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FUTURE SATELLITE NAVIGATION SYSTEMS TRANSPORT MARKETS AND APPLICATIONS

Abstract: Operational status and practical exploitation (March 2010) of Satellite Navigation Systems (SNS), as GPS and GLONASS, and Satellite Based Augmentation System (SBAS), as EGNOS are presented in this paper. Other systems in various part of the world are already available (WAAS, MSAS) or under development as Galileo, Compass, QZSS and GAGAN. The receivers of these systems are now found in every mode of transportation, maritime and land in particular. Additionally the most significant events in the satellite navigation systems in the nearest years and SNS markets and applications are described also.
Keywords: Satellite Navigation System, maritime and land transportation, transport markets

1. SATELLITE NAVIGATION SYSTEMS TODAY AND IN THE FUTURE

Satellite Navigation Systems (SNS) provide signals that can be used to accurately locate the position of people and places, and to provide safe navigation information for moving platforms such as aircraft, ships, and cars, anywhere on the surface of the Earth and out to near space. At present (March 2010) unique fully operational and global system is American GPS (Global Positioning System – Navstar) and its differential mode DGPS.

1.1. Satellite Navigation Systems – current status

The GPS constellation currently has 30 operational space vehicles, not including the SVN49/PRN1 that has still not been set healthy because of an onboard multipath problem. The malfunction of this GPS IIR–M satellite is very important for all users because this satellite is the first in the history who broadcasts the signal on the frequency L5. Seven satellites of the latest block IIR–M emit two signals for civil users (L1 C/A and L2C).

The GLONASS constellation has 22 satellites, 19 operational, 2 in maintenance, 1 in decommissioning phase (March 2010). As the number of satellites fully operational, 24, is less than nominal 24, the user's position cannot be obtained from this Russian system at any point on the Earth and at any moment. The second civil frequency (L2) is transmitted by satellites block M since 2003.

Galileo system, sponsored by the European Union, is under construction. The spatial segment consists of two test satellites, GIOVE–A and GIOVE–B only. The second satellite operates on hydrogen maser atomic clock.

China, who have announced plans for own SNS, has developed a regional satellite based navigation system known as Beidou. The initial constellation of three geostationary satellites was completed in 2003. This initial regional system is being expanded into a global system to be known as Beidou–2 or Compass. Finally it will likely include 5 GEO and 30 MEO satellites.

The other components of GNSS are the Satellite Based Augmentation Systems (SBAS) that enhance the integrity, accuracy, and operation of SNS, GPS and GLONASS. Today the SBAS as Wide Area Augmentation System (WAAS), Multi-functional Transport Satellite Based Augmentation System (MSAS) and European Geostationary Navigation Overlay System (EGNOS) are accessible in USA and Canada, Japan and Europe and North Africa adequately. While WAAS and MSAS are fully operational since few years, EGNOS officially entered into operational phase with the provision of the Open Service as of only October 1, 2009.

In order to complement the augmentation systems all over the world and to keep coherence and compatibility with GPS system, the Department of Defense of the United States is cooperating with India to develop new system over Indian space. This is the GPS and Geo Augmented Navigation – GAGAN, new SBAS, actually under construction [10].

1.2. Satellite Navigation Systems construction and modernization

The GPS and GLONASS systems are undergoing modernization (new frequencies, new signals, new monitoring stations, etc.) and continuous improvement to increase its accuracy, availability, integrity, and resistance to interference, while at same time maintaining at least the performance it enjoys today with existing already receivers.

United States Air Force officials are moving to reconfigure the GPS constellation to create a 27 satellites geometry that will improve the availability and accuracy of positioning, navigation, and timing capabilities, in particular for U.S. military forces [9].

A third civil signal at the GLONASS L3 frequency will be on newer GLONASS K satellites, perhaps starting in 2010 (table 1).

The first two in–orbit validation (IOV) Galileo satellites are scheduled for launch 2010, followed by two more in April 2011.

EGNOS has claimed that they will eventually transmit integrity information for users of GPS and GLONASS as well as for Galileo.

Between 2008 and 2013, the FAA (Federal Aviation Administration) will make the necessary changes in the ground equipment of WAAS to handle the L5 signal from GPS. Having two frequencies for ionospheric corrections will eliminate loss of vertical guidance caused by ionospheric storms.

Japan has had a plan to display a new system called the Quasi–Zenith Satellite System (QZSS), which services include enhanced accuracy GPS signals, communications and broadcasting. The first launch of QZSS satellite is planed for 2010.

The most significant events in the satellite navigation systems waited into 12 nearest years (2010–2021) with the consequences for civilian users are presented in table 1. Because of two or three frequencies make possible the calculation of ionosphere correction, the user's position accuracy increases. Unlike actual generation of GPS and GLONASS systems next generation of these systems, GPS III and GLONASS K, and new system Galileo will provide integrity information.

Table 1

The most significant events in the satellite navigation systems in the nearest years and their consequences for civilian users

Year	Event	Consequences for civilian users
2010	first GPS Block IIF satellite	the third civil frequency
	first GLONASS K satellite	new CDMA signals
	launch of two Galileo IOV (In Orbit Validation) satellites	the first Galileo satellites operational
	first launch of QZSS spacecraft	the first satellite of the new Japan's system
	first GAGAN payload on orbit	the first satellite of India's SBAS
	additional launches of Compass satellites	new GEO and MEO satellites of China's system
2011	24 GLONASS satellites	two systems (GLONASS and GPS) fully operational
2014	Galileo constellation with 16 satellites (4 IOV and 12 fully operational)	for the first time in history, integrity information for the users of the all the world
	the first launch of GPS III A satellite	the beginning of the third generation of GPS system
2016	Galileo constellation 27–30 satellites	full access to all signals and services
	24 GPS satellites transmitting L2C	full access to two civil frequencies
2018	24 GPS satellites transmitting L5	full access to three civil frequencies
2019	30 GLONASS K satellites	full access to three civil frequencies, integrity information
2020	35 Compass satellites fully operational	full access to all signals and services
2021	24 GPS satellites block III transmitting L1C	full access to new block III, integrity information and new signal L1C

2. GNSS MARKETS AND APPLICATIONS

The satellite based services called GNSS (Global Navigation Satellite Systems) include all SNSs and theirs differential modes, and all SBASs.

The first GNSSs (GPS and GLONASS) was designed to serve the military's need for accurate navigation on land, sea, air and space, but because the satellites transmit unencrypted, freely available civilian signals, applications in these same milieus have inculcated modern life [3]. That's today why we can distinct the military user and civilian user. There are significant differences between GNSS commercial and military markets, car in the commercial marketplace: the market size varies smoothly, the seller bears the development risk, there are many buyers, competitors for market share and similar products, prices are set by marginal utility.

The most important applications of GPS with the details of service needs, price sensitivity and the projected sales in units in the years 2006 and 2020 are presented in the table 2. The number of the user's receivers in the sea & rail transport and road transport (in–vehicle) will be in 2020 seven times greater than in 2006, but the biggest and most broadbased business opportunities is cell phone most certainly.

Table 2

GPS applications, the projected sales in units

Applications	**Service Needs**	**Price Sensitivity**	**Sales in units · 10^3**	
			Year	
			2006	**2020**
Aviation	Certified safety of life service, global interoperability, high accuracy + high integrity, standardized integration	low	100	600
In–Vehicle	Moderate to high accuracy and integrity, indoor and urban canyon	high	4 000	30 000
Maritime/Rail	High precision and integrity navigation, inland waterways, efficient ocean routes, positive train control	moderate	400	3 000
Mobile/Phone	Indoor and urban canyon usage, low accuracy, miniaturized, low power	very high	200	$2 \cdot 10^6$

The Japanese have moved out smartly in adopting satellite navigation, in different mode of transportation also. They were the first to put GPS receivers in automobiles, among the first to use GPS for tracking. Japan had been creating digitized maps of all its roads since 1988. Today there are more than manufactures of GPS car navigation units in this country and more than 10 million units installed in vehicles. The deployment into vehicles in the rest of the world has not been as swift.

At the 2003 Civil GPS Service Interface Committee meeting, it was reported by the Department of Transport that there are more than 420 million cars and 130 million trucks in the world, with 150 million cars and 40 million trucks in North America. To talk over GNSS market additionally we must take into account the fact that Americans drive a total of 11 billion miles per day.

By 2005 there were about 15 million GPS receivers in automobiles in USA, and about 26 million in Europe. In Poland the number of GPS receivers installed in cars also grows quickly. As far as in 2006 was them only tens thousands, is in 2007 already 200 thousands and in 2008 350 thousands.

Today marine navigation market is maturing. Along with radios and radar, a GPS navigation receiver is a piece of standard equipment on any boat operating far from shore. Actually there are about 1 million commercial coastal and inland vessels, few thousands ferries, several hundred major ships, 90,000 registered merchant vessel worldwide, must of which on involved fishing. Additionally there are about 50 million boats worldwide, in this in USA 20 million. Of these almost 98 % are pleasure craft. We can assume that on the most from them equipped is already in GPS receiver at least [3, 10].

Finally we can say, that the number of GNSS users in every mode of transportation will grow up worldwide, e.g. by 2010 year, about 200 million GNSS receivers will have been deployed in China, with more than 700 million users expected by 2020.

In 2002 GNSS business was on the order of $11 billion, today it is approximately $20 billion. Nowadays it is composed largely of GPS hardware, software, and services. Market estimates run as high as $330 billion by 2020, and that seems feasible given the expansion in systems, equipment and applications. A truly exciting and major growth area for GNSS equipment and services is in what is euphemistically called transport telematics, or vehicle location–awareness services.

3. GNSS IN DIFFERENT MODE OF TRANSPORTATION

Nowadays the GNSS receivers, GPS in particular, are found in every mode of transportation, from small gliders to 747 transports (air), from small rowboats to ocean liners (marine) and from small cars to great trucks and buses (land). We must say there are only a small number of ships and aircraft in the world compared to the number of automobiles and trucks. Therefore by applying GPS to these more common modes of transportation, the market expanded greatly. By adding communications to the navigation function, accurate tracking systems became another obvious way to make use of GPS. The applications of SNS and SBAS, both these already working, as and only built, we can find in the table 3. From this table results that all SBAS were created on needs of the transport, but today each system can be used in two other modes successfully.

The accuracy of the position solution determined by SNS is ultimately expressed as the product of a geometry factor and a pseudorange error factor [8]:

$$\text{error in SNS solution} = (\text{geometry factor}) \cdot (\text{pseudorange error factor}) \qquad (1)$$

As the error in mentioned solution can be expressed by σ_ρ – the standard deviation of the positioning accuracy, geometry factor by the dilution of precision (DOP) coefficient and pseudorange error factor by the term UERE (User Equivalent Range Error) σ_{UERE}, the relation (1) can be defined as:

$$\sigma_\rho = DOP \cdot \sigma_{UERE} \quad (2)$$

Table 3

Applications of Satellite Navigation Systems (SNS) and Satellite Based Augmentation Systems (SBAS) in Different Transport Modes (March 2010)

Transport	**SNS**					**SBAS**		
	Full Operational Capability (FOC)		without FOC	under construction		EGNOS	WAAS	MSAS
	GPS	DGPS	GLONASS	Galileo	Compass			
land	✓	✓	✓	✓	✓			
maritime	✓	✓	✓	✓	✓			
air	✓		✓	✓	✓	✓	✓	✓

In open area DOP coefficient value depends on the number of satellites (ls) visible above masking elevation angle H_{min} by the observer and the configuration of these satellites. In restricted area (coastal and harbour navigation, urban area) user's position accuracy depends on the parameters mentioned for open area and the dimensions and position of the obstacles. This accuracy can be decreased when the masking elevation angle causing by the obstacles is greater than masking angle of observer's receiver.

3.1. Marine transportation

The GPS system was available to civilian users from the very beginning. The first community interested was the maritime one, for both professional and recreational purposes. The fact that GPS accuracy is less in vertical coordinates that in the horizontal plane is really of no importance for such applications.

Nowadays the typical maritime applications include also the rescue and replenishment of–shore platforms, cruising positioning, digging waterways, or positioning and monitoring of off–shore platforms. Other typical applications consist in coupling SNS receivers installed on the ship's bridge with dedicated sensors such as radar, ARPA, ECDIS (Electronic Chart Display and Information System), AIS (Automatic Identification System), echo–sounders, plotter, autopilot, fish–finders, and so on [10].

GPS receivers have become standard equipment on boats of all sizes today, and they perform a very valuable service to the global maritime community. However experience has shown that stand alone GPS system does not provide sufficient accuracy for a reliable operation of the system. That's why many maritime administrations have implemented a

DGPS service in their waters to improve safety and efficiency of navigation [7]. At present more than 300 DGPS reference stations have status operational; and this number is still increasing [1]. In this paper these stations are called IALA DGPS.

For maritime users (channel and coastal navigation, harbour approach) the IALA DGPS stations are situated at seashore, for inland navigation the additional stations must be installed inside the land in properly chosen places. The provision of DGPS corrections can be realized in two different ways:

- IALA DGPS network covering all inland waterways of the chosen region or the territory of the all country. This solution became realized in Germany;
- the distribution of the DGPS corrections via AIS base stations. This solution became realized in Austria, via DoRIS (Donau River Information Services) system.

Several projects of the utilization SNS and SBAS in RIS, as GALEWAT, MARGAL, MUTIS, MARUSE are already realized in Europe, several following are prepared. The results obtained from measurements using EGNOS signals (GALEWAT project) showed that GPS augmented by EGNOS from Signal in Space can be a good candidate for inland waterway safety–critical applications with required accuracy below 10 m, high system availability, and protection level below 25 m [7].

An uninterrupted information about the ship's position is one of the most important elements of the safety of navigation in the sea transport in restricted and coastal areas, recommended by International Maritime Organization (IMO). In ocean waters the radionavigation system should provide positional information with a horizontal error not greater than 100 m with a probability of 95%, that's why in maritime area in oceanic navigation the satellite position accuracy is greater than IMO horizontal accuracy requirements are.

In coastal navigation the accuracy diminution is very small, it depends on the ship course, ship antenna height, observer's latitude, the distance from the coast and the top of this coast. On the approaches to the ports and in harbour area the position on many occasions can be obtained by DGPS, but in some areas the satellite visibility can be limited and due to that the position accuracy can be decreased. That's why in these areas the ship's position is most often determined by other available methods, e.g. radar [5].

The millions of pleasure crafts are usually in well-charted, so they could easily operate satisfactorily without precise satellite navigation. But when there is fog, GPS receiver become a potential lift saver.

3.2. Land transportation

In urban restricted area the user's position accuracy is less than in open area considerably for all SNSs. This accuracy depends on the height of the buildings, the width of the street and the angle between the North and street axis. As for every SNSs the distribution of satellite azimuths depends on observer's latitude, the user's position accuracy in the town depends on its geographic location. It means that the accuracy in the street with the same widths and the height of the buildings is in Helsinki, Berlin, Madrid and Singapore different. In urban area for the observer situated in the middle of the street (with given width and height of the buildings) the dependence of position accuracy on angle between the North and street axis is for Galileo system less than for GPS and GLONASS systems. These results were confirmed in research of the author [4, 5].

Research showed the safety improvements made via the application of GNSS technologies in vehicle navigation in the United States can reduce the national traffic death rate by about 30% from current levels, to below 1 per 100 million miles driven.

4. CONCLUSIONS

- many countries are pressing hard to get their own SNS or SBAS, or to be a significant player in the GNSS market. Next manufacturers in many countries, not always the same, are developing the receivers to enable use of these systems;
- it is forecast that two major domains of applications of the GNSS will be the transport and Location–Based Services (LBS), which will represent more than 70% of total market;
- the measurements realized within framework of several European projects showed the full usefulness of SNS and SBAS on inland waterways, on great European rivers as Rhine and Danube, in particular;
- as today GPS stand alone cannot give the information about integrity, the number of DGPS reference stations at sea shore should increase not only account position's accurary greater than in the case of GPS stand alone, but also for the fact that DGPS message provides the user with information that GPS system is functioning normally;
- nowadays only GPS is fully operational, the full operational capability (FOC) of every following system, as GLONASS, Galileo or Compass, will assure in urban area the possibility of fix position in almost all cases and will increase its accuracy. That's why the question which SNSs is the best in urban restricted area doesn't exist already, now the goal is GNSS; because the more SNSs, the more number of satellites visible by the user, all the better;
- land applications are the most promising market for GNSS equipment and services.

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PRZYSZŁOŚCIOWE WYKORZYSTANIE NAWIGACYJNYCH SYSTEMÓW SATELITARNYCH W TRANSPORCIE

Streszczenie: W artykule omówiono status operacyjny i problemy eksploatacyjne nawigacyjnych systemów satelitarnych (SNS), takich jak GPS i GLONASS oraz satelitarnych systemów wspomagających (SBAS), takich jak EGNOS. W różnych częściach świata dostępne są inne systemy (WAAS i MSAS), kolejne (Galileo, Compass, QZSS, GAGAN) są na etapie budowy. Odbiorniki w/w systemów znalazły zastosowanie we wszystkich rodzajach transportu. Omówiono też najważniejsze wydarzenia jakich można spodziewać się w najbliższych latach w dziedzinie SNS oraz wykorzystanie tychże systemów na rynku transportowym.

Słowa kluczowe: nawigacyjne systemy satelitarne, transport lądowy i morski, rynek transportowy