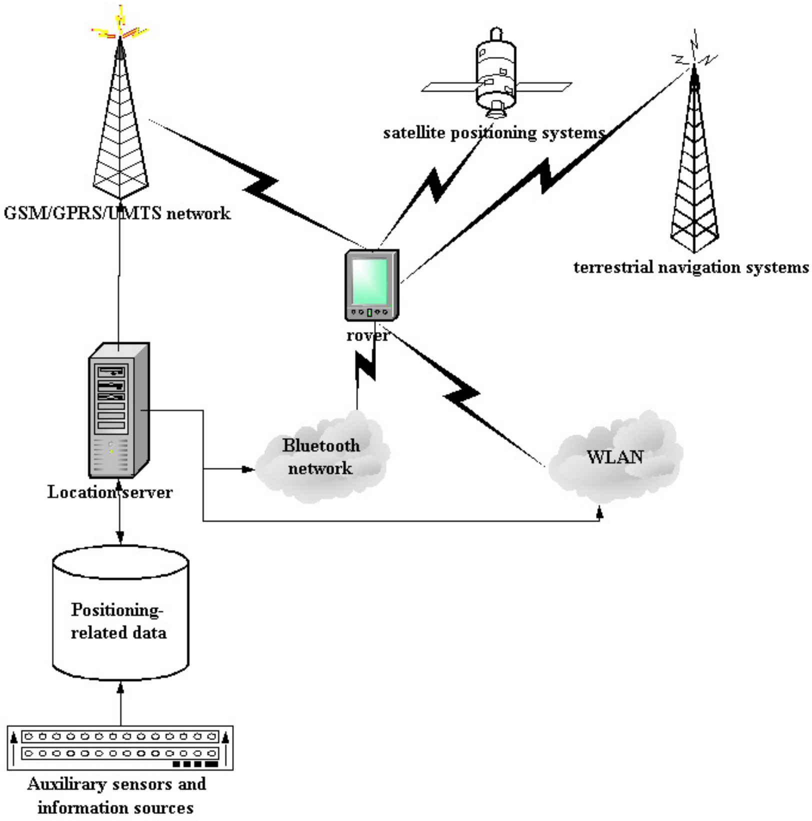

Fig 7 Assisted GNSS concept

Distributed positioning concept does not decline parallel implementation of A-GNSS concept, although it can provide fairly well results with simpler systems (A-GPS, for instance).
5.5 Integration challenges. Synergy between satellite positioning and mobile communications systems can be obtained either on the signalling or on application level.
Integration on signalling level provides better reliability and quality of data transfer. It also requires involvement of telecommunications industry and network operators.
Integration on application level offers more freedom in development. However, data transfer quality and deployment of un-standardised protocols could affect the success of this approach.

Reference:

General:
Filjar, R., Dešić, S., Huljenić, D. (2002). Distributed Positioning: A Network-supported Method for Satellite Positioning Performance Improvement. *J. of Navigation,* **55**, pp 477-484.
Kitching, I. D. (2000). GPS and Cellular Radio Measurement Integration, *J. of Navigation*, **53**, pp 451-463.
Peter Bennet's NMEA-0183 and GPS web-site at: http://vancouver-webpages.com/peter/ (accessed on 24 September, 2003)

LBS technical specifications for mobile communications systems:
3GPP TR 23.835 V1. 0. 0. (2003). 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Location Services (LCS); Study into Applicability of Galileo in LCS, Release 6
3GPP TS 03.71 V8. 7. 0. (2002). 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Digital Cellular Telecommunications System (Phase 2+); Location Services (LCS); (Functional description) – Stage 2, Release 1999

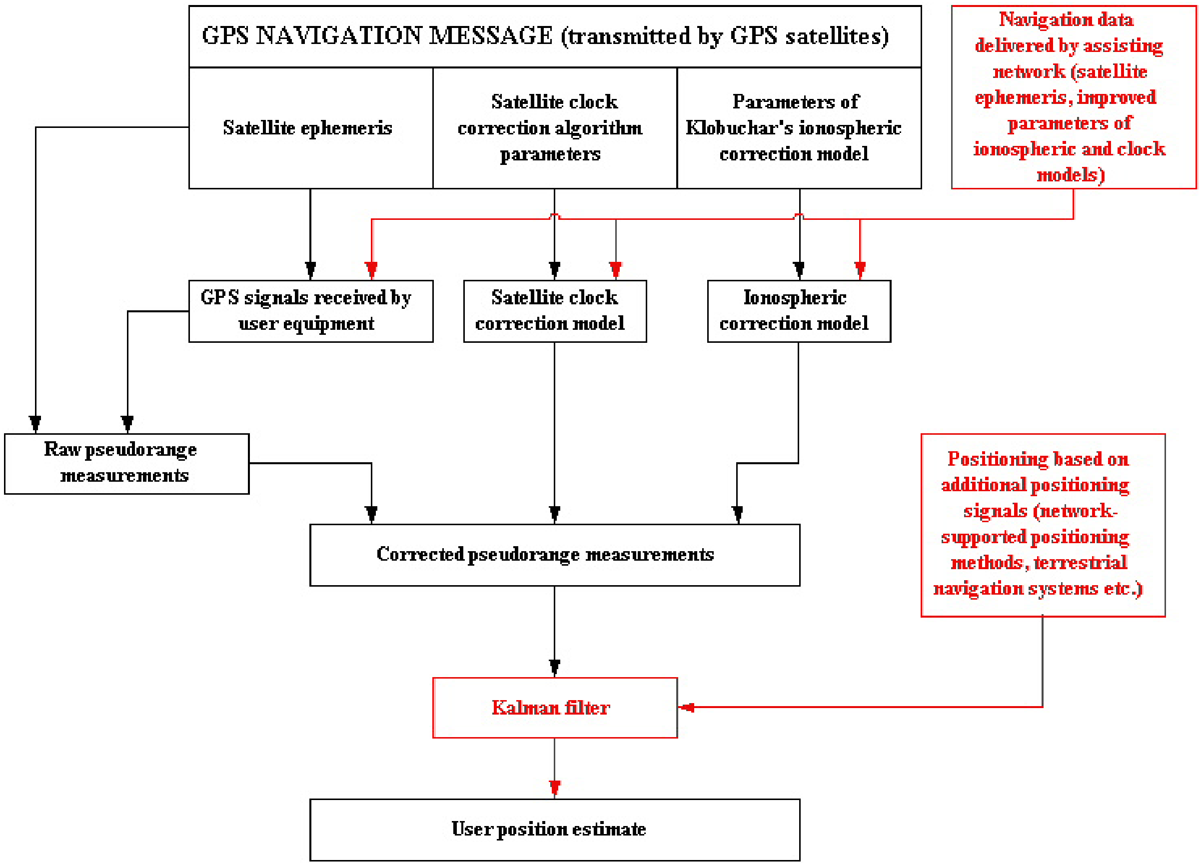

Fig 8 A-GNSS positioning procedure

3GPP TS 25.305 V5. 6. 0. (2003). 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Stage 2 Functional Specification of User Equipment (UE) positioning in UTRAN (Release 5)
3GPP TS 23.171 V3. 10. 0. (2003). 3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; Functional stage 2 aspects of location services in UMTS (Release 1999)
3GPP TS 04.31 V. (2003). 3rd Generation Partnership Project; Technical Specification Group GSM/EDGE Radio Access Network; Location Services (LCS); Mobile Station (MS) – Serving Mobile Location Centre (SMLC) Radio Resource LCS Protocol (RRLP) (Release 1999)
3GPP2 C.S0022-0 V. 1. 0. (1999). Location Services (Positioning Determination Service).
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3GPP2 S.R0019. (2000). Location-based Services System (LBSS).

3GPP specifications are freely available from: http://www.3gpp.org/specs/numbering.htm (accessed on 16 September, 2003)
3GPP2 specifications are available from: http://www.3gpp2.org/Public_html/specs/index.cfm (accessed on 16 September, 2003)

Ericsson Mobile Positioning achievements and documentation (included Mobile Positioning Centre V. 6. 0 available for free download – registration will be needed) can be accessed at: http://www.ericsson.com/mobilityworld/sub/open/technologies/mobile_positioning/index.html.

6. CONCLUSION. This paper attempts to provide a comprehensive view of satellite positioning systems and their importance for LBS development. After thorough examination of potential candidates, satellite positioning has emerged as the most promising basic positioning methods. In order to achieve full compliance with LBS positioning performance, satellite positioning needs assisting and augmentation. A number of solutions have been developed so far, with the most promising presented in this paper. Practice and commercial success will be decisive factors in choosing the best of them. Regardless of final decision for positioning system for LBS, satellite positioning will remain the foundation for every advanced positioning system deployed in LBS development.

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