Evolution of the Global Navigation Satellite Sysytem (GNSS)

By **Arup Dasgupta** - 09/20/2016 10 Minutes Read

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Finding your position on a globe is a problem that has bedeviled travelers and explorers from the time it was firmly established that the earth is not flat, at least geographically speaking. The main problem is finding a point of reference and a coordinate system that can be used to orient oneself on a sphere like object like the [illegible]he Pole Star provided a celestial point of reference and became North; hence the opposite end became the S[illegible]nd exactly in-between we placed an artefact called the equator.

The solar elevation at local noon, measured with a sextant, was converted to latitudes, but longitudes presented a big problem till an English carpenter-turned-clockmaker, John Harrison, developed a seagoing, accurate chronometer to determine the difference between local time and Greenwich time to calculate the longitude. Greenwich became longitude zero, another artefact which has since shifted westward by 100m.

From spheroid to spheroid

Sextants and chronometers are not everybody's toys. Therefore, their use remained a matter for sea and air navigation. Air navigation also needed new tools like ADF, INS and VOR. Land navigation was simpler, but needed maps, while navigation charts were needed for sea and air navigation. It soon became clear that maps and charts, based on local models of the earth called spheroids posed a problem while moving from one spheroid to another as one navigated the globe. It required mathematical transformations to maintain the accuracy of location from spheroid to spheroid. With the advent of satellites an opportunity arose to model the earth in its entirety using very precise measurements by geodetic and ranging satellites to create a global spheroid to which all measurements could be referenced. Thus, all forms of navigation could now use one unified model, the WGS 84 being the latest in the series.

Using satellites for navigation began with the US Navy Navigation Satellite System, NNSS in 1964 using the TRANSIT satellite system. This system proved to be useful not only for the Navy, but for civilians as well. Notably, in 1983, the height of Mount Everest was corrected by the TRANSIT system to 8,850m from the original 8,840m measured in 1856. (Today it stands at 8,848m as measured by the Chinese). From 1970, the Russians had similar systems named Parus for military use and Tsikada for civilian use. Today, the US TRANSIT system has been replaced by GPS and the Russian systems by GLONASS. There are several global and regional systems for position location and navigation. Other global systems under development are Europe's Galileo and China's COMPASS, now called BeiDou-2 or BDS. Among regional systems are India's IRNSS, now called NAVIC, and Japan's QZSS.

Working of GNSS receivers

Navigation satellites work on the principle of trilateration. Position of an object is determined by its latitude, longitude on the spheroid and height above Mean Sea Level. If at the time of measurement, the instantaneous position of three satellites are known and the distance of the point of measurement from each of these three satellites is known, then the latitude, longitude and height of the point can be determined using simple distance formula. In practice, a fourth satellite is needed to adjust for timing biases.

How does a GPS receiver determine its distance from each satellite? It does so by comparing a code generated by a satellite with the same code generated internally in the receiver. The time difference between the two codes multiplied by the speed of light gives the distance. That requires a very stable signal source on the satellites which is provided by the Rubidium clock which is used to generate the code and the carrier signal for the code. Each satellite has a unique code hence the receiver can identify each satellite in its view. The carrier also contains the precise orbital parameters of the satellite which is updated regularly. The orbital parameters are updated using Integrity and Range Monitoring Stations. A central control station uploads the orbital parameters and synchronizes the Rubidium clocks regularly on each GNSS satellite.

Signals from the GNSS satellites are transmitted in the L-band in five designated frequencies named L1 to L5. Of these L1 and L2 are used by all GNSS satellites, L3 is set apart for transmission from satellites to ground stations to detect nuclear explosions. L4 is to be used for ionospheric corrections and L5 will eventually support safety-of-life applications for aviation and provide improved availability and accuracy.

Global Systems

Global Positioning System, GPS – US

This is the oldest system which began operations in 1978 and grew to 32 planned satellites in Medium Earth Orbit, MEO of 20180 km. The orbits are so selected that at any given time at least six satellites are in view an observer anywhere on earth. Initially exclusive for military use, it was opened to the public in the mid 80s with a selective availability that restricted the positional accuracy to 100m. The military continues to enjoy 5m or better accuracy. SA was discontinued from 2000 during which time the military also developed technologies to deny GPS service on regional basis to potential adversaries. It is widely believed that this was used during the Kargil War.

GLONASS – Russia

Starting with a decision in 1978 GLONASS became operational by 1993 over Russia with 12 satellites in 2 orbits at 19,130 km. Its full capacity and global coverage was achieved by 2015 with 23 of 27 satellites operational. The accuracies are comparable to but a little lower than GPS. However, the accuracies are better than GPS in the higher latitudes. The frequencies are the same L1 and L2 but originally adopted a different access mode, FDMA before shifting to CDMA. GLONASS also works on a different spheroid model but its difference from the WGS84 is less than 40cm. Using both GLONASS and GPS together, GNSS receivers have access to 50 satellites and therefore can provide better position location faster, particularly in urban canyons and rugged mountainous areas.

Galileo – European Union

This project is being established by ESA under the leadership of Germany, France and Italy. Other European countries who have joined the project are Norway and Switzerland. Israel, Morocco and Ukraine have also joined the program. China was to have joined but later withdrew as it decided to proceed with its own BeiDou program. The program seeks to develop independent capability in the civilian space as opposed to GPS, BeiDou and GLONASS which are under military control. Galileo will have accuracy higher than GPS and GLONASS at one meter for public use and one centimeter for paid users. There is a provision for exclusive military use in case of extreme situations like war. The program was beset by funding problems as well as friction with US on security issues. However, these have been overcome and 12 of the planned 30 satellites are in orbit. Full operational status is expected by 2020.

Galileo is unique as it is designed to provide a new global search and rescue (SAR) function as part of the MEOSAR system. Apart from relaying the distress signals from emergency beacons to the rescue coordination centre, it will also provide a return link to the beacon to confirm receipt of the distress signal and launch of rescue. This does not exist in the current Cospas Sarsat system.

System	GPS	GLONASS	BeiDou	Galileo	NAVIC
Owner	United States	Russian Federation	China	European Union	India
Orbital altitude	20, 180 km (12, 540 mi)	19, 130 km, (11, 890 mi)	21, 150 km, (13, 140 mi)	23,222 km , (14, 429 mi)	36, 000 km, (22,000mi)
Period	11.97 h, (11 h 58 min)	11.26 h, (11 h 16 min)	12.63 h, (12 h 38 min)	14.08 h, (14h 5min)	
Number of satellites	32 (at least 24 by design)	28 (at least 24 by design) including: 24 operational 2 under check by the satellite prime contractor 2 in flight tests phase	5 geostationary orbit (GEO) satellites, 30 medium Earth orbit (MEO) satellites	4 in-orbit validation satellites + 8 full operation capable satellites in orbit 22 operational satellites budgeted	Total: 7 In Orbit: 7
Frequency	1.57542 GHz (L1 signal) 1.2276 GHz (L2 signal)	Around 1.602 GHz (SP) Around 1.246 GHz (SP)	1.561098 GHz (B1) 1.589742GHz (B1-2) 1.20714 GHz (B2) 1.26852 GHz (B3)	1.164-1.215 GHz (E5a and E5b) 1.260-1.300 GHz (E6) 1.559-1.592 GHz (E2-L1-E11)	L5-band 1164.45-1188.45 MHz S-band 2483.5-2500 MHz
Status	Operational	Operational	22 satellites operational, 40 additional satellites 2016-2010	8 satellites operational, 22 additional satellites 2016-2020	Operational

BDS / BeiDou-2 / COMPASS – China

The Chinese system began as a regional system, BeiDou-1 with three geostationary satellites serving China and its neighborhood. The signals were in the S-band and offered an accuracy of 20m. BeiDou-1 was decommissioned by end of 2012.

BeiDou-2 is a completely new system consisting of 35 satellites of which five are planned to be in geostationary orbit to provide BeiDou-1 compatibility to existing ground systems, 25 are planned in MEO and 5 are planned in inclined geosynchronous orbits. From records of launches there are 6 in geostationary orbit, 8 in inclined geosynchronous orbit and 5 in MEO. The extra satellites in GEO and IGSO are possibly in orbit spares. The BeiDou-2 frequencies overlap the Galileo frequencies, thus providing interoperability between the two systems. As of now, the system is referred as the BeiDou Navigation System, BDS, and currently serves China and its neighborhood. BeiDou is expected to become operational globally by 2020 providing 10m accuracy for public and higher for military use.

Regional Systems

NAVIC – India

The IRNSS system, christened NAVIC after operationalization, is a direct outcome of the restrictions placed on use of the GPS system by the US during the Kargil War with Pakistan. The NAVIC system consists of 7 satellites, 3 in geostationary orbit and 4 in inclined geosynchronous orbits. The system became operational in 2016. The system works in the L5 and S bands and provides better than 20m over the Indian Ocean region and 10m accuracy over India for public use and 10cm for authorized users, which includes the military.

> ***Catch up with our Info-graphic Section to get a quick & clear understanding of IRNSS:***
>
> ***https://www.geospatialworld.net/infographic-irnss-navic-indias-gps/***

QZSS – Japan

The QZSS or the Quasi-Zenith Satellite System has a unique configuration of the satellite orbit. It is a highly inclined slightly elliptical geosynchronous orbit which gives coverage over Japan and the Pacific region. As of now one satellite, MICHIBIKI has been launched, three more QZSS and one geostationary satellites are in the pipeline. Using the standard GNSS L1, L2 and L5 frequencies, QZSS will complement GPS and will provide positioning, augmented positioning and messaging services. Service is expected to begin from 2018. Ultimately, four more QZSS satellites are planned by 2020. Accuracy is expected to be better than 7m. The precision service will be around 2m and will use a DGPS signal on the L band.

Satellite Based Augmented Systems – SBAS

Based on these GNSS, there are several regional augmented navigation systems under the generic name Satellite Based Augmented System, SBAS. These are Wide Area Augmented System, WAAS in the US, European Geostationary Navigation Overlay Service, EGNOS in Europe and GPS-Aided GEO Augmented Navigation System, GAGAN in India, all based on the GPS system. MTSAT Satellite Based Augmentation Navigation System, MSAS, in Japan and System for Differential Corrections and Monitoring, SDCM, in Russia based on GLONASS and GPS are others. China is planning SNAS, Satellite Navigation Augmentation System, to provide WAAS-like service for the China region. These systems are primarily meant for aircraft navigation including landing and takeoff stages but are also used for other land and sea based navigation applications. They require additional equipment to augment the basic GNSS receivers.

The SBAS is an improvement of the positioning service of the GNSS. The problem with the GNSS is the error due to the atmosphere through which the signal has to pass before reaching the user equipment like a smartphone. This error, called the tropospheric and ionospheric error introduces random variations in the signal which degrades the accuracy in the measurement of the distance of the device from the satellite emitting the signal. Using a GNSS in a differential mode like DGPS can reduce this error. But, this is not possible in a fast moving object like an aircraft. In a SBAS, there are several ground stations which continuously measure the error and update corrections through another channel, like a geostationary satellite. These corrections are applied in real time and can bring down the error to one meter allowing for a CAT-I Instrument Landing System capability.

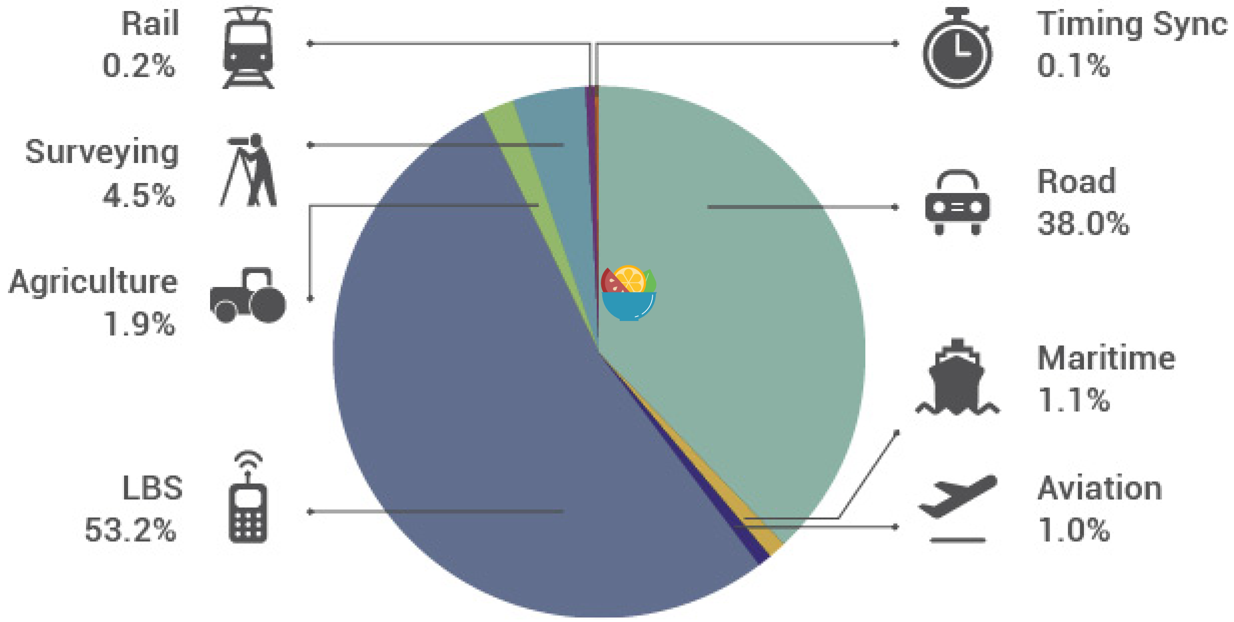
> *The number of GNSS devices is expected to reach 7 billion, almost one per person by 2019. Smartphone lead the market with 3.08 billion followed by road navigation devices at 0.26 billion as of 2014*

Other applications

Though GNSS began as a military system in the US and erstwhile USSR mainly for warship navigation and later extended to ICBMs, it soon became clear that there could be many applications in the civilian area. It took the disastrous Korean Airline flight 007 shooting in 1983 to convince the US that the system needed to be made available for civilian use and further, in 2000 the selective availability was turned off.

Though the US and Russia still exercise military control, new systems like Galileo, NAVIC, BDS and QZSS are primarily civil application driven. Applications of GNSS range from navigation and position location to precision agriculture, surveying, precision timing and scientific studies of the atmosphere and the earth's crust including earthquake prediction.

Business prospects



Cumulative core revenue 2013-2023

Issue 4 of the GNSS Market Report by the European GNSS Agency provides a very good picture of the GNSS marketplace. The study includes both core markets like personal navigation devices as well as assisted markets like smartphones, aviation, precision agriculture and search and rescue. The number of GNSS devices is expected to reach 7 billion, almost one per person by 2019. Smartphone lead the market with 3.08 billion followed by road navigation devices at 0.26 billion as of 2014. The expected growth area is the Asia-Pacific at 11% per annum such that by 2023 it will overtake the combined US and European markets. Middle East and Africa will show a growth rate of 19% as it starts from a low base.

In smart cities, GNSS will enable smart mobility and LBS applications as well as autonomous driving solutions, travel optimization and automatic transactions such as toll and parking charges. GNSS will be used in container and other mobile asset management. Big Data Analytics will use GNSS data for traffic modeling and management as well as crowd control. With the increased machine to machine interactions GNSS will become an invaluable part of the Internet of Things.

The core market (chip sets) will grow at 8.3% but will slow down to 4.6% from 2020 to 2023 due to lowering of costs but the downstream market of GNSS enabled devices will grow at 7%, beating the Global GDP forecast of 6.6%. LBS will hold the lion's share of 53.2%, followed by road navigation of 38%. Other major markets will be surveying (4.5%) and agriculture at 1.9%. Maritime, aviation, rail and timing will contribute the rest. While GPS is the lead GNSS followed by GLONASS, the focus is on how many devices support multiple GNSS constellations. While devices which support only one GNSS constellation are about 40%, the rest provide at least two GNSS capability with 21% supporting all four global systems, GPS, GLONASS, Galileo and BeiDou. This is a ... tor of the future course to be followed by chip makers and downstream device manufacturers and value a...

The road ahead

GNSS have proliferated into four major global and two regional systems. The military origin and the need to have independent military capability have driven this growth. With the opening of the system to civilian use there has been an explosion of applications which have democratized the system. New applications are being generated at a fast pace and this is a major growth area, particularly for the Asia-Pacific region.

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