Application of Positioning Systems in Intelligent Transport Systems

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Abstract

In this paper will be discussed Intelligent Transport System (ITS) and role of positioning systems in ITS. At the present there exist two different positioning systems. The first ones are satellite-based systems and the second ones are terrestrial-based systems. Each system has a different properties. The properties in terms of cost, accuracy and coverage for each of these two systems will be discussed. Then it will be described the main types of these systems and the positioning techniques in mobile networks. In conclusion UMTS and GPS/GNSS will be compared and the benefits of use of UMTS in conjunction with GNSS will be mentioned.

1. INTRODUCTION TO ITS

The problem of Intelligent Transport Systems (ITS) is very huge and solved all around the world. Increasing demands for transport facilities and the need to improve road safety have prompted authorities around the world to place more emphasis on the application of advanced technologies to enhance the operation and safety of all modes of transport. Collectively known as ITS, these technologies are aimed at improving road network performance and enhancing safety and environmental quality through the application of advanced computing, electronics and communications systems.

Many advanced aspects of ITS are not possible without positioning systems. In the context of ITS, positioning systems measure the location of cars, trucks, planes, buses and trains. Examples of positioning systems include Loran, Omega, the Global Positioning System (GPS), radar, sonar, terrestrial vehicle tracking system and dead reckoning (DR) systems. On the other hand, ITS is likely to profoundly influence the development of positioning systems.

All this means that engineers involved in the development of ITS will need to have an understanding of positioning systems and positioning systems experts will need to be familiar with some aspects of ITS.

2. POSITIONG SYSTEMS IN ITS

When used in the context of ITS, positioning systems are almost never stand-alone components. They are normally integrated into a larger system. This larger system will be complex and involve many different subsystems, requiring an understanding of systems engineering and an appreciation of the various components of the system. The ITS subsystems include, for example, the human-machine interface, sensors, communications, control computers and actuators. For example, a *traffic control system* might have the following subsystems:

- Sensor, such as video camera, to detect the presence of vehicles (sensor/positioning system).
- Central control computer.
- Traffic lights (actuators human-machine interface).
- Communications links to take information from the roadway sensors back to the control computer and to take information from the control computer back to the traffic lights.
- An operator interface to the control computer.

Wireless location has received considerable attention over the past few years. Many existing wireless location systems make use of radiolocation techniques. Radiolocation systems can be implemented in one of two ways. With the first approach, the mobile station uses signals transmitted by the base stations to calculate its own position. With the second approach, the base

stations measure the signal transmitted by the mobile station and relay it to a central site of processing. The second approach has the advantage of not requiring any modifications or specialized equipment in the mobile station handset, thus accommodating the large pool of handsets already in use in existing cellular networks.
At the present there exist two positioning systems:

- satellite-based systems (GPS, DGPS, GLONASS, EUTELTRACS, EGNOS, GALILEO)
- terrestrial-based systems (GSM, UMTS, IMT - 2000)

Many of satellite-based systems are used relatively long time and are broadly employed. The advantage of satellite-based systems is their relatively high accuracy and they allow to estimate the position in any place on the Earth surface. The systems are not usable in tunnels, underpasses, in areas with high buildings and very often inside buildings, too. Estimation of position by the radio mobile networks is relatively a new service, which is offered by many providers. The general advantage of this approach is exploitage of existing infrastructure. The other advantage is very high availability of service (it depends on coverage by the radio signal of network) and on the precision of estimate the position sufficed for usual applications in traffic. That service can be also offered in tunnels etc., if providers ensure the coverage in these places. At the present this service is ensured by the GSM network.

2.1. Cost

There are two important dimensions of cost: *infrastructure cost* and the *in-vehicle cost*. Infrastructure costs can be categorized as large and very large and in-vehicle costs in terms of low, medium and high[1]. Here it will be only considered the establishment costs.
Satellite-based systems have very large infrastructure costs because of the spacecraft hardware and the launch costs. These systems have low to medium in-vehicle costs.
Terrestrial-based systems have large infrastructure costs because of the necessity to establish many sites around the area of interest in order to pick up or transmit the signal. The in-vehicle units will be low to medium cost.

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1. In terms of 1997 U.S. dollars, very large infrastructure costs is of the order of billions of dollars, while large cost is of the order of ten to hundreds of millions of dollars. Low in-vehicle cost is of the order of $ 100, medium is of the order of $ 1,000 and high would be counted in tens of thousands of dollars.

2.2. Accuracy

It is difficult to generalize about the accuracy of these systems because the final accuracy of each implementation depends on many factors that are not inherent in the actual choice of technology. For example, the accuracy of a terrestrial-based remote positioning systems depends on the signal power and spectrum allocation. A very narrow bandwidth (30kHz) and low power (100mW) will result in poor accuracy, while a very large bandwidth (10 MHz) and high power level (30W) can result in high accuracy.

2.3. Coverage

Satellite-based positioning systems have the capacity to provide global coverage. In any particular region, there will be some black spots of poor coverage due to signal being occluded by buildings, mountains and other features. An important feature of the coverage pattern for a system that uses nongeostationary satellites is that the location of the black spots will vary as the satellite constellation moves across the sky.
Terrestrial-based systems have potential to provide coverage over a wide area (e.g. a metropolitan area), subject to the cost of installing sufficient base stations. A typical coverage plot for a region serviced by a terrestrial-based systems is similar to that of a satellite-based system. However, in this case, the location of major black spots will not change with time, changing only when a new base station is installed or old base station is relocated.

3. SATELLITE-BASED SYSTEMS

As was mentioned above, there are few types of satellite-based systems, which are used at the present.

3.1. GPS

At the present GPS (**G**lobal **P**ositioning **S**ystem) is the most perfect satellite-based positioning system in the world. The official name of this whole system is GPS NAVSTAR (**Nav**igation **S**ystem for **T**iming **A**nd Ranging). It allows to estimate the position of static and moving objects in any place on the Earth surface by the three-dimensional coordinates (latitude, altitude, longitude). System works 24 hours non-stop in any weather. US Ministry of Defense is its controller and system initially was created for military purposes. One of part its is reserved for military usage and the second part can be utilized for free for any user, who has GPS receiver. System GPS is composed

of 24 satellites orbiting around the Earth about 20,000 km over the Earth surface in 6 orbits.
GPS satellites send the signal, which involves the information about the time and position of the satellite. The signals are transmitted on two frequencies called L1 (1575.42 MHz) and L2 (1227.60 MHz). GPS receiver, on the base of information obtained from the received signal, is able to calculate its position. For estimation of position by the three-dimensional coordinates it is necessary to have signal received from four satellites at least. The accuracy of GPS grows with the number of satellites, which GPS receiver targets.
GPS offers *SPS* (**S**tandard **P**ositioning **S**ervice), which uses frequency L1 and *PPS* (**P**recision **P**ositioning **S**ervice), which uses frequency L2. In the system *SA* approach (**S**elective **A**vailability) was used, which aggravates the accuracy of positioning to 100 m. The SA approach was on 2.5.2000 interrupted and now the achieved accuracy is 25 m. The error of PPS service is under 5 m and the error of SPS is under 25 m.

3.2. DGPS

For many applications the accuracy, guaranteed by SPS service, is not sufficient. Therefore, it was established DGPS (**D**ifferential **GPS**), which enables correction of measuring data. There is a reference receiver, which is placed in the know point at the Earth. Data, which enable correction of measured imaginary ranges, are obtained by comparing measured and actual position of reference position. DGPS receivers can now correct the measuring data and they can estimate the position much precisely. For correcting data transmission mobile radio network can be used. Using DGPS the error can be pressed under 1 m. DGPS receivers are relatively complicated and relatively expansive, too.

3.3. GLONASS

GLONASS (**Glo**baľnaja **Na**vigacionnaja **S**putnikovaja **S**istema) is the positioning system, which is controlled by Russia. The space segment is similar to GPS. The main difference against GPS consists in using two frequencies by satellites, which work with FDMA (**F**requency **D**ivision **M**ultiple **A**ccess) opposite to GPS, which works with CDMA (**C**ode **D**ivision **M**ultiple **A**ccess). In term of accuracy of measurement both systems are similar. At the present GLONASS is using as additive system to GPS (e.g. in air transport). A lots of producers offer receivers, which are able to work with GPS and GLONASS signals, too.

3.4. EUTELTRACS

Euteltracs is an European system, which exploits geostationary satellites Eutelsat. This is an active positioning system allowing estimation of position and it allows mobile communication, too. It is composed of user terminal (dispatcher centre), provider's system controller centre network, earth centre, mobile communication terminals and satellites. The accuracy of this system is about 400 m. System Euteltracs is commercially used for localization of trucks and for communication with them in the whole Europe, in the Mid-East and in the north of Africa.

3.4. EGNOS

EGNOS (**E**uropean **G**eostationary **N**avigation **O**verlay **S**ystem) is a European navigation system. It was developed especially for requirements of air transport, because the accuracy of GPS and GLONASS is not sufficient for these purposes. It can be used in ship, road and railway transport. Working principle is similar to DGPS, but the correcting data are transmitted by specialized satellites. It also offers an additive information about the state of GPS and GLONASS satellites. This solution has enabled considerably increase the availability of this service for more then 99 % (GPS 84 %) and also the accuracy. In the category 1 the horizontally accuracy is 16 m (by GPS with SA is 100 m) and the verticall accuracy is from 4 to 6 m (by GPS with SA is 156 m). In the future this system will exploit the signals from prepared European navigation system GALILEO.

3.5. GALILEO

GALILEO will be a global European navigation satellite-based system, which will be introduced the EU countries together with other states. Its structure is very similar to GPS. System have to be compatible with GPS and with GLONASS. Full traffic is supposed at least in the year 2008. The main parameters are present in the tab 2.

Tab.1.:

Precision of Service	Availability [% of time]	Accuracy [m]	
		Horizontal	Vertical
low	99,5	13	35
standard	99,5	4	8
high	99,5	0,1	0,1

4. TERRESTRIAL-BASED SYSTEMS

Positioning service is relatively a new service in GSM (and in other types of mobile cellular networks). Usually, with GSM, the position is determined by time difference techniques in base stations. In terms of network traffic, it allows to improve the network's parameters, charging vs. position and increase the user's security. Very significant reason is the possibility of realization of transportation systems on the base of this networks.
UMTS evolves from GSM and both systems are predicted to exist in parallel for several years.

4.1. Positioning techniques in mobile networks

Wireless network operators can use any of three solutions to provide the location information demand: radio triangulation; a network-driven GPS-based scheme and a network-assisted or autonomous GPS method. Also hand set CDMA positioning is discussed.
The network-based triangulation method uses three or more receiving sites to monitor a call and compare signal strength, time of arrival and distance or angle of arrival of a signal from a handset. These location techniques are independent from external systems. They are described briefly below.

1. Signal Strength
Radiolocation using signal strength is a well know location method that uses a mathematical model for the relation between the distance and the signal strength. The distance between the mobile station (MS) and base station (BS) can be estimated measuring the signal strength at the BS. The MS lies on a circle around the BS. With two BS, two interception points can be obtained. With a third BS the ambiguity can be solved instantaneously.
For signal-strength-based location systems, the primary source of error is multipath fading and shadowing. Finally, in CDMA cellular systems the MSs are power controlled to combat the near-far effect. TDMA cellular systems use power control to conserve battery power in the MSs. Therefore, for signal-strength-based systems it is necessary for the transmit power of the MSs to be known and controlled with reasonable accuracy.

2. Angle of Arrival (AoA)
Using antenna arrays, the direction where the signal originates from, can be determined. With at least two BSs, an interception point of the two lines can be determined. The drawback of this method is that in the case where there is no LOS (**L**ine **O**f **S**ight) between MS and BS the last reflection of the signal is used for the measurement. Under multipath conditions, which are in general the case, the reflected signals interfere with the LOS signal.
For microcells, the BSs may be placed below rooftop level. Consequently, the BSs will be often surrounded by local scatterers such that the signals arrive at the BSs with a large AOA spread. Thus, while the AOA approach is useful for macrocells, it may be impractical for microcells.

3. Time of Arrival (ToA)
One of the most accurate method based on the network's activity is ToA. That technique is based on the measurement of the time which a signal needs to travel from the BS to the MS. In 2 dimensions the distance MS - BS lies on a circle. The interception of 2 circles results in two possible position solutions. Thus, in order to solve the ambiguity and to eliminate the clock error of the MS at least 3 BSs are necessary. This technique is the same as those used in general for GPS.
The main advantage of this method is high accuracy and the possibility of exploiting all mobile receivers, which are used. But the cost for providers is markedly higher then by the other methods, because it needs to install the LMUs (**L**ocation **M**easurement **U**nit).

4. Time Difference of Arrival (TDoA)
TDoA is a hyperbolic position determination technique. Two BSs measure the time difference of the arrival of the signal from a MS. Possible solutions where the time difference is constant lie on a hyperbola. In order to get an unambiguous position solution at least two hyperbolas, i.e. three BSs are necessary. This technique is also used, e.g. for LORAN-C.

5. Enhanced Observed Time Difference (E-OTD)
This method is based on position calculation directly in the receiver. The signal sent by a BS is received by the MS and by a reference measurement station with known coordinates. The time difference, and therefore the distance, between the BS and the MS is then determined by correlating the two received signals. The distance still contains the clock error of the MS. Performing this operation three times for different BSs solves the clock error and fixes the position of the MS. The necessary data exchange can be performed by means of SMS.
The advantage is high accuracy and the low load in a system, what is important especially in the areas

with dense settlement. Modification of receiver is the main disadvantage. It also seems, that it is an ideal method for high urban territories with a dense network of BSs and built-up area.
An example for realization of E-OTD is the CURSOR system of CPS (**C**ambridge **P**ositioning **S**ystems).

The techniques above have in common that the accuracy depends on the number of measurements and on the geometry of the positions of the MS and BS. If the measurements are redundant, least square techniques can be applied to get a better accuracy. On the other hand, an unfavorable geometry degrades the accuracy. This is e.g. the case if two BS and the MS are in a line so that no intercept points can be calculated (using e.g. ToA technique two concentric circles are obtained or with AoA only one line can be calculated). This is often the case in rural areas along motorways.

The network-driven GPS method places a minimal GPS front end in the handset and lets the wireless infrastructure equipment handle all the calculation and position determinations.

A realization of a hybrid system is e.g. SnapTrack, where the wireless network sends an estimate of the location of the handset to a server. The server informs the handset, which GPS satellites are in its area, and the handset takes a "snapshot" of the GPS signal, calculates its distance from all satellites in view and sends this information back to the server. The server software performs complex error correction and calculates the caller's precise latitude, longitude and altitude. For other location-based applications, the server can send the coordinates to a third-party service provider, a dispatcher or back to the handset..

4.2. Comparison UMTS and GNSS

UMTS will surely be available to a certain extent in buildings and many public underground places (e.g. metro) where positions can at least be determined roughly. The GSM, UMTS/IMT-2000 standard is adopted in over 100 countries. Inside the countries, especially in areas where the population density is high, the GSM/UMTS service is highly available. However in some rural areas, aside from motorways no GSM/UMTS service is available. In some countries network operators are obliged to cover a certain percentage of the population.
The accuracy performance depends mainly on the location where the mobile station is used for a position determination. At locations where less than 4 navigation satellites are in line of sight, no position can be determined if no other supplementary means (e.g. GSM/UMTS techniques) are used. This is the case e.g. inside buildings or inside a car, if the antenna is inside the car. In urban areas the usual multipath environment results from case to case in a position degradation of several 10 m. This is of course rather a general limitation of positioning systems than a problem of the combination with GSM/UMTS. However, the user might expect a good accuracy and availability, quasi independently of his location.
The following tab.2 shows the 67% performance in [m] of the localization techniques described above.

Tab.2:

	GSM	**UMTS**
TDoA/ E-OTD	90...160	5...20 (predicted by “CURSOR”)
AoA	100...200	100...200
ToA	N/A	50...200

No vertical position is available by GSM/UMTS.

UMTS and GPS/GNSS (**G**lobal **N**avigation **S**atellite **S**ystems) are depending on the application as well competing as supplementary systems. UMTS will certainly not reach the accuracy of GPS/GNSS where both systems are available with comparable quality. For reliable position determination, also outside the city centers and for 3-D position determination GPS is necessary.
The positioning capability with UMTS will be sufficient for E-911 requirements in urban areas. The accuracy of GNSS, however, will not be reached due to the low LOS visibility probability.
The great practical advantage of UMTS over GNSS positioning is that UMTS can be received in buildings and in bags. However there are GPS-solutions that also offer this capability.

The benefits of use of UMTS in conjunction with GNSS are:

- the main application, i.e. combination of mobile communication and precise positioning with differential GNSS can be integrated in one small (mobile phone-) handset
- data exchange for positioning (both directions) would be very easy
- high availability throughout the world (one
- standard)

- as a mass-market application the costs for the user would be low
- precision depending locally on the distance to next reference stations and globally on the geographical density of the reference stations (matter of provider)

Conclusion

The article briefly described some present and future localization methods and systems, which are useful for exploitation in ITS.
Because of many advantages and weak points in both systems (terrestrial and satellite) the solution for reaching precise and available localization system will be in joint localization covering the whole area used by ITS (outdoor and indoor).

REFERENCIES

1. Drane, Ch., Rizos,Ch., *Positioning System in Intelligent Transport Systems;* Artech House, Boston · London
2. Balbach, O., *UMTS - Competing Navigation System and Supplemental Communication System to GNSS;* IfEN Gesellschaft für Satellitennavigation mbH (IfEN GmbH) D-85579 Neubiberg, Germany
3. Collective of employes of university of Žilina, *Správa pre úvodnú oponentúru a kontrolný deň IV/2003*
4. Caffery, James J., Stüber , Gordon L., *Overwiew of Radiolocation in CDMA Cellular Systems;* IEEE Communications Magazine, April 1998
5. *Odborný článok na tému: Lokalizácia;* April 15, 2002, http://www.mobilmania.sk
6. *Globálny polohový systém - GPS;* http://www.navitel.sk/gps.html

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