PERFORMANCE ANALYSIS OF MULTI-GNSS SYSTEM BASED ON DOP, INTEROPERABILITY AND RAIM WITH A NEW APPROACH TO GNSS BASED TRACKING SYSTEM

A thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Science
in
Electrical, Electronic and Communication Engineering

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CERTIFICATION

This thesis paper entitled **"Performance Analysis of Multi-GNSS System Based on DOP, Interoperability and RAIM with a New Approach to GNSS Based Tracking System"** submitted by the group under mention, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical, Electronic and Communication Engineering on December 2014.

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DECLARATION

We hereby declare that the thesis titled "**Performance Analysis of Multi-GNSS System Based on DOP, Interoperability and RAIM with a New Approach to GNSS Based Tracking System**" is submitted to the Department of Electrical, Electronic and Communication Engineering for the partial fulfillment of the requirement for Bachelor of Science Degree on Electrical, Electronic and Communication Engineering (Course Number 400).

This is our original work under the supervision of Gp Capt Dr. Md Hossam-E-Haider and was not submitted elsewhere for the award of any other degree or any other publication.

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ABSTRACT

Global Navigation Satellite System (GNSS) is basically a system of satellites providing autonomous geo spatial positioning with global coverage. There are mainly four GNSS systems currently in operation. They are the United States' Global Positioning System (GPS), Russian Federation's Global Orbiting Navigation Satellite System (GLONASS), Chinese BeiDou Navigation Satellite System (BDS) and European Galileo. Navigation basically means any of several methods of determining or planning an object's position and course by geometry, astronomy, radio signals etc. This combines two concepts. The first is the determination of the position and velocity of a moving body with respect to a known reference, sometimes known as the science of navigation. The second is the planning and maintenance of a course from one location to another while avoiding obstacles and collisions. GNSS constellation is very important in determining these things. More precisely the Dilution of Precision plays a vital role in accuracy of the navigation system.

Interoperability means combining information (pseudorange measurements, navigation data) from two or more GNSS systems at the user receiver to achieve better performance than employing either system separately. Monitoring the integrity of a navigation system is essential to ensure that the navigation solution is within tolerable constraints. Receiver Autonomous Integrity Monitoring (RAIM) refers to integrity monitoring of GNSS navigation signals performed by a receiver independent of external reference systems. A multi constellation context due to the introduction of Galileo and GPS, great improvement could be expected from RAIM performance. Recognizing the strategic importance Galileo has the provision to be interoperable with GPS. The efficiency of any GNSS system depends largely on the receiver available at the user end. In this thesis GNSS receivers are discussed in detail and next generation GNSS receivers are illustrated briefly.

A new indoor GPS tracking system is proposed in our thesis. This system integrates positioning technology, user interface and dynamic information provision. We have shortly discussed this system in the 4th floor of Tower Building-1 of MIST. The whole system is currently a proposed idea and we are hoping to see its effective implementation in the near future.

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LIST OF ABBREVIATIONS

ASIC	Application-Specific Integrated Circuit
ADC	Analog to Digital Converter
AGGA	Advanced GPS/Galileo ASIC
ASC	Antenna Switch Controller
AGC	Automatic Gain Control
AMBA	Advanced Microcontroller Bus Architecture
APB	AHB and AMBA Peripheral Bus
AHB	Advanced High - Performance Bus
A-GPS	Assisted - Global Positioning Systems
BDT	BeiDou Time
BOC	Binary Offset Carrier
CGCS 2000	China Geodetic Coordinate System 2000
CDC	Clock Domain Crossing
CIC	Communication Interrupt Controller
DSP	Digital Signal Processors
DDC	Digital Down Converters
DAC	Digital to Analogue
DBF	Digital Beam - Forming
DMA	Direct Memory Access
DSU	Debug Support Unit
DF	Dual - Frequency
EIRP	Effective Isotropic Radiated Power
ECEF	Earth Centered Earth Fixed
EC	Epoch Clock
EOPP	ESA's Earth Observation Preparatory Programme
EO	Earth Orbit
FPGA	Field Programmable Gate Array
FLL/PLL/ DLL	Frequency/Phase/Delay Locked Loops

FDMA	Frequency Division Multiple Access
FD	Fault Detection
FDE	Fault Detection and Exclusion
FA	False Alarm
FOC	Full Orbit Constellation
GPST	GPS System Time
GLONASSST	GLONASS System Time
GTRF	Galileo Terrestrial Reference Frame
GNSS	Global Navigation Satellite System
GEO	Geostationary Earth Orbit
GSM	Global System Mobile Communication
GNSS	Global Navigation Satellite System
GIC	GNSS Interrupt Controller
GPS	Global Positioning System
GLONASS	GlobalNaya Navigatsionnaya Sputnikovaya Sistema
GDOP	Geometric Dilution of Precision
HUI	Human User Interface
HDOP	Horizontal Dilution of Precision
IR	Integrity Risk
IMO	International Maritime Organization
ICG	International Committee On GNSS
ITU	International Telecommunications Union
INS	Inertial Navigation System
ICT	Information and Communications Technologies
IMT	Instrument Measurement Time
ICAO	International Civil Aviation Organization
ITRF	International Reference Frame
JGS	Japan Satellite Navigation Geodetic System
LEO	Low Earth Orbit
LBS	Location - Based Services
LO	Local Oscillator
LNA	Low Noise Amplifiers

LFSR	Linear Feedback Shift Register
LEO	Low Earth Orbit
MD	Missed Detection
MEO	Medium Earth Orbit
ME	Measurement Epoch
NAPA	Navigation Chip for Pedestrian Navigation and Higher Precision Applications
OSGRS	Open Source GNSS Reference Server
PL	Protection Level
PE–90	Parameter of the Earth 1990
PNT	Positioning, Navigation and Timing
PDA	Personal Digital Assistants
PPS	Precise Positioning Service
PDOP	Position Dilution of Precision
PLL	Phase Locked Loop
PIC	Primary Interrupt Controller
PPS	Pulse Per Second
PZ–90	Parametry Zemli 1990
PVT	Position Velocity and Time
POD	Precise Orbit Determination
QZSS	Quasi - Zenith Satellite System
RAAN	Right Ascension of Ascending Node
RAIM	Receiver Autonomous Integrity Monitoring
RFC	Radio Frequency Compatibility
RFID	Radio Frequency Identification
RO	Radio Occultation
RF	Radio Frequency
SNS	Satellite Navigation Systems
SBAS	Satellite Based Augmentation System
SA	Selective Availability
SPS	Standard Positioning Service
SoC	System-on-Chip
SPI	Serial Peripheral Interface

S&R	Search and Rescue
SDR	Software Defined Radio
SF	Single - Frequency
TAI	Time Atomic International
TDOP	Time Dilution of Precision
TBG	Time Base Generator
UERE	User Equivalent Range Error
UART	Universal Asynchronous Receiver/Transmitter
USO	Ultra Stable Oscillators
UTC	Universal Time Coordinated
VDOP	Vertical Dilution of Precision
VCO	Voltage - Controlled Oscillator
WiFi	Wireless Wide Area Network
WiFi AP	WiFi Access Points
WGS84	World Geodetic System 1984

CHAPTER 1

INTRODUCTION

1.1 Introduction to GNSS

A satellite navigation or SAT NAV system is a system of satellites that provide autonomous geo-spatial positioning with global coverage. It allows small electronic receivers to determine their location (longitude, latitude and altitude) to within a few meters using time signals transmitted along a line-of-sight by radio from satellites. A satellite navigation system with global coverage may be termed as a global navigation satellite system or GNSS. The term 'Global navigation satellite system' (GNSS) refers to a constellation of satellites providing signals from space transmitting positioning and timing data. Global coverage for each system is generally achieved by a satellite constellation of 20 ~ 30 Medium Earth Orbit (MEO) satellites spread between several orbital planes. The actual systems vary but use orbit inclinations of >50° and orbital periods of roughly twelve hours (at an altitude of about 20,000 kilometers (12,000 mi)).

1.2 History of GNSS

It can be ascertained as a matter of fact that the early predecessors of GNSS were the ground based Decca Navigator System, Long Range Navigation (LORAN), GEE and Omega radio navigation systems, which used terrestrial long wave radio transmitters instead of satellites. As such positioning systems broadcast a radio pulse from a known "master" location, followed by repeated pulses from a number of "slave" stations. The occurrence of delay between the reception and sending of the signal at the slaves were carefully controlled, allowing the receivers to compare the delay between reception and the delay between sending. Mathematically, the distance of each of the slaves could be determined, providing a fix from this evaluation.

Transit was the first satellite navigation system which was a highly articulate system developed by the U.S. military in the 1960s. Its development started in 1958, with the first experimental satellite launched in 1961 and system operational in 1964. The principle of Doppler effect was employed in the case of Transit's operation. In this case, it was ascertained that the satellites travelled on well-known paths and broadcast their signals on a well known frequency. However the received frequency will differ slightly from the broadcast frequency because of the movement of the satellite with respect to the receiver. As a result of monitoring this frequency shift over a short time interval, the receiver can determine its location to one side or the other of the satellite and several such measurements combined with a precise knowledge of the satellite's orbit can fix a particular position. The system was opened to civil use from 1967 and was decommissioned in 1996. Transit comprised between 4 and 7 low altitude (1,100 km) satellites, each broadcasting at 150 MHz and 400 MHz.

It was also accurately predicted by mathematical calculations that a part of an orbiting satellite's broadcast included its precise orbital data. With the sole purpose of ensuring accuracy the U.S. Naval Observatory (USNO) continuously observed the precise orbits of these satellites. Once a satellite's orbit deviated, the USNO would send the updated information to the satellite. Subsequent broadcasts from an updated satellite would certain the most recent accurate information about its orbit.

It was estimated that modern systems were more of a direct nature. In this case, the satellite broadcasts a signal that contains orbital data (from which the position of the satellite can be calculated) and the precise time the signal was transmitted. Then the orbital data is transmitted in a data message that is superimposed on a code that serves as a timing reference. In addition, the satellite uses an atomic clock to maintain synchronization of all the satellites in the constellation. The receiver compares the time of broadcast encoded in the transmission with the time of reception measured by an internal clock, thereby measuring the time-of-flight to the satellite. A variety of such accurate measurements can be made at the same time to different satellites, allowing a continual fix to be generated in real time using an adapted version of trilateration.

Present day satellite navigation systems that provide enhanced accuracy and integrity monitoring usable for civil navigation are classified as follows:

- **GNSS-1** is the first generation system and is the combination of existing satellite navigation systems (GPS and GLONASS), with Satellite Based Augmentation Systems

(SBAS) or Ground Based Augmentation Systems (GBAS). In the United States, the satellite based component is the Wide Area Augmentation System (WAAS), in Europe it is the European Geostationary Navigation Overlay Service (EGNOS) and in Japan it is the Multi-Functional Satellite Augmentation System (MSAS). Ground based augmentation is provided by systems like the Local Area Augmentation System (LAAS).

- **GNSS-2** is the second generation of systems that independently provides a full civilian satellite navigation system, exemplified by the European Galileo positioning system. These systems will provide the accuracy and integrity monitoring necessary for civil navigation. This system consists of L1 and L2 frequencies for civil use and L5 for system integrity. Development is also in progress to provide GPS with civil use L2 and L5 frequencies, making it a GNSS-2 system.
- Core satellite navigation systems, currently GPS (U.S.), GLONASS (Russia), Compass (China) and Galileo (EU).
- Global Satellite Based Augmentation Systems (SBAS) such as Omnistar and StarFire.
- Regional SBAS including WAAS (U.S.), EGNOS (EU), MSAS (Japan) and GAGAN (India).
- Regional Satellite Navigation Systems such as China's BeiDou, India's yet-to-be-operational Indian Regional Navigation Satellite System (IRNSS) and Japan's proposed Quasi-Zenith Satellite System (QZSS).
- Continental scale Ground Based Augmentation Systems (GBAS) for example the Australian Ground Based Regional-augmentation System (GRAS) and the US Department of Transportation National Differential GPS (DGPS) service.
- Regional scale GBAS such as Continuously Operating Reference Station (CORS) networks.
- Local GBAS typified by a single GPS reference station operating Real Time Kinematic (RTK) corrections.

1.3 GNSS User Architecture

It is possible to navigate with GNSS signals using a variety of configurations. The following sections provide an overview of the most common setups.

1.3.1 Stand-Alone Satellite Navigation

This is the basic method of GNSS navigation where only the received signals from a GNSS constellation, such as the publicly available GPS standard positioning service (SPS) are used. This includes applications such as assisting boats to find their way in and out of harbors using only a stand-alone receiver. The performance of stand-alone GNSS is sufficient only for a limited number of applications. Many applications either desire or require higher accuracy than a stand-alone SPS can provide. For this reason, GNSS is often combined with other sensors and signals.

1.3.2 Differential GNSS (DGNSS) Navigation

Differential systems are primarily intended to improve the stand-alone accuracy of a GNSS receiver position estimate, while also providing information on the position integrity. Surveying engineering work is an example of an application that often uses differential carrier phase GNSS. Figure 1.1 shows the basic configuration of an example DGNSS implementation. ‘‘Differential’’ indicates that a difference is being taken to mitigate some of the errors present in the stand-alone navigation estimate in an attempt to improve users’ knowledge of their position. This will typically consist of a reference system measuring some of the satellite system errors and relaying this information over a radio frequency link to users in the vicinity. An example of such a system providing coverage in North America is the wide area augmentation system (WAAS).

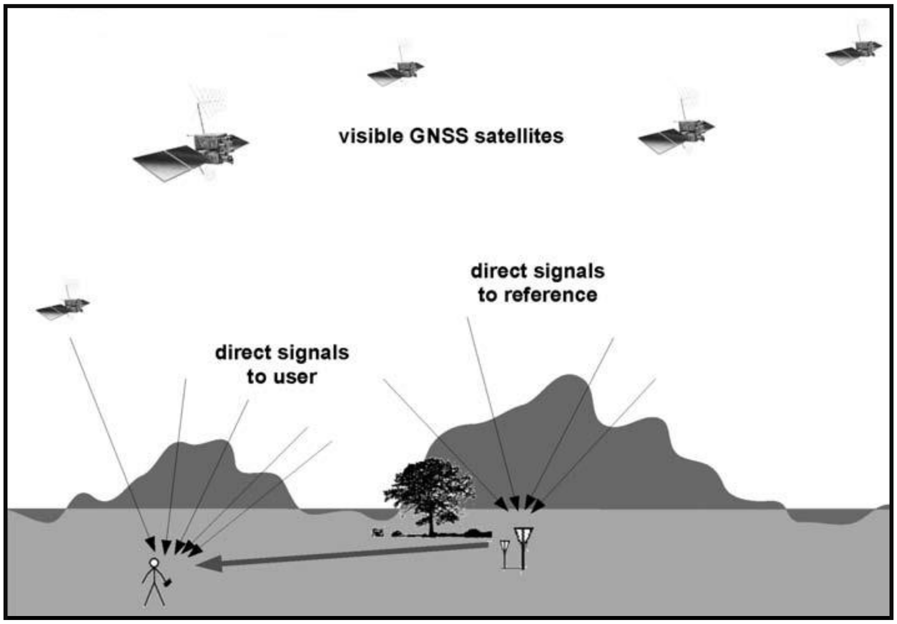


Figure 1.1 : A typical example of a DGNSS user configuration.

1.3.3 Network-Assisted GNSS (A-GNSS) Navigation

Whenever a communications network is used to relay information to a GNSS receiver, it can be said to be receiving assistance. This is called assisted GNSS or A-GNSS. In this regard, DGNSS described above can be thought of as a subset of A-GNSS. This assistance is often a correction to raw measurements calculated elsewhere and sent over a radio link to remote receivers. However, unlike DGNSS, in A-GNSS this assistance can often include more basic information used to assist the receiver in performing an accelerated position fix or to extend the validity of the satellite information used during positioning. For example, each GNSS satellite transmits data on its signal with detailed information on its orbit, clock parameters, integrity and status information. This information is required to estimate the user position. The relatively slow rate (i.e., 50 Hz or 20 ms per data bit in the case of the GPS L1 C/A signal) at which this information is modulated onto the satellite signal is seen as a drawback. However, in an A-GNSS, the necessary satellite information as well as the approximate location of the user can be determined externally (using reference stations and a central server for example) and sent to the user receiver upon request to help provide a much faster time to first position fix. This is a method employed widely in the implementation of mobile phone–based and in-car–based satellite navigation systems.

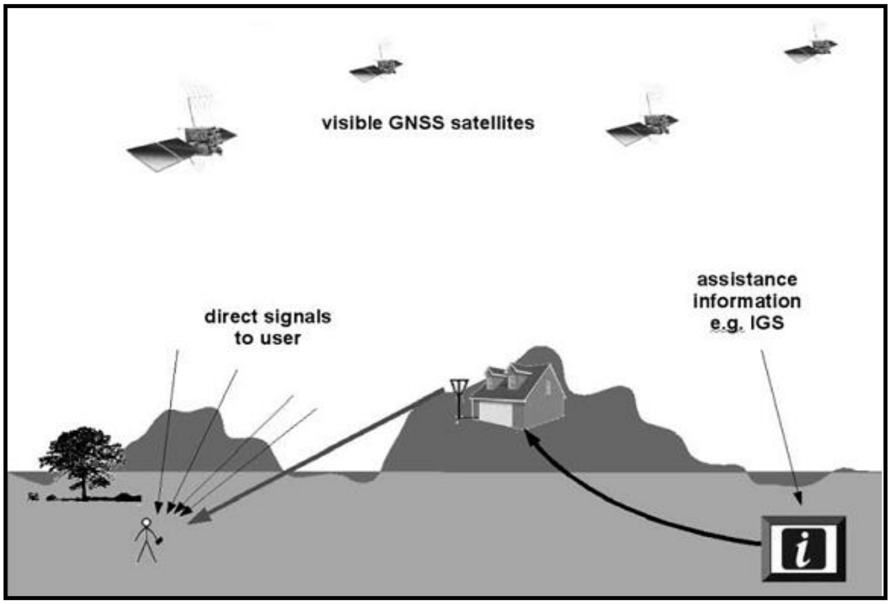


Figure 1.2 : A typical example of a AGNSS user configuration.

Using satellite navigation data in this way holds the potential for greatly improving GNSS receiver performance and reducing the processing load required in the receiver. The advantage of A-GNSS is particularly relevant in the area of software-based GNSS receivers where the management of the processing load is of great importance. Additionally, it is worth noting that the navigation data contained on the satellite signal is only valid for a short period of time (conservatively, only a few hours). This leaves open the opportunity - which many have jumped in to fill - to extend the usable duration of the satellite orbit parameters. These methods use modeling techniques to predict the locations of the GNSS satellites with sufficient accuracy for positioning up to several weeks into the future.

In a network - assisted system, such an extended period of validity is very useful, especially if the receiver is traveling in a difficult environment where tracking gaps resulting in incomplete navigation data messages from the satellites are common.

1.4 GNSS Segment

GNSS usually consists of three segments: space segment, control segment and user segment.

- **Space Segment**: It consists of a network of satellites that are placed above the Earth in nearly circular orbital planes. In general, there are three different orbit altitudes:

- Low Earth Orbit (LEO) satellites are located at an altitude of under 2000 km and circulate the Earth in the range of 95 to 120 min.
- Medium Earth Orbit (MEO) satellites are located at an altitude of 5000 km to 12000 km and take around 6 h to circulate the Earth.
- Geostationary Earth Orbit (GEO) satellites are located at an altitude of 35786 km, in which they exactly match the earth rotation speed and remain exactly at the same point from the earth view. GNSS Global coverage is generally achieved by a satellite constellation of 20 ~ 30 MEO satellites spread between several orbital planes.

- **Control Segment:** It consists of a system of tracking stations located around the world performing continuous observation of visible satellites.
- **User Segment:** It consists of GNSS passive receivers able to decode received signals from satellites and obtain information from them about their position and time.

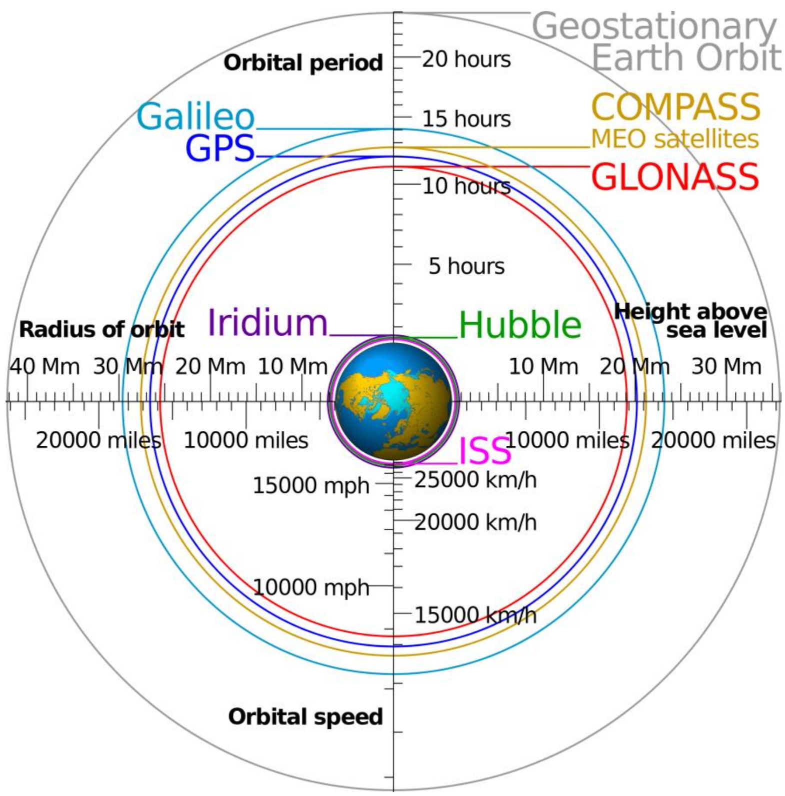


Figure 1.3 : Orbit altitudes for GNSS.

1.4.1 Trilateration

GNSS basic positioning is based on trilateration positioning method. The position has to be determined in three dimensional spaces, so 3D trilateration requires at least knowing 3 points. However, the GNSS receiver requires four ranges of four satellites to determine its position where three are for calculating the position in 3D and the fourth one is for time synchronization to correct receiver clock error.

To determine its position, a GNSS receiver performs the following steps:

- Determine which satellites are going to be used. It will depend on the geometry between satellite and receiver and satellite signal state and health.
- Select four satellites: 3 for positioning and 1 for synchronization issues caused by the receiver clock error.
- Determine the pseudorange for each satellite.
- Correct pseudorange by using correction formulas to define satellites accurate range.
- Using the orbit parameters included in the received navigation message, calculates the unknown receiver position.

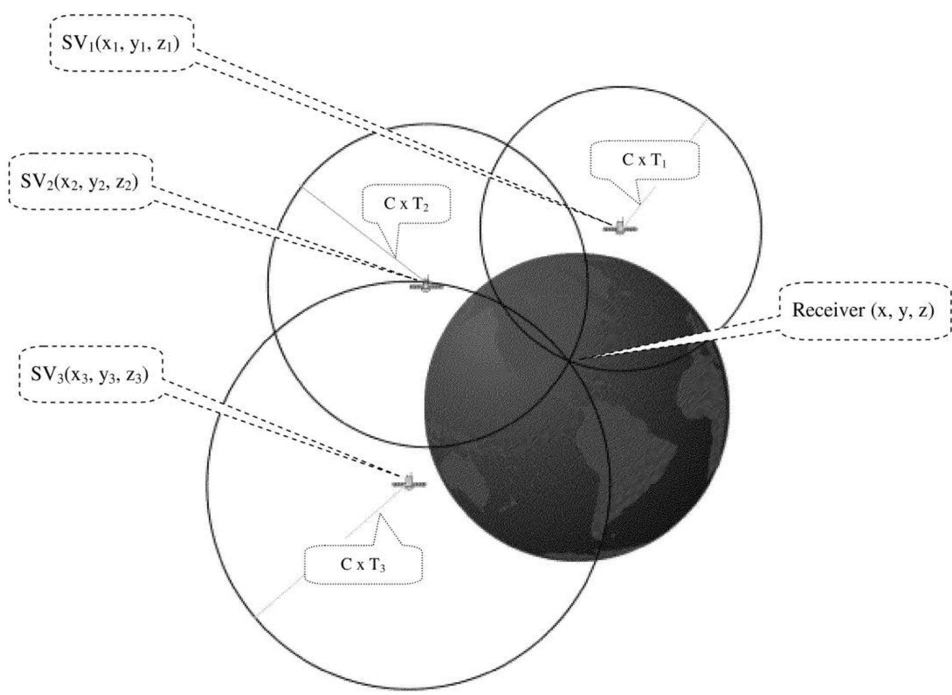


Figure 1.4 : Trilateration positioning method.

1.5 GNSS Signal Background

A GNSS is a spread spectrum system, where the spread signal occupies a bandwidth much greater than the rate of the data being transmitted. This redundancy of bandwidth serves to suppress the detrimental effects of interfering signals and reduces the peak transmitted signal power levels to effectively hide the signal in background noise. The spreading technique denoted Direct Sequence Spread Spectrum (DS-SS) refers to a technique where a carrier wave is modulated by a data signal overlaid with a high frequency pseudorandom noise (PRN) spreading signal.

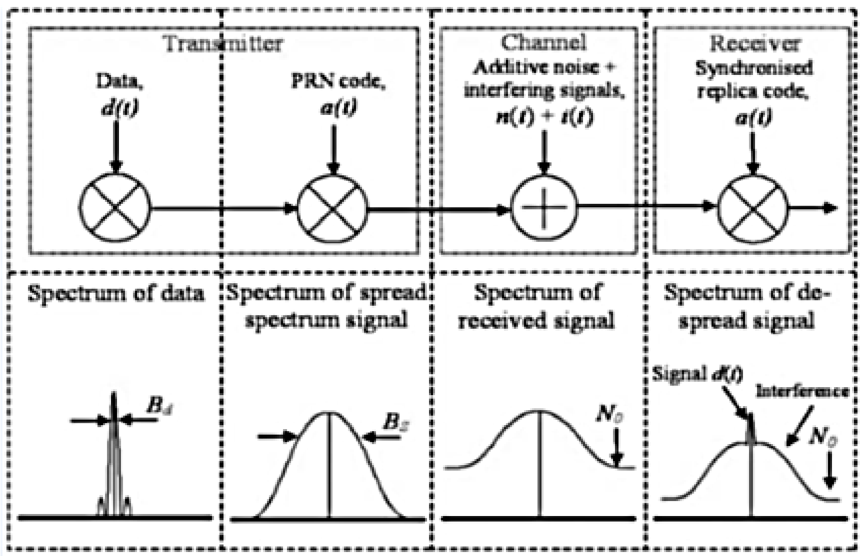


Figure 1.5 : Simplified conceptual spread spectrum system.

Figure 1.5 shows a conceptual diagram of a spread spectrum system, with the modulation onto the carrier omitted for simplicity. The narrow bandwidth, B_d of the data signal $d(t)$ is spread by a PRN code spreading signal, $a(t)$ of significantly higher bandwidth, B_z. The transmitted signal then passes through a channel, which applies additive noise, $n(t)$ and interfering signals, $i(t)$. A synchronized replica spreading code signal multiplied onto the received signal will then result in recovery of the desired signal with some error from thermal noise (spectral density N_o) and interference.

The innovation of GNSS, including the Global Positioning System (GPS), is that it uses the PRN code sequence as a ranging signal. In combination with its associated data signal this allows the path difference from transmitter to receiver to be recovered. The GPS satellite signals share the same carrier frequency and are separable in a receiver only because each respective transmission employs a unique PRN spreading code. Each effective bit of the PRN code sequence is called a *chip.*

Despite the fact that GPS is a code modulation of a continuous wave (CW) carrier, the navigational or ranging signal can be viewed as a sequence of periodic pulses, with a periodicity equal to the code length and pulse width of one chip. The range to each differently located GPS satellite is measured by the timing of these pulses and comparing the relative time delay of the pulses enables three-dimensional navigation. Heritage GPS uses binary PSK (BPSK) modulation, where ideally the carrier phase changes instantaneously by 180°, depending on the data-modulated spreading sequence. A BPSK modulated signal can be written as

$$S_{PSK}(t) = \sqrt{2P} \times a(t) \times \cos(\omega t) \times d(t) \tag{1.1}$$

Where, $d(t)$, $a(t) \in (-1, +1)$.

P is the signal power, $d(t)$ is the biphase data signal, $a(t)$ is the biphase PRN code spreading signal and ω is the carrier frequency. The designation BPSK-R (f_c) has been adopted to define this type of modulation, where f_c is the chipping rate and is a multiple of 1.023 MHz.

Currently, GPS consists of between 24 and 32 satellites broadcasting three navigational signals in the L-band, one signal available for civil use transmitted on the L1 carrier frequency and two military signals transmitted on the L1 and L2 carriers. The future 30-satellite Galileo constellation will introduce six data-modulated and four dataless signals into the L-band spectrum occupying four frequency bands.

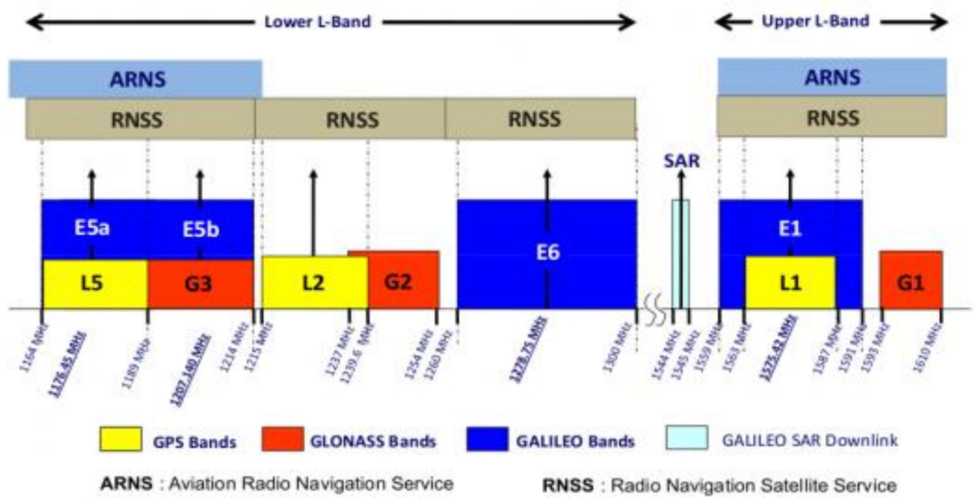


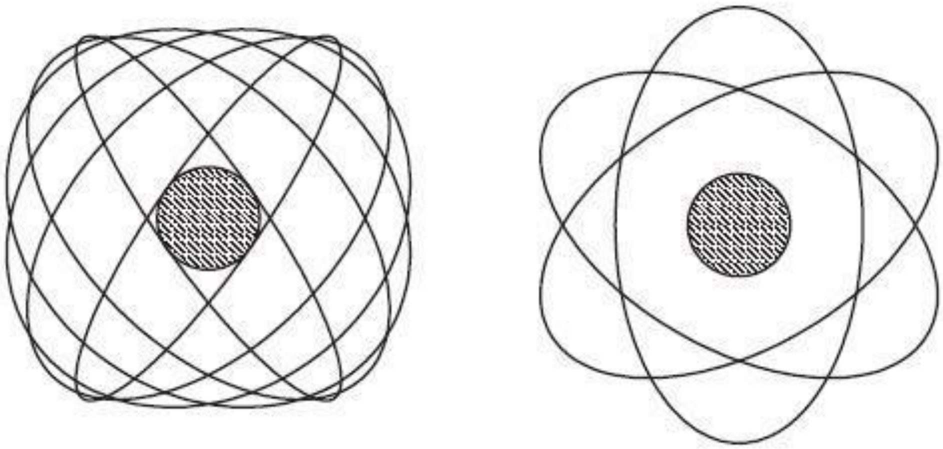
Figure 1.6 : Frequency band of GNSS systems.

1.6 GNSS Classification

There are many working GNSS systems. New systems are planning to be launched while existing systems are developing day by day.

1.6.1 Global Positioning System (GPS)

NAVSTAR GPS was developed by the U.S. government as a military navigation system. GPS provides continuous positioning and timing information, anywhere in the world under any weather conditions. Because it serves an unlimited number of users as well as being used for security reasons, GPS is a one-way-ranging (passive) system. To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes. With this constellation geometry, four to ten GPS satellites will be visible anywhere in the world, if an elevation angle of 10° is considered. The orbital radius (i.e., nominal distance from the center of mass of the Earth to the satellite) is approximately 26,600 km. The orbits are nearly circular and equally spaced around the equator at a 60° separation with a nominal inclination relative to the equatorial plane of 55°. The nominal orbital period of a GPS satellite is one-half of a sidereal day or 11 hours, 58 minutes.



. Figure 1.7 : GPS satellites orbit (a) viewed from equatorial plane (b) viewed from pole.

In each plane there are four operational satellites. There are 10 different GPS navigation signals, broadcast across three bands, known as link 1 (L1), link 2 (L2) and link 5 (L5). The carrier frequencies are 1575.42 MHz for L1, 1227.60 MHz for L2 and 1176.45 MHz for L5, while the declared double-sided signal bandwidth is 30.69 MHz in each band.

Figure 1.8 : GPS satellite.

1.6.2 GLONASS

GLONASS, Globalnaya Navigatsionnaya Sputnikovaya Sistema, was developed as a military navigation system by the USSR from the mid 1970s, in parallel to GPS. Like GPS, it was designed to offer both a civil and a military positioning service. The first satellite was launched in 1982. Following the dissolution of the Soviet Union, GLONASS development was continued by Russia, with a full satellite constellation achieved in 1995. However, due to financial problems and the relatively short lifetime of the satellites, the constellation was then allowed to decay, reaching a number of seven satellites in 2001.

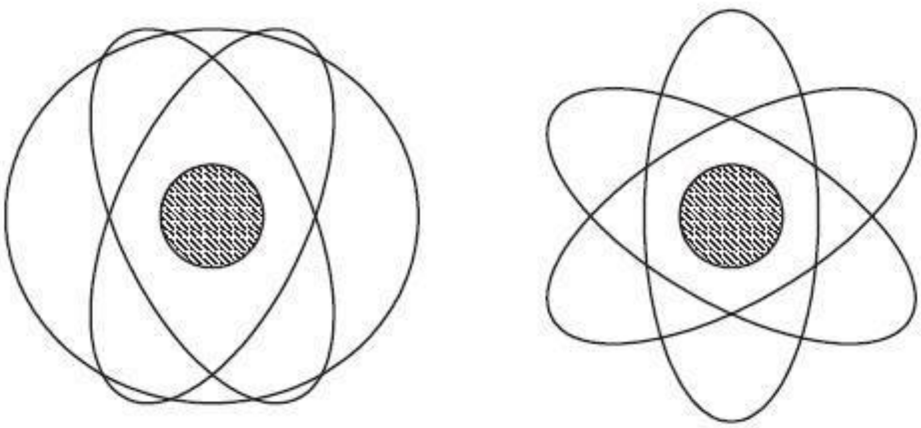


Figure 1.9 : GLONASS satellites orbit (a) viewed from equatorial plane (b) viewed from pole.

Figure 1.10 : GLONASS Satellite.

1.6.3 Galileo

Galileo is in its development phase and its initial operational capability is planned for 2010~2012 with full operational capability by 2014. The fully deployed Galileo system consists of 30 satellites (27 operational + 3 active spares), positioned in three circular Medium Earth Orbit (MEO) planes at 23,222 km altitude above the Earth and at an inclination of the orbital planes of 56 degrees to the equator. The nominal orbital period is 14 hours, 5 minutes, giving 1.7 orbits per sidereal day. So far four operational satellites launched - the basic minimum for satellite navigation in principle - serve to validate the Galileo concept with both segments: space and related ground infrastructure.

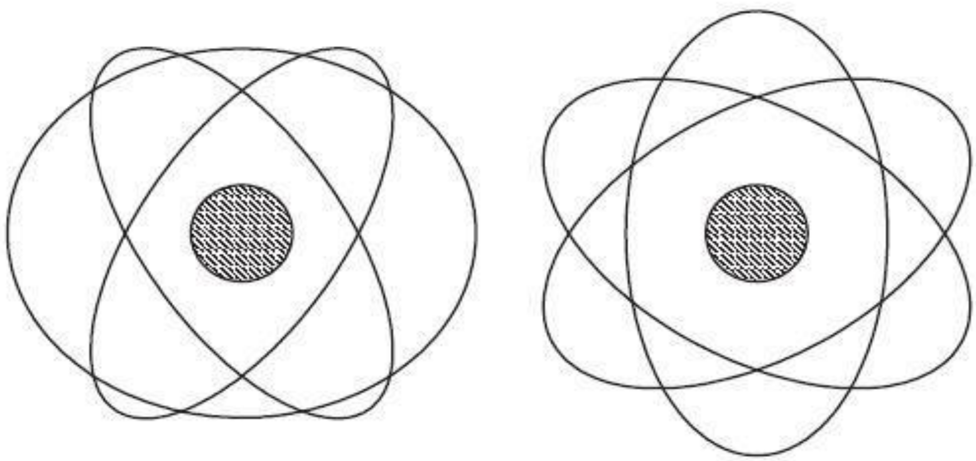


Figure 1.11 : Galileo satellites orbit (a) viewed from equatorial plane (b) viewed from pole.

Galileo broadcasts 10 different navigation signals across three frequency bands: E5, E6 and E1-L1-E2. The E5 band is 92.07 MHz (90 × 1.023 MHz) wide and centered at 1191.795 MHz. It is partitioned into E5a and E5b sub bands, with carrier frequencies of 1176.45 and 1207.14 MHz, respectively. The E6 and E1-L1-E2 bands are both 40.92 MHz wide and centered at 1278.75 and 1575.42 MHz respectively.

Figure 1.12 : Galileo Satellite.

1.6.4 BeiDou Navigation Satellite System

The BeiDou Navigation Satellite System is a Chinese satellite navigation system. It consists of two separate satellite constellations – a limited test system that has been operating since 2000 and a full-scale global navigation system that is currently under construction. BeiDou-1 is an experimental regional navigation system, which consists of four satellites (three working satellites and one backup satellite). The satellites themselves were based on the Chinese DFH-3 geostationary communications satellite and had a launch weight of 1,000 kilograms (2,200 pounds) each. Unlike the American GPS, Russian GLONASS and European Galileo systems, which use medium Earth orbit satellites, BeiDou-1 uses satellites in geostationary orbit. This means that the system does not require a large constellation of satellites, but it also limits the coverage to areas on Earth where the satellites are visible. The area that can be serviced is from longitude 70°E to 140°E and from latitude 5°N to 55°N. A frequency of the system is 2491.75 MHz.

1.7 GNSS Applications

Global Navigation Satellite System (GNSS) receivers, using the GPS, GLONASS, Galileo or BeiDou system are used in many applications. Those are briefly discussed here.

- Automobiles can be equipped with GNSS receivers at the factory or as after market equipment. Units often display moving maps and information about location, speed, direction and nearby streets and points of interest.
- Aircraft navigation systems usually display a "moving map" and are often connected to the autopilot for en-route navigation. Cockpit-mounted GNSS receivers and glass cockpits are appearing in general aviation aircraft of all sizes, using technologies such as WAAS or LAAS to increase accuracy. Many of these systems may be certified for instrument flight rules navigation and some can also be used for final approach and landing operations. Glider pilots use GNSS Flight Recorders to log GNSS data verifying their arrival at turn points in gliding competitions. Flight computers installed in many gliders also use GNSS to compute wind speed aloft and glide paths to way points such as alternate airports or mountain passes, to aid enroute decision making for cross-country soaring.
- Boats and ships can use GNSS to navigate all of the world's lakes, seas and oceans. Maritime GNSS units include functions useful on water, such as "man overboard" (MOB) functions that allow instantly marking the location where a person has fallen overboard, which simplifies rescue efforts. GNSS may be connected to the ships self-steering gear and Chart plotters using the National Marine Electronics Association (NMEA) 0183 interface. GNSS can also improve the security of shipping traffic by enabling Automatic Identification System (AIS).
- Heavy equipment can use GNSS in construction, mining and precision agriculture. The blades and buckets of construction equipment are controlled automatically in GNSS-based machine guidance systems. Agricultural equipment may use GNSS to steer automatically, or as a visual aid displayed on a screen for the driver. This is very useful for controlled traffic and row crop operations and when spraying. Harvesters with yield monitors can also use GNSS to create a yield map of the paddock being harvested.

- Spacecraft are now beginning to use GNSS as a navigational tool. The addition of a GNSS receiver to a spacecraft allows precise orbit determination without ground tracking. This, in turn, enables autonomous spacecraft navigation, formation flying and autonomous rendezvous. The use of GNSS in MEO, GEO, HEO and highly elliptical orbits is feasible only if the receiver can acquire and track the much weaker (15~20 dB) GNSS side-lobe signals. This design constraint and the radiation environment found in space, prevents the use of Commercial off-the-shelf (COTS) receivers. Low earth orbit satellite constellations such as the one operated by ORBCOMM uses GPS receivers on all satellites.
- Survey-Grade GNSS receivers can be used to position survey markers, buildings and road construction. These units use the signal from both the L1 and L2 GPS frequencies. Even though the L2 code data are encrypted, the signal's carrier wave enables correction of some ionospheric errors. These dual-frequency GPS receivers typically cost US$10,000 or more, but can have positioning errors on the order of one centimeter or less when used in carrier phase differential GPS mode.
- Most mapping grade GNSS receivers use the carrier wave data from only the L1 frequency, but have a precise crystal oscillator which reduces errors related to receiver clock jitter. This allows positioning errors on the order of one meter or less in real-time, with a differential GNSS signal received using a separate radio receiver. By storing the carrier phase measurements and differentially post-processing the data, positioning errors on the order of 10 centimeters are possible with these receivers. Several projects, including OpenStreetMap and TierraWiki, allow users to create maps collaboratively, much like a wiki, using consumer-grade GPS receivers.
- High precision measurements of crustal strain can be made with differential GNSS by finding the relative displacement between GNSS sensors. Multiple stations situated around an actively deforming area (such as a volcano or fault zone) can be used to find strain and ground movement. These measurements can then be used to interpret the cause of the deformation, such as a dike or sill beneath the surface of an active volcano.
- Many systems that must be accurately synchronized use GNSS as a source of accurate time. GNSS can be used as a reference clock for time code generators or Network Time Protocol (NTP) time servers. Sensors (for seismology or other monitoring application),

can use GNSS as a precise time source, so events may be timed accurately. Time division multiple access (TDMA) communications networks often rely on this precise timing to synchronize RF generating equipment, network equipment and multiplexers.

1.8 Objective of the Thesis

The main objective of this thesis is to study and analyze the performance of GNSS i.e. GPS, Galileo, improvements in interoperability of GPS-Galileo and a GNSS based tracking system. The main purposes are:

- To study the constellation and availability of the satellite system;
- To study the effect of interoperability of GPS - Galileo;
- To analyze the preciseness of the system;
- To monitor the integrity of the navigation system;
- To analyze GNSS specially GPS receivers and their supporting technology;
- To propose a GPS tracking system;

1.9 Organization of the Thesis

Chapter 1 is the introductory chapter. It consists of the basics of satellite navigation, its evolution and present status.

Chapter 2 presents the model of satellite constellation and describes the satellite tracking systems.

Chapter 3 depicts the preciseness of GNSS positioning errors i.e. DOP values.

Chapter 4 represents the Receiver Autonomous Integrity Monitoring (RAIM) algorithm, its working principle and the improvement of RAIM.

Chapter 5 shows the interoperability and compatibility of the GNSS systems.

Chapter 6 briefly discusses the design of GNSS receivers and gives idea on some next generation receivers.

Chapter 7 presents a theoretical design of a GPS based tracking system.

Chapter 8 represents the result summary, concluding remarks and scope of future work.

CHAPTER 2

SATELLITE CONSTELLATION AND AVAILABILITY

2.1 Satellite Constellation

A group of artificial satellites working in concert is known as a satellite constellation. Such a constellation can be considered to be a number of satellites with coordinated ground coverage, operating together under shared control, synchronised so that they overlap well in coverage and complement rather than interfere with other satellites coverage. A circular satellite network system can be either an LEO or MEO satellite network according to the orbital altitude.

In the composition of a multilayered constellation, usually the number of GEO satellites is the smallest. The orbital altitude of GEO satellites is the highest and the link loss is the heaviest, hence the required user terminal's effective isotropic radiated power (EIRP) and G/T value is the highest. The number of MEO and LEO satellite is usually larger. The orbital altitudes of MEO and LEO satellites are lower and the link loss is relatively small, which makes lower EIRP and G/T requirements of the ground station. Compared with GEO satellites, LEO and MEO satellites are more conductive to the communication between ground users and the satellite.

2.2 LEO Satellite Constellation

A LEO communication satellite constellation system is a constellation of satellites that orbit the Earth at an altitude of about 500 ~ 1500 km and provide wireless communications between terminals on the ground. There are two major types of constellations: Polar and Walker (Figure 2.1). Both constellations are designed to provide the most efficient global coverage by using a minimum number of satellites, each with its own advantages and disadvantages.

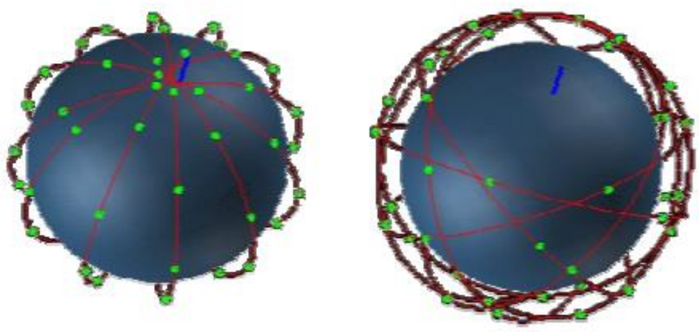


Figure 2.1 : Polar (left) and Walker satellite constellation (right) .

A polar constellation provides coverage for the entire globe, including the poles, while a Walker constellation only covers areas below a certain latitude (such as +/-70° in the case of Globalstar). With the same number of satellites, a Walker constellation can therefore provide a higher diversity than a polar constellation. Diversity is the average number of satellites simultaneously in view of a user on the ground. A high diversity will bring technical benefits such as higher availability, fewer dropped connections and reduced multipath fading. LEO systems overcome the distance problem that plagues the GEO systems. Time delay for LEO systems is on the order of 10 milliseconds, negligible for voice communication.

2.3 GPS: Satellite Constellation

The presently available full constellation guarantees simultaneous observations of at least four GPS satellites from (almost) every point on the surface of the Earth at (almost) every time of the day. This is accomplished by 24 satellites (21 plus 3 active spares) located in six orbital planes in almost circular orbits with an altitude of about 20,200 km above the surface of the Earth. The orbital plane is inclined by 55°(degrees) with respect to the equator. The sidereal revolution period of the GPS satellites is 11 hours 58 minutes (approximately half a sidereal day). Consequently, the same satellite configuration is repeated 4 minutes earlier every day for one and the same location. Due to this orbital revolution period the GPS satellites are in deep 2:1 resonance with the rotation of the Earth with respect to inertial space which gives rise to resonance perturbations. The orbits are arranged so that at least six satellites are always within line of sight from almost everywhere on Earth's surface.

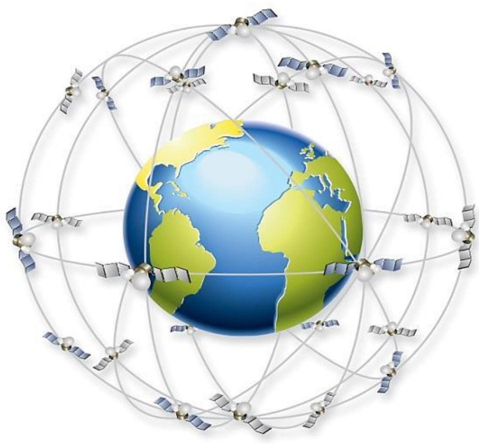


Figure 2.2 : GPS Satellite constellation.

The result of this objective is that the four satellites are not evenly spaced (90° degrees) apart within each orbit. In general terms, the angular difference between satellites in each orbit is 30°, 105°, 120°, and 105° (degrees) apart which sum to 360° degrees.

2.4 Galileo: Satellite Constellation

The fully deployed Galileo system will consist out of 30 satellites, 27 operational satellites and 3 active in orbit spares. The Galileo satellites will be positioned in three circular Medium Earth Orbital (MEO) planes with an altitude of 23,222 km above the Earth. This means the Galileo satellites are above the GPS and GLONASS satellites. The so called "repeat cycle" for the Galileo satellite orbits is 10 days. The orbital revolution period being 14 hours and 7 minutes. The inclination of the orbital planes will be 56° (degrees) with reference to the equatorial plane. In full orbit constellation (FOC) the Galileo navigation signals will provide good coverage even at latitudes up to 75° degrees north, which corresponds to the North Cape, and beyond. The large number of satellites together with the optimisation of the constellation, and the availability of three active spare satellites, will ensure that the loss of one satellite does not affect the end users of the system.

2.5 GLONASS: Satellite Constellation

A fully operational GLONASS constellation consists of 24 satellites, with 21 used for transmitting signals and three for in - orbit spares, deployed in three orbital planes. The three orbital planes ascending nodes are separated by 120° (degrees) with each plane containing eight equally spaced satellites. The orbits are roughly circular, with an inclination of about 64.8° (degrees), and orbit the Earth at an altitude of 19,100 km, which yields an orbital period of approximately 11 hours, 15 minutes. The planes themselves have a latitude displacement of 15° (degrees), which results in the satellites crossing the equator one at a time, instead of three at once. The overall arrangement is such that, if the constellation is fully populated, a minimum of 5 satellites are in view from any given point at any given time. This guarantees for continuous and global navigation for users world-wide.

Each satellite is identified by a "slot" number, which defines the corresponding orbital plane and the location within the plane; numbers 1 ~ 8 are in plane one, 9 ~ 16 are in plane two, and 17 ~ 24 are in plane three.

A characteristic of the GLONASS constellation is that any given satellite only passes over the exact same spot on the Earth every eighth sidereal day. However, as each orbit plane contains eight satellites, a satellite will pass the same place every sidereal day. For comparison, each GPS satellite passes over the same spot once every sidereal day. So opposed to the GPS the ground-track of the GLONASS satellites do not repeat after one day. This avoids the resonance effects which makes station keeping of GPS satellites difficult and expensive.

2.6 Satellite Availability

Availability depends on the constellation or geometry of the satellites. Good satellite geometry is obtained when the satellites are spread out in the sky. In general, the more spread out the satellites are in the sky, the better is the satellite geometry, and vice versa. The combined system definitely gives more satellite availability than any single system.

2.7 Analysis and Result

In order to determine satellite availability, different cases can be considered. One is the tracking of the satellites and the another is for spatial variation where the simulation is done for the entire world. Therefore, analysis is carried out for these two cases.

2.7.1 Satellite Tracking

Satellite tracking defines how much satellites are come to view at a time. It provides the geometry of the satellite placement and has very important role in accuracy and reliability analysis.

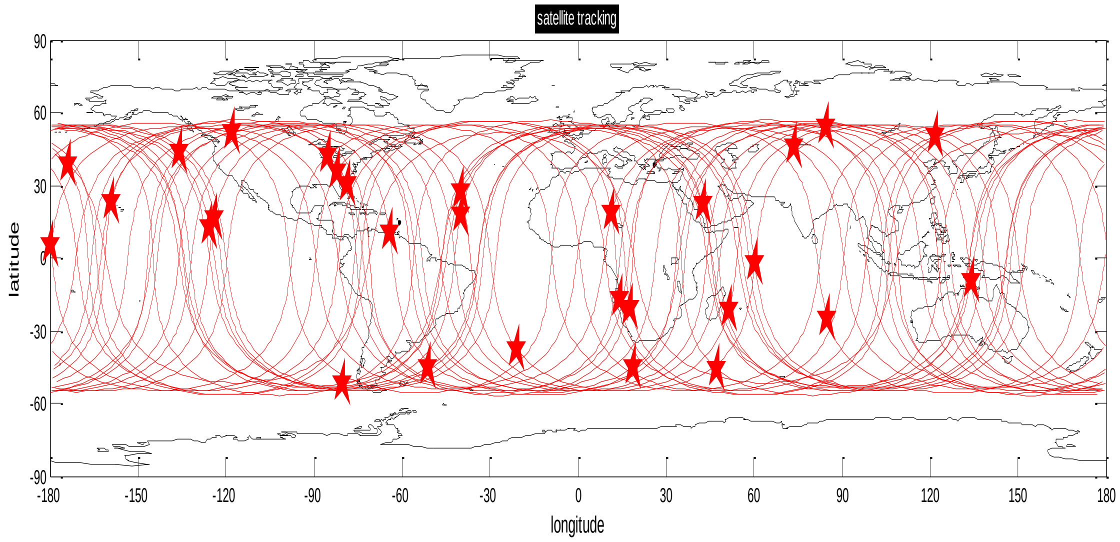


Figure 2.3 (a) : Satellite tracking of GPS.

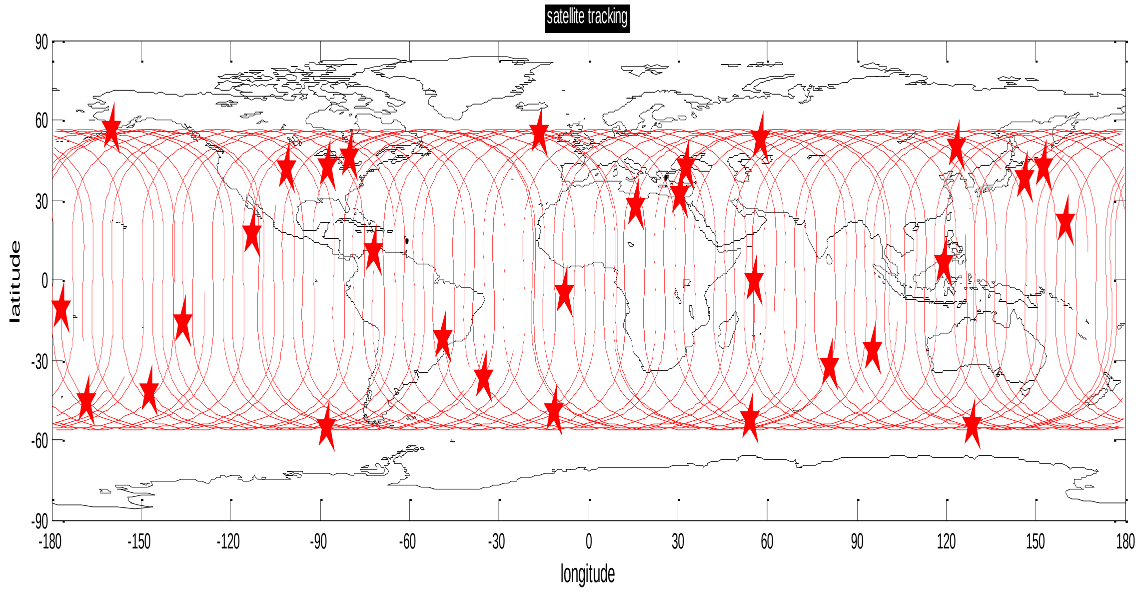


Figure 2.3 (b) : Satellite tracking of Galileo.

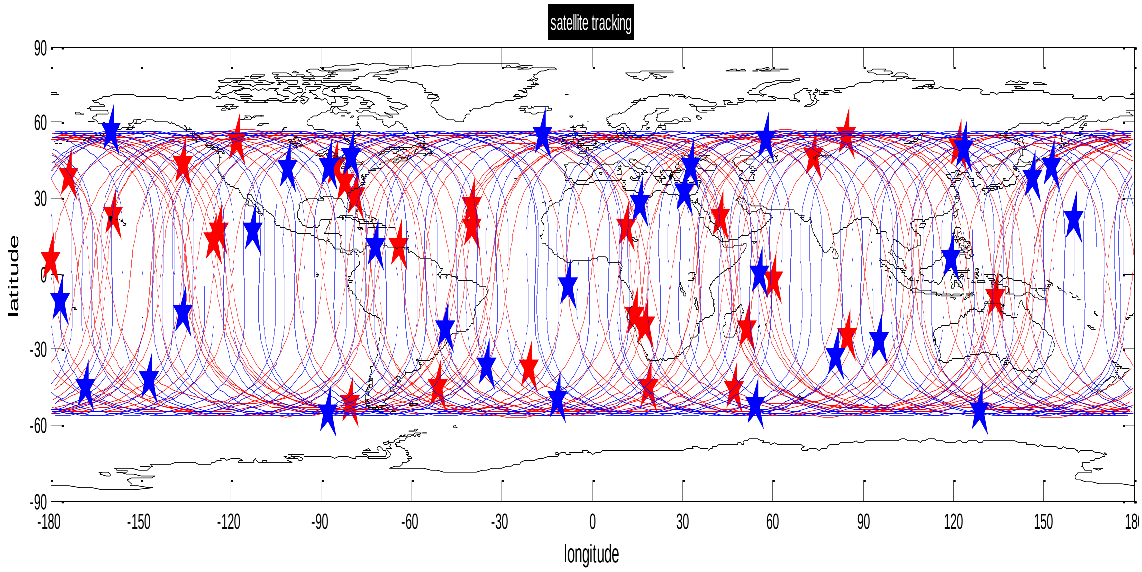


Figure 2.3 (c) : Combined constellation of GPS and Galileo.

Combination of two systems give improved geometry as it provides more number of satellites and accuracy.

2.7.2 Spatial Variation of the Entire World

In spatial variation it is examined that how much satellites are available for individual satellite system worldwide and how combined system of GPS-Galileo improved this variation. If we consider the combined system we find that the number of available satellites increases as combined constellation contains more satellites. The number of satellites in combined system doubles the number of satellites in single system (cut of elevation 10).

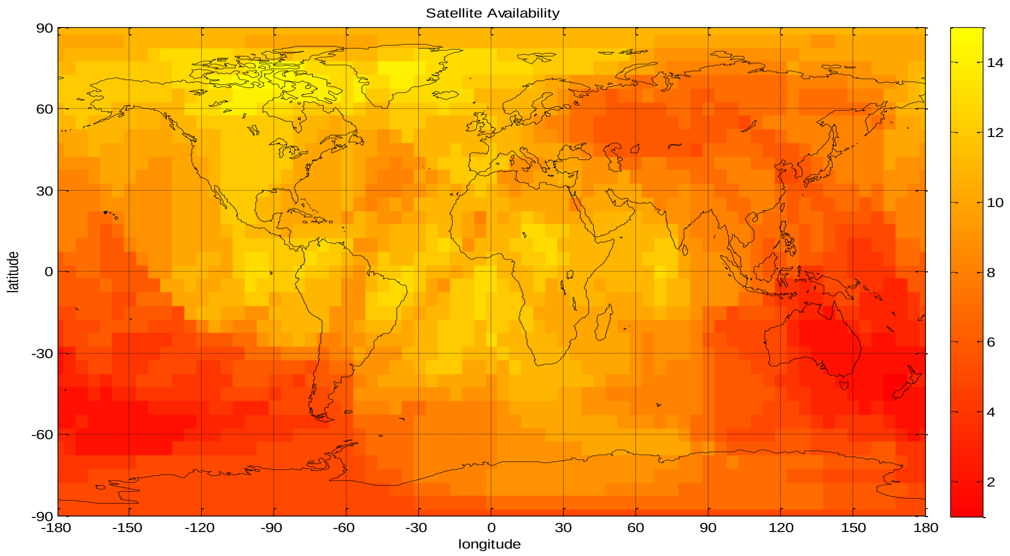


Figure 2.4 (a) : GPS satellites availability all over the world.

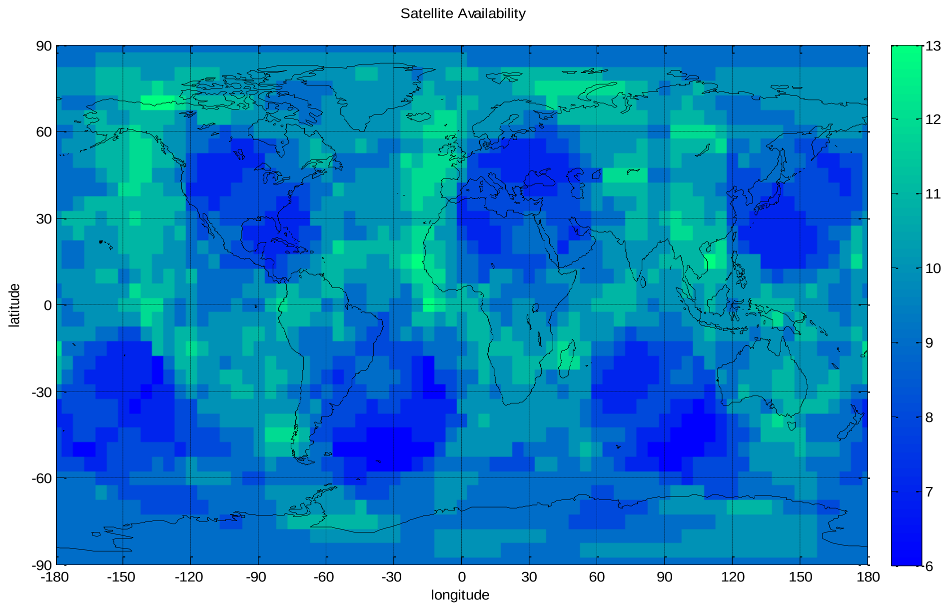


Figure 2.4 (b) : Galileo satellites availability all over the world.

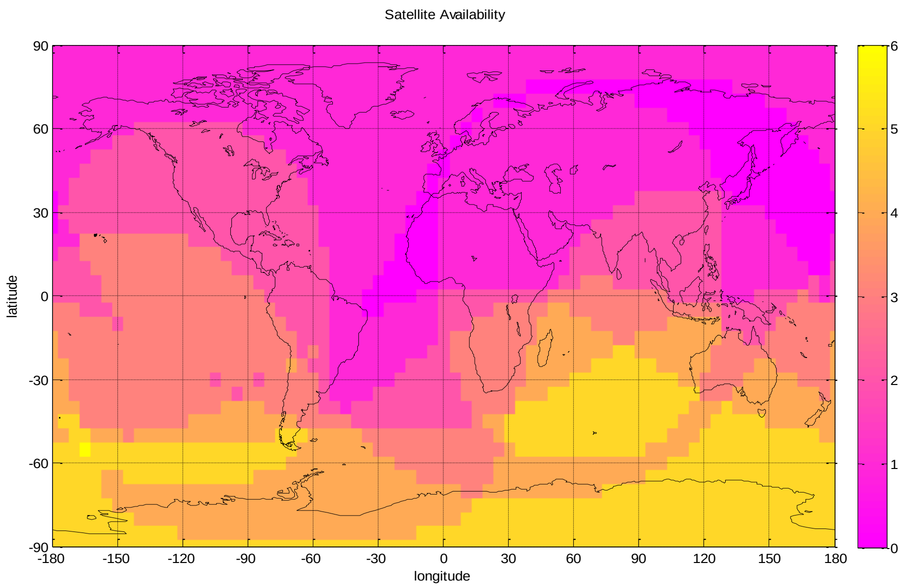


Figure 2.4 (c) : GLONASS satellites availability all over the world.

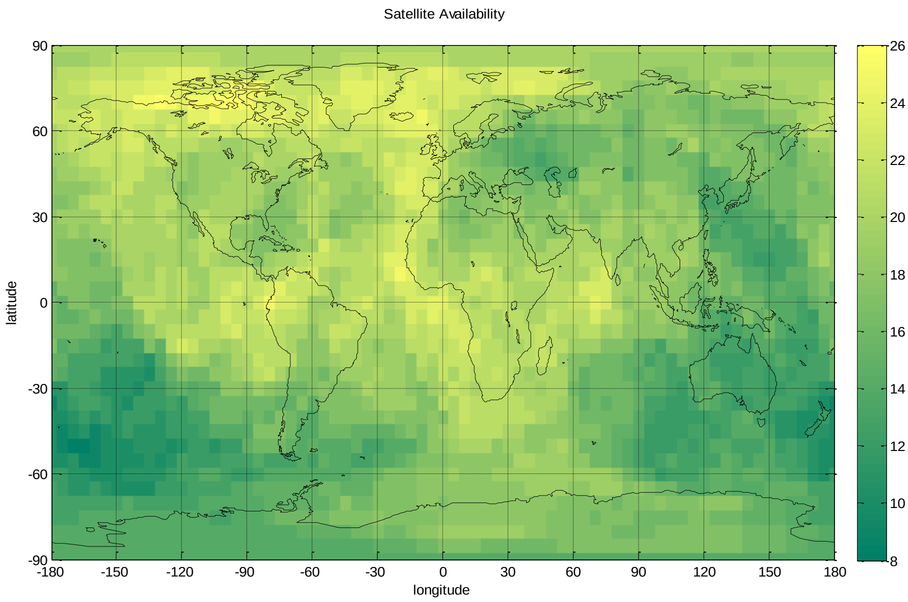


Figure 2.4 (d) : Combined GPS-Galileo system satellites availability all over the world.

The combined GPS-Galileo system provides highest 26(twenty six) satellites where GPS system alone provides 14(fourteen) satellites, Galileo system provides 13(thirteen) satellites and GLONASS system provides only 6(six) satellites respectively.

2.8 Graphical Analysis

Another analysis for each satellite system and their combined can be obtained by the graphical analysis.

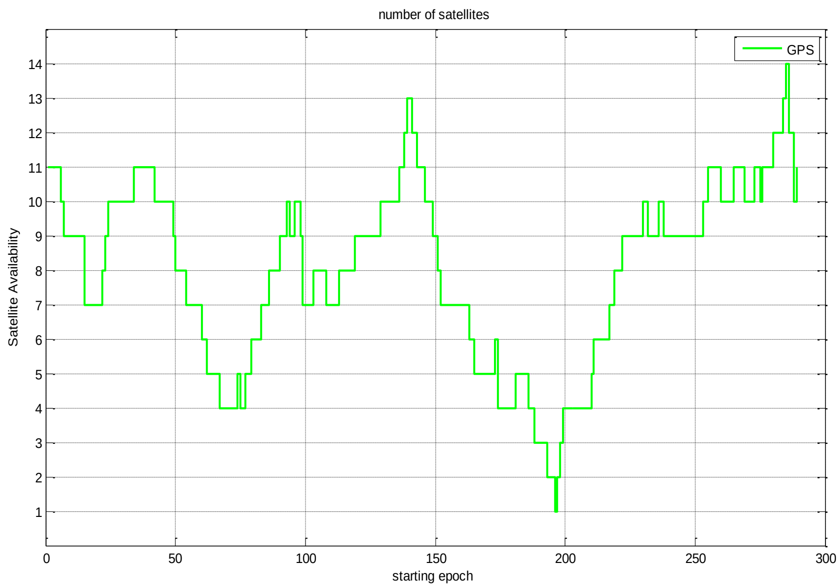


Figure 2.5 (a) : GPS satellites availability (14 satellites).

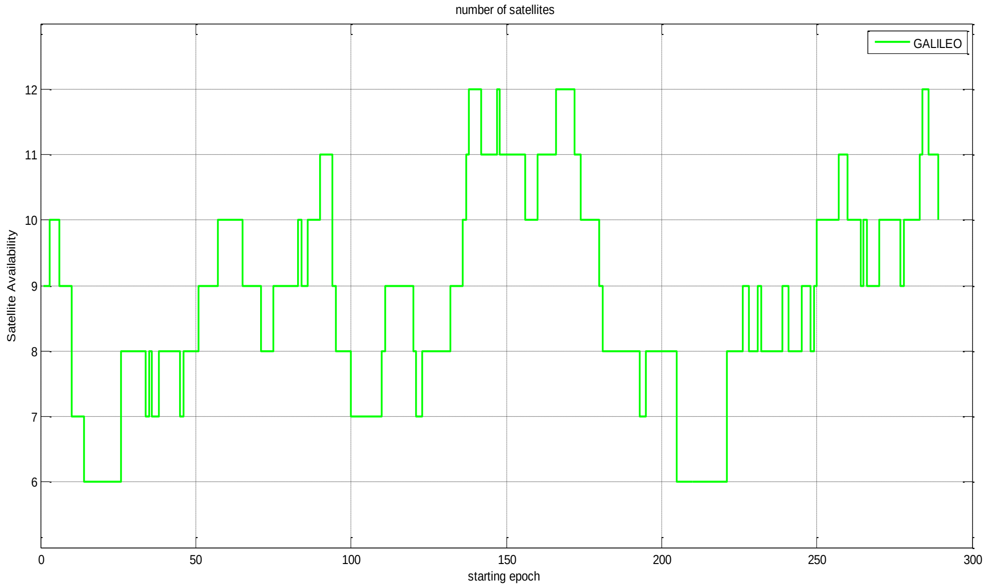


Figure 2.5 (b) : Galileo satellites availability (12 satellites).

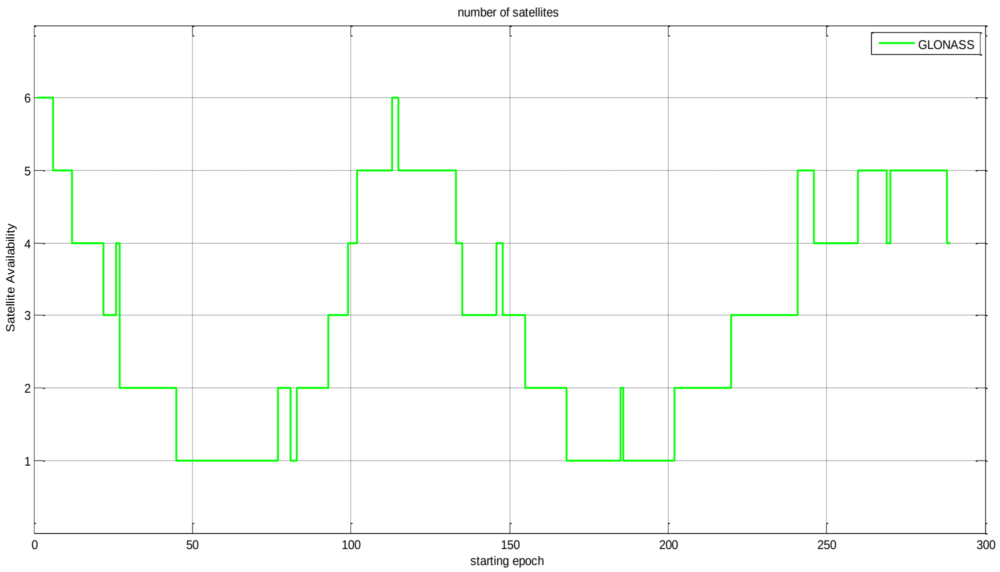


Figure 2.5 (c) : GLONASS satellites availability (6 satellites).

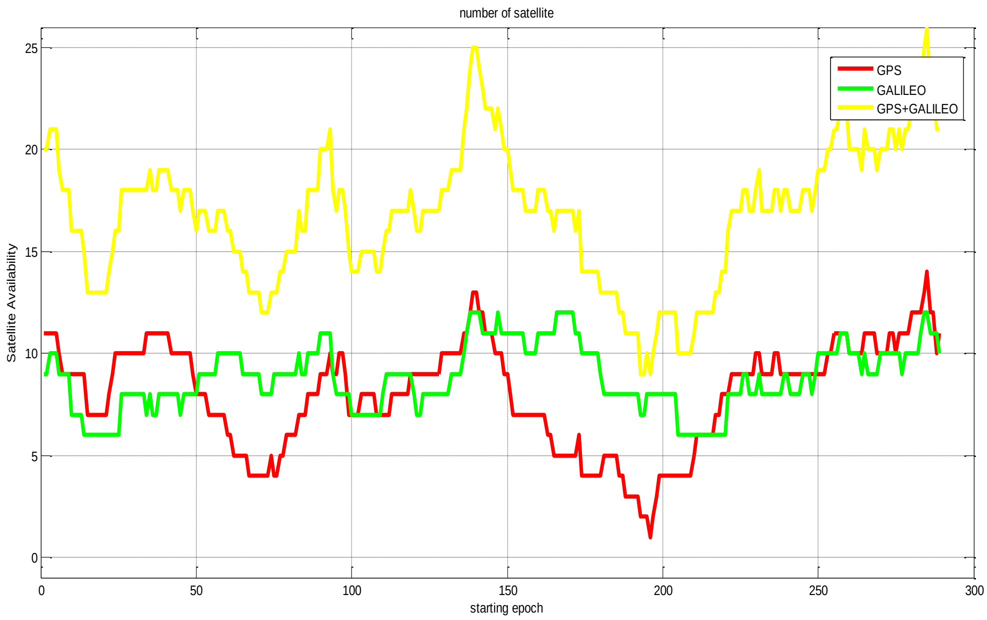


Figure 2.5 (d) : Combined GPS-Galileo satellites availability.

Availability mainly depends on the constellation or geometry of satellites. The number of satellites will be different at different location at same time. This is because of the satellite geometry. Also the number of satellites available will vary at a specific location with time as the satellites are moving on its own orbit.

CHAPTER 3

SATELLITE GEOMETRY & DILUTION OF PRECISION

3.1 Satellite Geometry

The accuracy of GPS system is affected by several factors. One such factor is satellite geometry, which represents the geometric locations of the GPS satellites as seen by GPS receiver. This plays a very important role in determining the total positioning accuracy. Better the geometry, better the position accuracy. The satellite geometry effect can be measured by a single dimensionless number called Geometric Dilution of Precision (GDOP). Lower the GDOP value, better the satellite geometry. GPS requires minimum of four satellites to compute user position. When more number of satellites are in view, best four satellites are taken in order to reduce the redundancy. With four satellites, best geometry is obtained when one of the satellites is at the zenith and remaining three forms an equilateral triangle and all the four together forms a tetrahedron structure. The larger the volume of the tetrahedron, the better is the value of GDOP. Similarly, greater the number of satellites, better the value of GDOP. Practically, GDOP ranges from 2 to 6. Monitoring of GDOP is also an important aspect for high-precision applications such as surveying and Integrity monitoring in the GPS receivers.

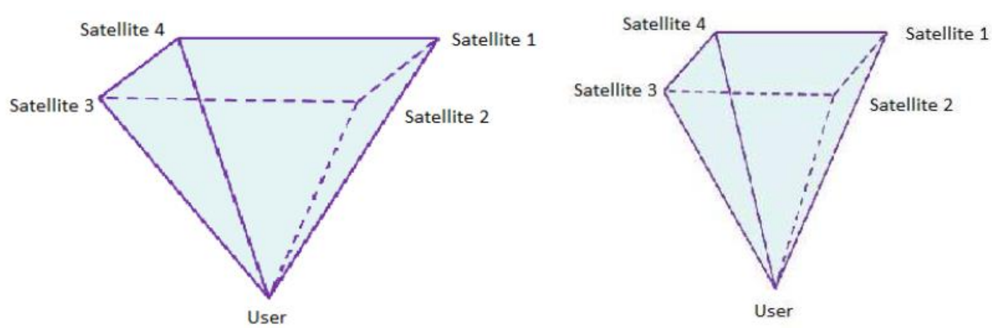


Figure 3.1 : Tetrahedron structure for better GDOP (left) and worse GDOP (right).

GPS is a satellite based navigation system is developed to provide user with his position, velocity and time. A GPS receiver computes its position using a technique called '3-Dimensional multilateration', which is the process of figuring out where a number of spheres intersect, with each sphere has a satellite at its center. The radius of the sphere is the distance between the receiver and the satellite. Ideally, these spheres intersect at one point, which is the possible solution to the current position of the receiver. In reality, this intersection of spheres forms an area. In such case, the current position of the receiver may be at any point with in the area, causing an uncertainty in the receiver position. Figure 3.2 represents the trilateration, in which the shaded part represents the possible area in which receiver would be located and the actual receiver position, is represented by a small circle.

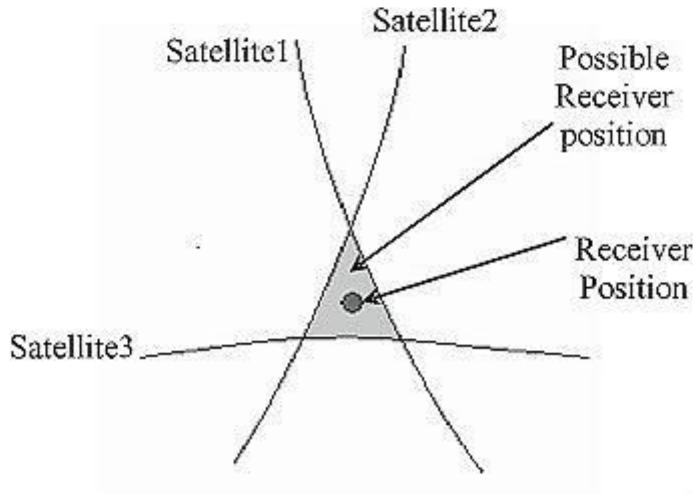


Figure 3.2 : Trilateration.

Several external sources introduce errors into GPS position estimated by a GPS receiver. One important source of error is the geometry of the satellites from which signals are being received. The computed receiver position can vary depending on which satellites are used for the measurement. Different satellite geometries can magnify or lessen the position error. DOP can be computed by selecting optimum four satellites or by using all satellites in view. Wider the angular separation between the satellites, lower the DOP. Lower the DOP, better the geometry.

Navigation solution accuracy can be degraded by satellite geometry which represents the geometric locations of the satellites seen by receiver. As an example, Satellite geometry representation is illustrated for two satellites in Figure 3.3. Two arcs are drawn from each satellite considering the satellite as the center. Inner arc is drawn considering true range as the radius and outer arc is drawn with pseudorange as the radius. Intersection area of these arcs of the two satellites represents the possible user location. When the two satellites are placed farther, intersection area is small which indicates low uncertainty of position, this in turn represents better satellite geometry. When the two satellites are placed closer, intersection area is large which indicates high uncertainty of position, this in turn represents poor satellite geometry. In the similar way, with many satellites in view, a good geometry is formed when the satellites are spread wider in space. As GPS requires minimum of four satellites for user position determination, Figure 3.4 represents the satellite geometry with four satellites if the four satellites spread apart, GDOP obtained is minimum and this forms the good satellite geometry. When the satellites are closer, GDOP obtained is maximum which indicates the Geometry is poor.

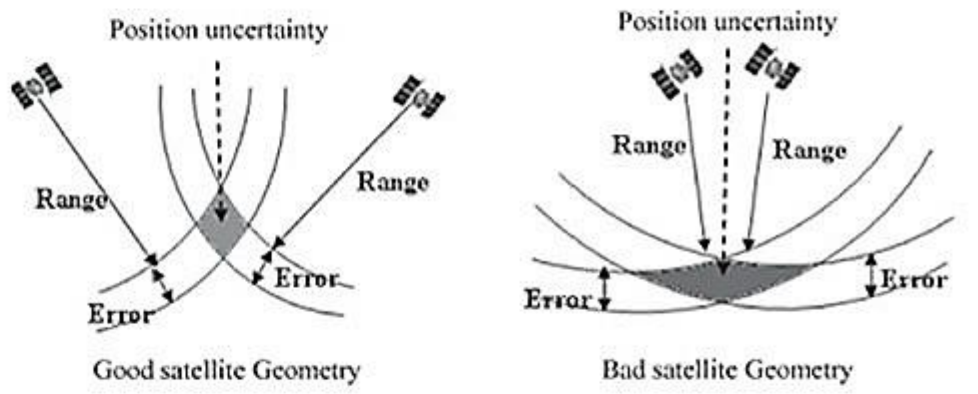


Figure 3.3 : Satellite Geometry representation for two satellites.

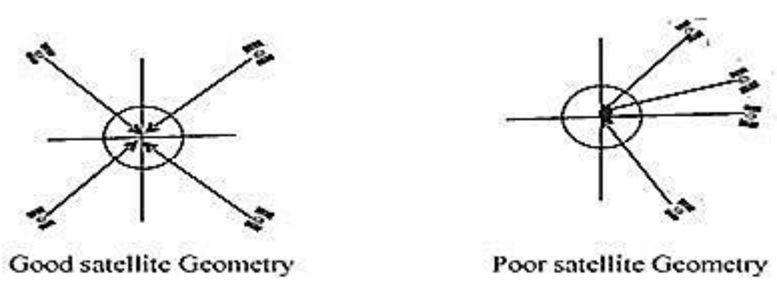


Figure 3.4 : Satellite Geometry representation.

3.2 Dilution of Precision

Dilution of Precision (DOP) often called as Geometric Dilution of Precision (GDOP) is a dimensionless number, which is a measure of satellite geometry. There are two ways,

- DOP analysis for best four satellites: In such case, GDOP computation is based on the optimum four satellites in view.
- DOP analysis with all satellites in view: The more the satellites used in the solution, smaller the DOP value and hence smaller the solution error. GDOP computed with all satellites in view is better than the one computed using best four satellites.

GDOP is resolved into various forms as,

- Position Dilution of Precision (PDOP): It is a measure of the uncertainty in three dimensional position of the navigation solution.
- Horizontal Dilution of Precision (HDOP): It is a measure of uncertainty in horizontal position (Longitude and Latitude) of the navigation solution.
- Vertical Dilution of Precision (VDOP): It is a measure of uncertainty in vertical position (Altitude) of the navigation solution.
- Time Dilution of Precision (TDOP): It is a measure of uncertainty in receiver clock .

Table 3.1 : DOP Ratings

DOP Value	Ratings
1	Ideal
2 ~ 4	Excellent
4 ~ 6	Good
6 ~ 8	Moderate
8 ~ 20	Fair
20 ~ 50	Poor

3.2.1 Computation of Dilution of Precision (DOP)

Satellite navigation depends on accurate range measurements in order to determine the position of the receiver. Navigation solution of the receiver is nothing but the computation of receiver's three dimensional coordinates and its clock offset from four or more simultaneous pseudorange measurements. Prior to solving for three-dimensional user position, we will examine the fundamental concepts involving satellite-to-user range determination with nonsynchronized clocks and PRN codes. There are a number of error sources that affect range measurement accuracy (e.g., measurement noise and propagation delays); however, these can generally be considered negligible when compared to the errors experienced from nonsynchronized clocks.

3.2.2 Determining Satellite to User Range

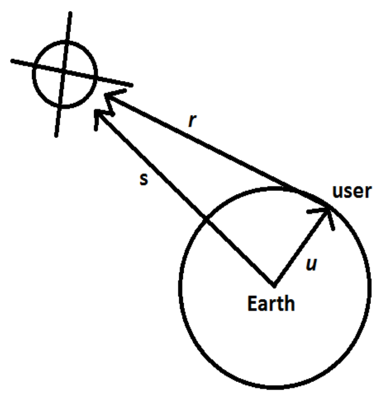


Figure 3.5 : Determining satellite to user range.

Let u represents the user receiver's position with respect to the ECEF (Earth Centered Earth Fixed) coordinate system origin. The user's position coordinates x_u , y_u , z_u are considered unknown . Vector r represents the vector offset from the user to the satellite. Vector s represents the position of the satellite relative to the coordinate origin. The satellite and receiver clocks are generally not synchronized. By multiplying this propagation time Δt, by the speed of light the true satellite to user distance can be computed.

The satellite to user vector r is, $r = ||s - u||$ (3.1)

Geometric range, $r = c(T_u - T_s) = c\Delta t$ (3.2)

Pseudorange, $\rho = c[(T_u + t_u) - (T_s - \delta t)]$

$$= c(T_u - T_s) + c(t_u - \delta t)$$

$$= r + c(t_u - \delta t) \quad (3.3)$$

Where,

T_s = System time at which the signal left the satellite.

T_u = System time at which the signal reached the user receiver.

δt = Offset of the satellite clock from system time

t_u = Offset of the receiver clock from system time.

c = Speed of light.

The system Equation, $\rho = ||s - u|| + ct_u$ (3.4)

For four satellite,

$$\rho_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + ct_u$$

$$\rho_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + ct_u$$

$$\rho_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + ct_u \quad (3.5)$$

$$\rho_4 = \sqrt{(x_4 - x_u)^2 + (y_4 - y_u)^2 + (z_4 - z_u)^2} + ct_u$$

Let a single pseudorange be represented by

$$\rho_j = \sqrt{\left(x_j - x_u\right)^2 + \left(y_j - y_u\right)^2 + \left(z_j - z_u\right)^2} + ct_u$$

$$= f(x_u, y_u, z_u, t_u) \quad (3.6)$$

Where $x_j, y_j \; and \; z_j$ denote the jth satellite position in three dimensions and j ranges from 1 to 4.

Using the approximate position location,

$$\hat{\rho}_j = \sqrt{\left(x_j - \hat{x}_u\right)^2 + \left(y_j - \hat{y}_u\right)^2 + \left(z_j - \hat{z}_u\right)^2} + c\hat{t}_u$$

$$= f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u) \quad (3.7)$$

As stated above, the unknown user position and receiver clock offset is considered to consist of an approximate component and an incremental component. So,

$$x_u = \hat{x}_u + \Delta x_u$$

$$y_u = \hat{y}_u + \Delta y_u$$

$$z_u = \hat{z}_u + \Delta z_u \quad (3.8)$$

$$t_u = \hat{t}_u + \Delta t_u$$

Therefore, we can write

$$f(x_u, y_u, z_u, t_u) = f(\hat{x}_u + \Delta x_u, \hat{y}_u + \Delta y_u, \hat{z}_u + \Delta z_u, \hat{t}_u) \quad (3.9)$$

Expansion by Taylor Series,

$$f(\hat{x}_u + \Delta x_u, \hat{y}_u + \Delta y_u, \hat{z}_u + \Delta z_u, \hat{t}_u + \Delta t_u) \;=\; f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)$$

$$+ \frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{x}_u} \Delta x_u + \frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{y}_u} \Delta y_u + \frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{z}_u} \Delta z_u + \frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{t}_u} \Delta t_u + \; \ldots \quad (3.10)$$

The partials derivatives evaluate as follows,

$$\frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{x}_u} = -\frac{x_j - \hat{x}_u}{\hat{r}_j} = -a_{x_j}$$

$$\frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{y}_u} = -\frac{y_j - \hat{y}_u}{\hat{r}_j} = -a_{y_j}$$

$$\frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{z}_u} = -\frac{z_j - \hat{z}_u}{\hat{r}_j} = -a_{z_j} \tag{3.11}$$

$$\frac{\delta f(\hat{x}_u, \hat{y}_u, \hat{z}_u, \hat{t}_u)}{\delta \hat{t}_u} = c$$

Where,

$$\hat{r}_j = \sqrt{\left(x_j - \hat{x}_u\right)^2 + \left(y_j - \hat{y}_u\right)^2 + \left(z_j - \hat{z}_u\right)^2} \tag{3.12}$$

The a_{x_j}, a_{y_j} and a_{z_j} terms denote the direction cosines of the unit vector pointing form the approximate user position to the jth satellite.

$$a_j = (a_{xj}, a_{yj}, a_{zj})$$

Now, we can write,

$$\rho_j - \hat{\rho}_j = -\frac{x_j - \hat{x}_u}{\hat{r}_j}\Delta x_u - \frac{y_j - \hat{y}_u}{\hat{r}_j}\Delta y_u - \frac{z_j - \hat{z}_u}{\hat{r}_j}\Delta z_u + c\Delta t_u \tag{3.13}$$

Now if $\Delta\rho_j = \hat{\rho}_j - \rho_j$

$$\hat{\rho}_j - \rho_j = \frac{x_j - \hat{x}_u}{\hat{r}_j}\Delta x_u + \frac{y_j - \hat{y}_u}{\hat{r}_j}\Delta y_u + \frac{z_j - \hat{z}_u}{\hat{r}_j}\Delta z_u - c\Delta t_u \tag{3.14}$$

So, $$\Delta\rho_j = a_{x_j}\Delta x_u + a_{y_j}\Delta y_u + a_{z_j}\Delta z_u - c\Delta t_u \tag{3.15}$$

The unknown quantities can be determined by solving the set of linear equations below,

$$\Delta\rho_1 = a_{x1}\Delta x_u + a_{y1}\Delta y_u + a_{z1}\Delta z_u - c\Delta t_u$$

$$\Delta\rho_2 = a_{x2}\Delta x_u + a_{y2}\Delta y_u + a_{z2}\Delta z_u - c\Delta t_u$$

$$\Delta\rho_3 = a_{x3}\Delta x_u + a_{y3}\Delta y_u + a_{z3}\Delta z_u - c\Delta t_u \tag{3.16}$$

$$\Delta\rho_4 = a_{x4}\Delta x_u + a_{y4}\Delta y_u + a_{z4}\Delta z_u - c\Delta t_u$$

In the matrix form,

$$\Delta\rho = \begin{bmatrix}\Delta\rho_1\\ \Delta\rho_2\\ \Delta\rho_3\\ \Delta\rho_4\end{bmatrix} \quad H = \begin{bmatrix}a_{x1}\ a_{y1}\ a_{z1}\ 1\\ a_{x2}\ a_{y2}\ a_{z2}\ 1\\ a_{x3}\ a_{y3}\ a_{z3}\ 1\\ a_{x4}\ a_{y4}\ a_{z4}\ 1\end{bmatrix} \quad \Delta x = \begin{bmatrix}\Delta x_u\\ \Delta y_u\\ \Delta z_u\\ -c\Delta t_u\end{bmatrix} \tag{3.17}$$

Finally, $\Delta\rho = H\Delta x$ (3.18)

The solution is, $\Delta x = H^{-1}\Delta\rho$ (3.19)

The basic pseudorange equation containing user coordinate (x_u, y_u, z_u) and time offset t_u, determines the overall accuracy of the receiver derives coordinates.

$$\delta\rho = H\delta x + e \tag{3.20}$$

Where e is an error vector, It is generally assumed that E[e]=0.

With 'M' satellites in view '*H*' represents M x 4 Line of sight vector (LOS) matrix in which each term represents direction vector between the receiver and the satellite.

δp represents M×1 matrix of pseudorange measurements.

δx represents 4×1 navigation error state vector that include receiver position and clock offset.

e represents M×1 Vector of Gaussian pseudorange measurement noise.

For M = 4 Satellites,

$$\delta x = H^{-1}\delta\rho \tag{3.21}$$

With more satellites in view (M >4),

$$\delta x = (H^{\mathrm{T}}H)^{-1}H^{\mathrm{T}}\delta\rho \tag{3.22}$$

The covariance of δx,

$$\begin{aligned}\mathrm{cov}(\delta x) &= E(\delta x\delta x^T)\\ &= E[(H^T H)^{-1}H^T\delta\rho\ \delta\rho^T\ H(H^T H)^{-T}]\\ &= (H^T H)^{-1}H^T d\rho\ d\rho^T\ H(H^T H)^{-T}\\ &= (H^T H)^{-1}H^T \mathrm{cov}(d\rho)\ H(H^T H)^{-T}\end{aligned} \tag{3.23}$$

cov ($\delta\rho$) represents the pseudo range errors .They are statistically independent which results in a diagonal covariance matrix. It is assumed that they have same variance (σ_n) for each satellite, so we have

$$\mathrm{cov}(\delta\rho) = \sigma_n^2 \tag{3.24}$$

So,

$$\begin{aligned}E(\delta x\delta x^T) &= \sigma_n^2(H^T H)^{-1}H^T H(H^T H)^{-T}\\ &= \sigma_n^2(H^T H)^{-T}\end{aligned} \tag{3.25}$$

As $(H^T H)$ is symmetric, transpose is not required.

$$\mathrm{cov}(\delta x) = \sigma_n^2(H^T H)^{-1} \tag{3.26}$$

Let $G = (H^T H)^{-1}$ so that $\mathrm{cov}(\delta x) = \sigma_n^2 G$

$$\begin{bmatrix}\sigma_x^2 & \mathrm{cov(x,y)} & \mathrm{cov}(x,z) & \mathrm{cov}(x,b)\\ \mathrm{cov}(y,x) & \sigma_y^2 & \mathrm{cov}(y,z) & \mathrm{cov}(y,b)\\ \mathrm{cov}(z,x) & \mathrm{cov}(z,y) & \sigma_z^2 & \mathrm{cov}(z,b)\\ \mathrm{cov}(b,x) & \mathrm{cov}(b,y) & \mathrm{cov}(b,z) & \sigma_b^2\end{bmatrix} = \sigma_n^2\begin{bmatrix}\mathrm{G_{xx}} & \mathrm{G_{xy}} & \mathrm{G_{xz}} & \mathrm{G_{xb}}\\ \mathrm{G_{yx}} & \mathrm{G_{yy}} & \mathrm{G_{yz}} & \mathrm{G_{yb}}\\ \mathrm{G_{zx}} & \mathrm{G_{zy}} & \mathrm{G_{zz}} & \mathrm{G_{zb}}\\ \mathrm{G_{bx}} & \mathrm{G_{by}} & \mathrm{G_{bz}} & \mathrm{G_{bb}}\end{bmatrix} \tag{3.27}$$

The elements of G give a measure of the satellite geometry, Dilution of Precision (DOP). Various DOPs values can be calculated from the diagonal elements of G.

So we can write,

$$\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_b^2 = \sigma_n^2(\mathrm{G}_{xx} + G_{yy} + G_{zz} + G_{bb}) \quad (3.28)$$

$$\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_b^2} = \sigma_n\sqrt{(G_{xx} + G_{yy} + G_{zz} + G_{bb})} \quad (3.29)$$

$$\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 + \sigma_b^2} = \sigma_n.GDOP \quad (3.30)$$

Therefore,

$$\mathrm{GDOP} = \frac{\sqrt{\sigma_x^2+\sigma_y^2+\sigma_z^2+\sigma_b^2}}{\sigma_n} = \sqrt{(G_{xx} + G_{yy} + G_{zz} + G_{bb})} \quad (3.31)$$

$$\mathrm{PDOP} = \frac{\sqrt{\sigma_x^2+\sigma_y^2+\sigma_z^2}}{\sigma_n} = \sqrt{(G_{xx} + G_{yy} + G_{zz})} \quad (3.32)$$

$$\mathrm{HDOP} = \frac{\sqrt{\sigma_x^2+\sigma_y^2}}{\sigma_n} = \sqrt{(G_{xx} + G_{yy})} \quad (3.33)$$

$$\mathrm{VDOP} = \frac{\sigma_\mathrm{z}}{\sigma_\mathrm{n}} = \sqrt{\mathrm{G_{zz}}} \quad (3.34)$$

$$\mathrm{TDOP} = \frac{\sigma_\mathrm{b}}{\sigma_\mathrm{n}} = \sqrt{\mathrm{G_{bb}}} \quad (3.35)$$

Therefore,

$$\mathrm{PDOP}^2 = \mathrm{HDOP}^2+\mathrm{VDOP}^2 \quad (3.36)$$

$$\mathrm{GDOP}^2 = \mathrm{PDOP}^2+\mathrm{TDOP}^2 \quad (3.37)$$

$$\text{GPS Position Accuracy} = \mathrm{UERE}\times\mathrm{GDOP} \quad (3.38)$$

3.2.3 User Equivalent Range Error (UERE)

UERE is defined as the root sum square of the various errors and biases. Multiplying UERE with GDOP gives expected accuracy of the GPS positioning at one-sigma (1-σ) level and is given in following equation,

GPS Position accuracy = UERE ×GDOP

σ represents the standard deviation of the pseudorange measurement error plus the residual model error which we have assumed to be equal for all simultaneous observations. If we further assume that the measurement error and the model error components all are independent then we can simply root-sum-square these errors to obtain a value for σ. When we combine receiver noise, satellite clock and ephemeris error, atmospheric error, multipath and SA (Selective Availability) - all expressed in units of distance, we obtain a quantity known as the total user equivalent range error (UERE), which we can use for σ. For Standard Positioning Service (SPS), the total UERE is typically in the neighborhood of 25 meters. When SA is turned off, total UERE could be less than 5 meters, with the actual value dominated by ionospheric and multipath effects. Dual frequency Precise Positioning Service (PPS) users, with the capability to remove almost all of the ionospheric delay from the pseudorange observations, can experience ever smaller UEREs. Future users of the proposed new civilian GPS signals will likewise be able to compensate for ionospheric effects and achieve superior UEREs.

High DOP values can sometimes occur even for all-in-view receivers operating at midlatitudes. In some environments, such as heavily forested areas or urban canyons, a GPS receiver's antenna may not have a clear view of the whole sky because of obstructions. If it can only receive GPS signals from a small region of the sky, the DOPs will be large, and position accuracy will suffer. Being able to track more satellites can help in such situations, and a combined GPS/GLONASS receiver may provide acceptable accuracies. New receiver technology permitting use of weaker GPS signals, even those present inside buildings, will also be beneficial.

3.3 Analysis and Result

We know that ideal value of DOP is 1, if the value is between 2 and 4, then it is excellent further if the value is between 4 and 6, it is good the for 6 to 8, it is moderate and for 8 to 20 it is fair.

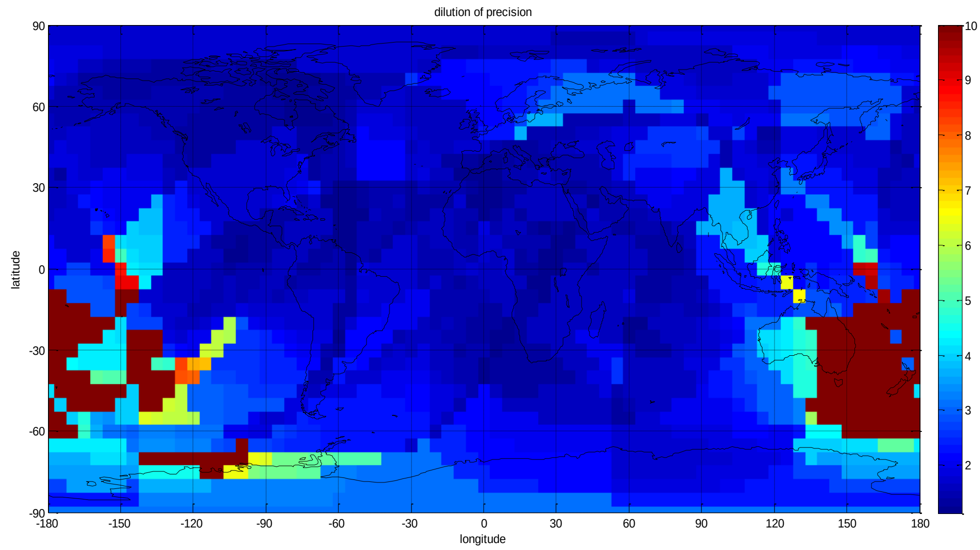


Figure 3.6 (a) : DOP analysis of GPS system (cut off elevation 5).

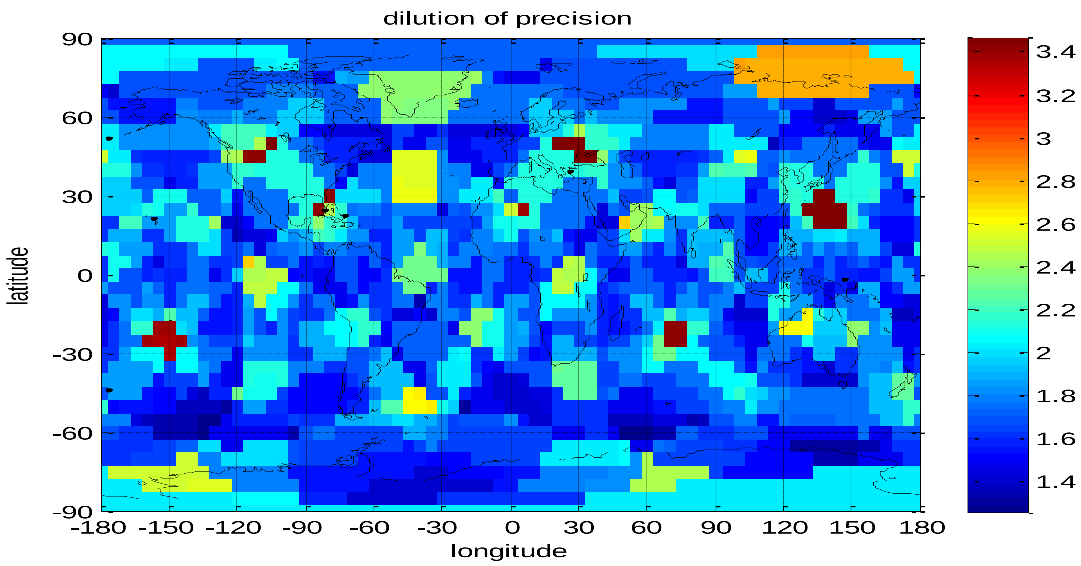


Figure 3.6 (b) : DOP analysis of Galileo system (cut off elevation 5).

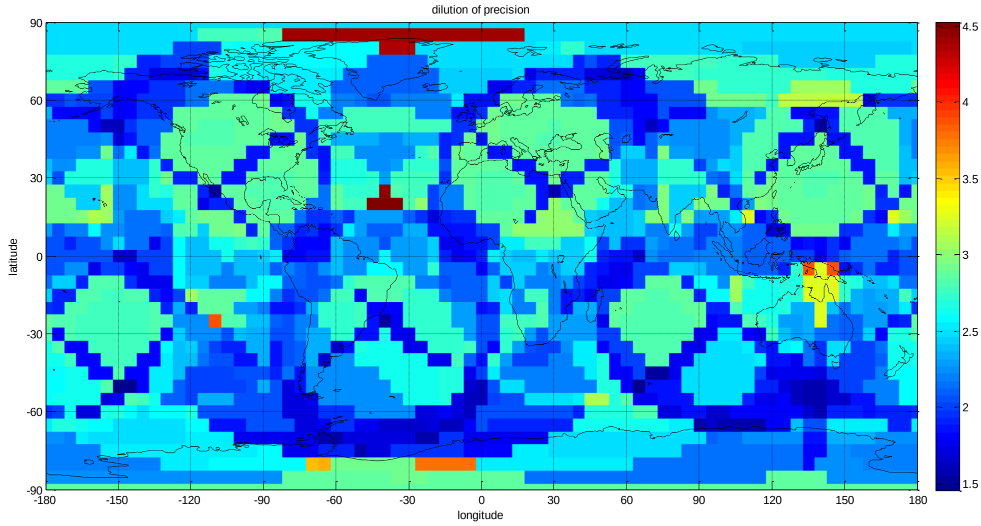


Figure 3.6 (c) : DOP analysis of combined GPS-Galileo system (cut off elevation 15).

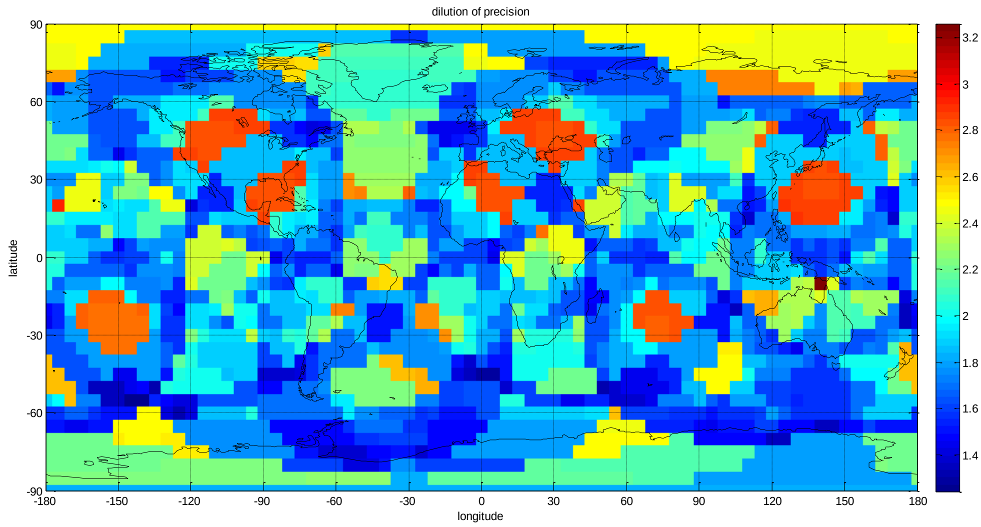


Figure 3.6 (d) : DOP analysis of combined GPS-Galileo system (cut off elevation 10).

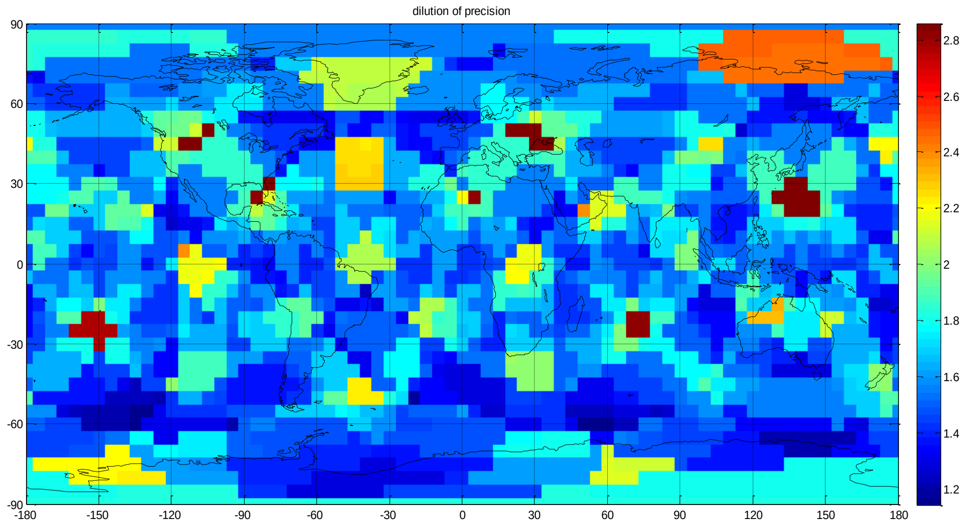


Figure 3.6 (e) : DOP analysis of combined GPS-Galileo system (cut off elevation 5).

Cut off elevation angle is an important parameter for the satellite geometry. The value of the DOP depends on the cut off elevation angle of the system. The cut off elevation angle and satellite visibility is inversely proportional to each other. The simulations for DOP for different cut off angle are shown. For GPS standalone system, the DOP is poor but for Galileo it is slightly improved.

If we introduce combined system, there is immense improvement. As the cut off elevation angle is decreasing from 15 to 10 to 5, the better satellite geometry is obtained. For cut-off elevation angle 15, the value is 4.5 then for 10, it is 3.2 and for 5, the value of DOP is reduced to 2.8 which give excellent positioning accuracy.

3.4 Graphical Analysis

From the peak value of the graphical simulation, the value of DOP can be obtained and the number of satellite can be determined.

The simulation is done for GPS, Galileo and GPS - Galileo combined system. We can observe the improvement of the satellite geometry from the peak value of DOP obtained from the graphical analysis.

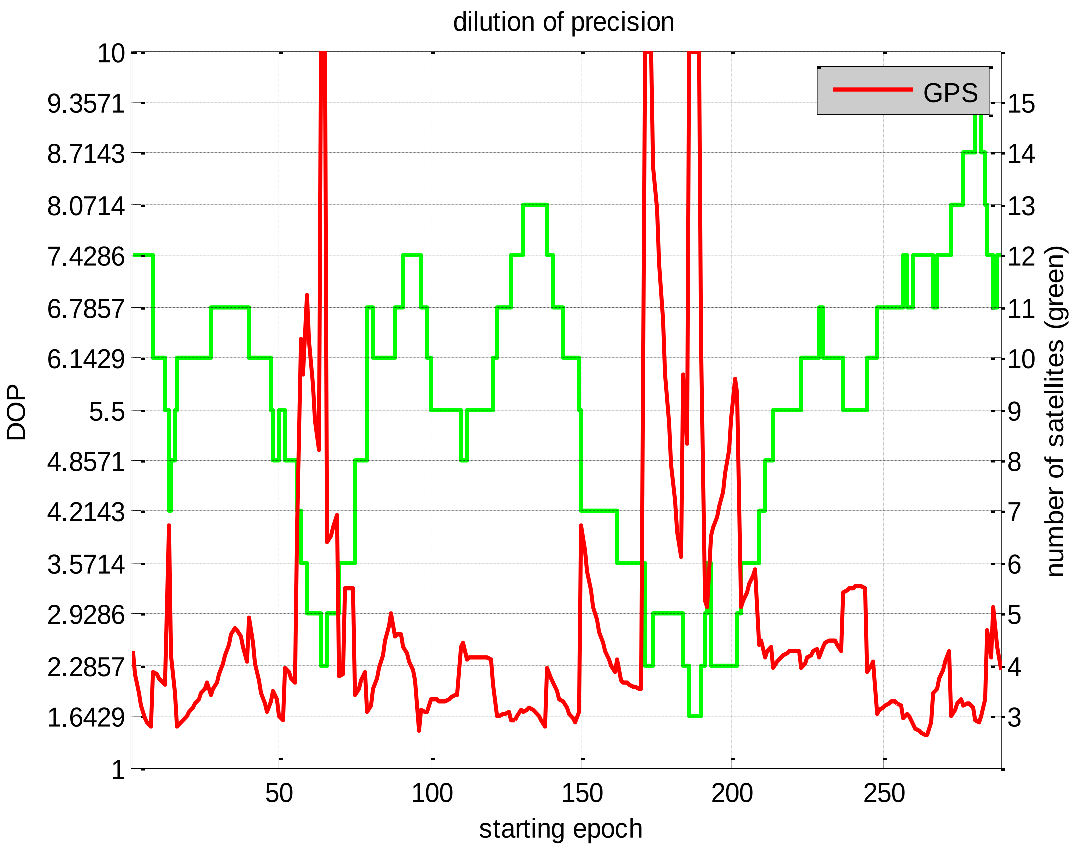


Figure 3.7 (a) : DOP analysis of GPS system.

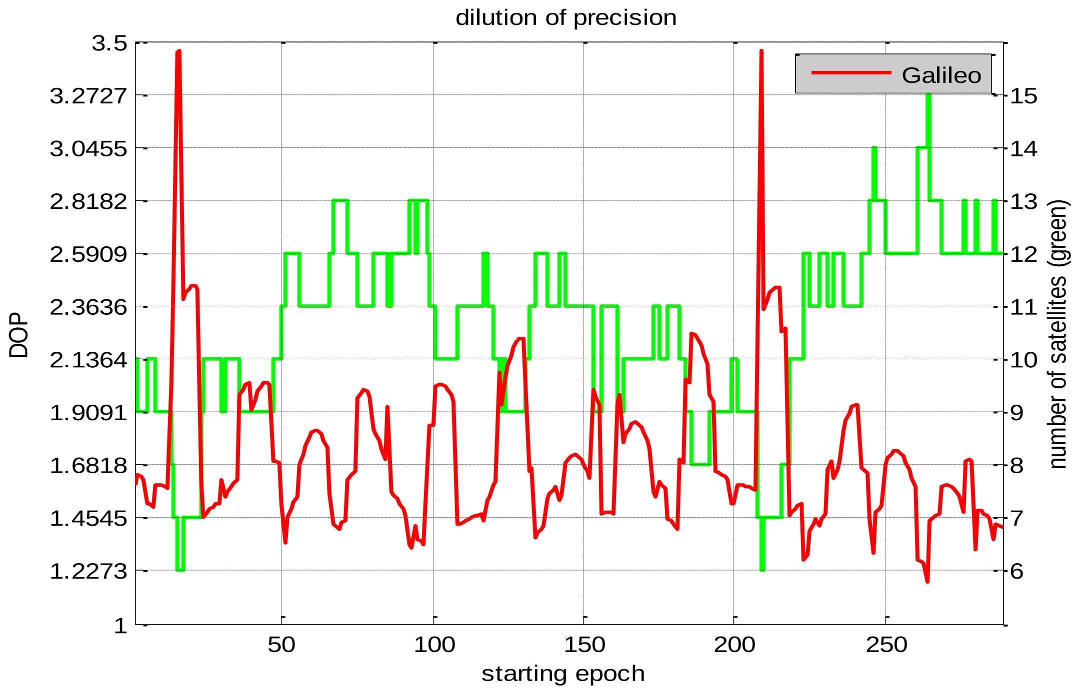


Figure 3.7 (b) : DOP analysis of Galileo system.

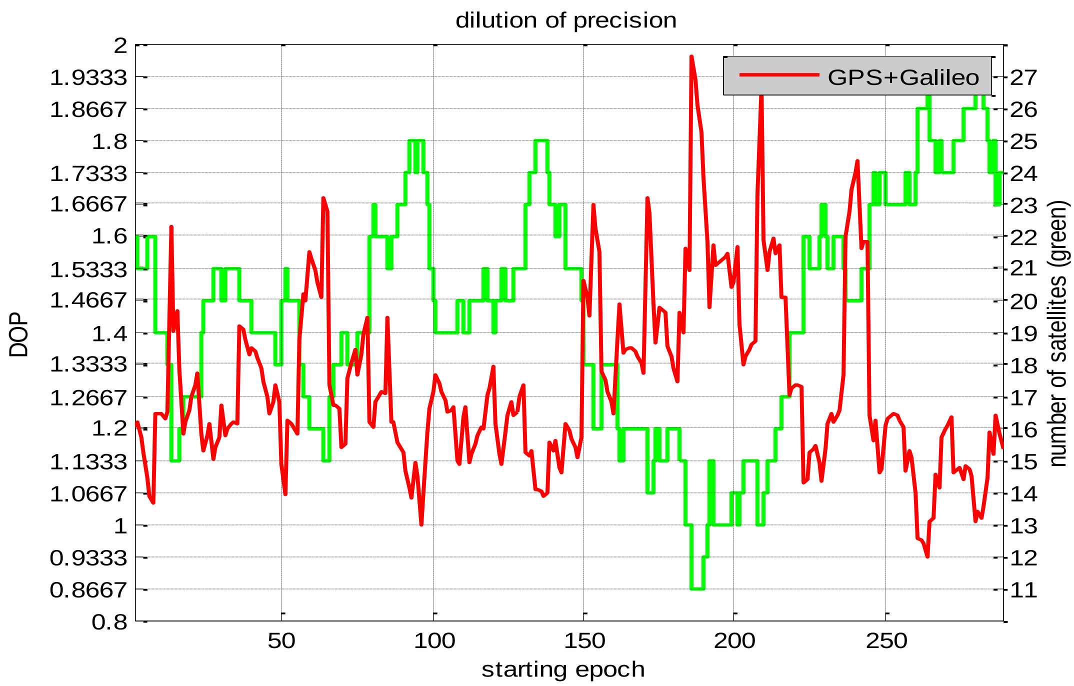


Figure 3.7 (c) : DOP analysis of combined GPS -Galileo system.

For GPS system, the peak value of the DOP is very high near to 10 which is not at all desired. For Galileo system, it is reduced up to 3.3 which is good.

When both GPS and Galileo system are combined, we get the peak value of DOP at a reduced level approximately 2 which is a desired figure.

Therefore, by observing the simulation we can conclude that by using combined system, we can have lower DOP and better satellite geometry.

CHAPTER 4

INTEROPERABILITY AND COMPATIBILITY

4.1 Compatibility

Compatibility refers to the ability of U.S. and foreign space-based PNT (positioning, navigation and timing) services to be used separately or together without interfering with each individual service or signal, and without adversely affecting navigation warfare. Compatibility refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference or other harm to an individual system or service. ICG (International committee on GNSS) recommends that new signals avoid spectral overlap between each system's authorized service signals and the signals of other systems. ITU (International Telecommunications Union) provides procedures for resolving radio frequency signal incompatibility. Recognizing that spectral separation of authorized service signals and other systems signals is not, in practice, always feasible and that such overlap exists now and might continue to do so in the future.

4.2 Interoperability

Interoperability refers to the ability of civil U.S. and foreign space-based PNT services to be used together to provide better capabilities at the user level than would be achieved by relying solely on one service or signal. Interoperability of systems and augmentations and their services is provided by interoperability of signals, geodesy and time references. Signal interoperability depends on the user market. Both common and separated central frequencies of navigation signals are essential – Signals with common central frequencies minimize cost, mass, size and power consumption of the user equipment – Signals with separate central frequencies provide better reliability and robustness of the navigation service.

4.3 Modes of Transport

There are three main modes of transport: land, maritime and area. In each mode one of the most important elements of the safety is continuous knowledge of the current position of the user. Depending on the mode information about this position can be obtained from many different methods, but the method which can be used in all modes, at any moment and any point in the world are global satellite navigation systems (SNS) and additionally in some areas of the world satellite based augmentation system (SBAS). All these systems are known also as GNSS (Global Navigation Satellite System). Each SNS and SBAS found application in one and very often in two or even all three modes of transport. It means that nowadays the many user of transport can make the choice of SNS and if it is possible, use or no of SBAS. Some parameters important for theirs exploitation differ, the problem of compatibility and interoperability of all these systems became for all users of transport essential problem a carrier frequency, reference datum and time reference.

Nowadays in each mode of transport at least one SNS is used. Both SNS fully operational GPS and GLONASS provide the continuous of the current user's position but without information about integrity. As the accuracy of this position is sometimes in some regions, for some users insufficient the need of the construction at least one another SNS or SBAS is indispensable. Which SNS or SBAS is recommended depends on the mode of the transport.

4.3.1 Carrier Frequency

All current and future carrier frequencies used in SNSs and SBASs are presented in the table 4.1. Each SNS uses or will use three different frequencies at least but one frequency (1176.45 MHz) will be the same in all four SNS, next two (1207.14 MHz and 1575.42 MHz) in three SNS. Nowadays the frequency 1575.42 MHz is common for all SBAS for broadcast GNSS correction, the other frequency 1176.45 MHz will be it in the near future. All five frequencies currently used or planned in three SNS, GPS, Galileo and BeiDou, and in all SBAS are based on the fundamental frequency f_o = 10.23 MHz, in the case of 1176.45 MHz, 1207.14 MHz, 1227.60 MHz, 1278.75 MHz and 1575.42 MHz, the factor (. f_o) is 115, 118, 120, 125 and 154, respectively. In the case of GLONASS system the signals use FDMA (Frequency division multiple access) techniques, hence a different carrier frequency per satellite. In the case of SNS radio frequency compatibility (RFC) involves consideration of technical factors such as the protection of user equipment against radio frequency interference from other SNS, effects on receiver noise floor and cross-correlation amongst signals. Almost 80 MEO (Medium earth orbit) satellites of four SNS and near 10 GEO (Geostationary Earth Orbit) satellites of all SBAS can contribute to increase the receiver noise floor, hence affecting the signal to noise ratio at GNSS receivers.

Table 4.1 : Signal in space, frequency carrier in different satellite navigation systems.

CARRIER FREQUENCY [MHZ]	SYSTEM AND CARRIER SYMBOL				
	GPS	GLONASS	Galileo	BEIDOU	SBAS
1176.45	L5 -satellites IIF and III in future	L5 - Satellites K2 and later	E5a - all satellites, signals 1 and 2	B2a	WAAS in future
1207.14	-	L3- Satellites K1 and later	E5b - all satellites, signals 3 and 4	B2b	-
1227.60	L2 - all Satellites current and future	-	-	-	-
1242.9375 ~ 1247.75	-	L1 –all satellites M and later	-	-	-
1278.75	-	-	E6-all satellites, signals 5,6 and 7	-	-
1575.42	L2 -all satellites current and future	-	E2-L1-E1, all satellites signals 8, 9 and 10	B1c	All systems current and future
1598.0625 ~ 1604.25	-	L1 –all satellites M and later	-	-	-

That is why the selection of the same carrier frequency for two or more SNS has a high impact on user's receiver complexity and cost. Regarding user equipment the standards in what concerns RFC exist only for maritime and aviation transport's users, IMO (International Maritime Organization) and ICAO (International Civil Aviation Organization) requirements, respectively. In the case of QZSS (Quasi-Zenith Satellite System) to ensure compatibility and interoperability with modernized GPS civil signals, the GPS availability enhancement signals transmitted from QZSS satellites use modernized GPS civil signal as a base, transmitting the L1C/A, L1C, L2C and L5 signals. This minimizes changes to specifications and receiver designs. In addition, L1C and L5 of above signals transmitted by QZSS satellites have interoperability with not only GPS but also

Galileo and other GNSS in the future. L1C signal transmitted by the first QZSS Michibiki satellite is the first truly interoperable signal.

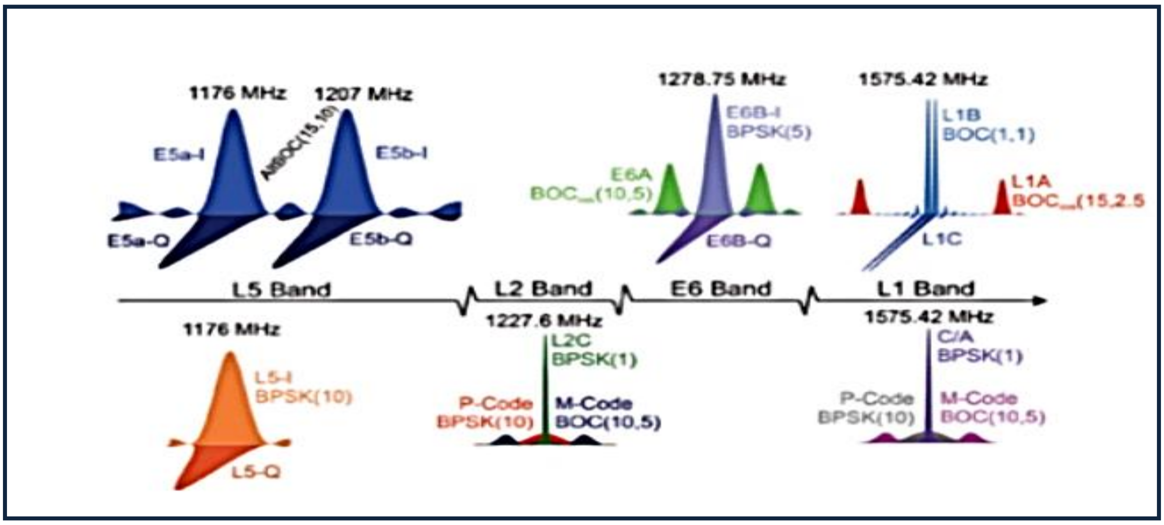


Figure 4.1 : Interoperability between GPS and Galileo Open Service on L1 and L5/E5a. From the technical point of view interoperability also exists between the GPS M-Code and the Galileo PRS on L1.

4.3.2 Reference Datum

Although the international civil coordinate reference standard is the International Reference Frame (ITRF), each GNSS has its own reference frame, which depends on the control stations co-ordinates hence guaranteeing independence among systems. The reference frame for GPS system is World Geodetic System 1984 (WGS84), its present version is almost identical with the latest version ITRF. The coordinates in GLONASS system are based on the parameter of the Earth 1990 (PE–90) frame, since September 2007 in version 90.02, also known as Parametry Zemli 1990 (PZ–90.02). The new reference geocentric coordinate system for GLONASS, PZ 90.11 is already coordinated with the ITRF at the centimetre level and shall be introduced soon. Its introduction will make possible to improve the GLONASS accuracy characteristics by 15a20%. Galileo system will have its own reference frame GTRF (Galileo Terrestrial Reference Frame), BEIDOU system adopts the China Geodetic Coordinate System 2000 (CGCS2000). As currently all SBAS augment GPS system only, the reference frame for all these systems is WGS84 also. The QZSS geodetic coordinate system is known as the Japan satellite navigation Geodetic System (JGS). This coordinate system is defined as the approach to ITRF. Two SNS are said to be interoperable from a reference frame perspective if the difference between frames is below target accuracy. Three reference frames, WGS84, GTRF and ITRF, differ by only a few centimetres (i.e. this difference between WGS84 and GTRF is expected to be within 3 cm), so this is only an issue for high-precision users. Therefore we can say that the problem of compatibility of SNS and SBAS in the case of reference frame (datum) for transport users does not exist. For some transport users, marine (ship) and road (car), in particular, this problem appears not till then when the position obtained from GNSS receiver must be plotted on the chart or introduced to electronic chart. The GNSS position must be determined in the same geodetic datum on which the chart was published meanwhile the majority of the currently used charts are not yet referred to WGS4. As position referred to different datum's can differ by several hundred meters or even more the user must have the possibility to choose the right datum in the receiver or know the Satellite Derived Positions notes.

4.3.3 System Time

While most clocks in the world are synchronized to UTC (Universal Time Coordinated), the atomic clocks on the satellites are set to own SNS time. Galileo system time (GST) is based on TAI (Time Atomic International), whereas GPS system time (GPST) and GLONASS system time (GLONASSST) are based on, respectively, the U.S. and Russian versions of UTC. GPST and GST are expected to be within the nanoseconds order of magnitude. In the case of Chinese SNS the time reference is BeiDou Time (BDT), related to UTC through UTC (NTSC – National Time Service Centre of Chinese Academy of Science). BDT offset with respect to UTC is controlled within 100 ns (modulo 1 second). The QZSS time, called QZSST, conforms to UTC and the offset with respect to the GPS system time, GPST, is controlled. The time offset between the difference reference times SNS will be emitted in the navigation message of these systems. Various agreements already specify the time offsets and its provision to the user. The data concerning the offset of GST with respect to TAI and UTC will be included in the Galileo navigation message. UTC can be obtained from GPS receiver and in the future from Galileo receiver, by adding the integral number of leap seconds and fine UTC/TAI correction information contained in the navigation data. In order to provide an estimate of UTC from GPS, the navigation message broadcast by each GPS satellite includes estimates of the time difference between GPST and UTC (USNO) modulo one second, and its rate.

4.4 GPS and Galileo Orbital Plane Drifts

GPS and Galileo satellite constellations have been designed independently and are optimised for standalone use. The Galileo satellites are planned to be distributed on 3 orbital planes about 3400km above the GPS constellations which consists of 6 orbital planes. The orbital planes of both constellations are equally distributed. In the context of Interoperability various performance assessments for the combination of GPS and Galileo constellations have been made, however, so far all analysis have been based on the nominal constellations, i.e. the first planes of both constellations both have a right ascension of ascending node (RAAN) of 0°, (coplanar Galileo and GPS planes). Further, all satellite orbits are subject to a drift in RAAN that is caused by natural orbit perturbations. Due to the higher orbital altitude, the drift rate of Galileo orbits is slower than that of the GPS constellation. Consequently, the RAAN offset from the nominal case increases with approx. 5° per year. Besides the drift, the initial RAAN offset at constellation deployment will determine the overall performance for the following years of the mission. One of the most important parameters describing a satellite orbit is the Right Ascension of the Ascending Node (RAAN). The RAAN describes the longitude orientation of the orbital plane in inertial space shown in Figure 4.2.

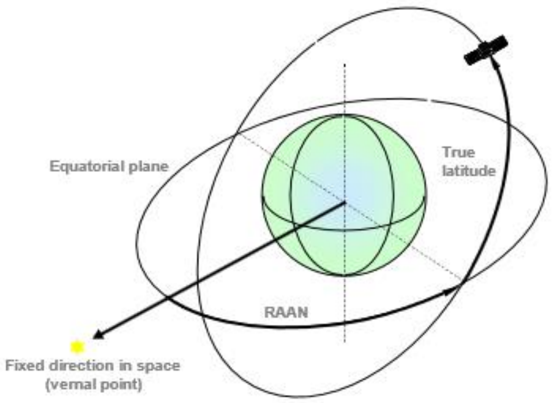


Figure 4.2 : Definition of the right ascension of ascending node (RAAN).

The position of the satellite on the orbit itself is measured by the true latitude, which originates in the ascending node (the point where the satellite orbit transits the equatorial plane in northern direction).

All satellite orbits are subject to a drift in the parameter RAAN that is caused by natural orbit perturbations, particularly the first order secular drift rate due to the oblateness of the Earth This has the form:

$$\dot{\Omega}_{sec} = -\frac{3nJ_2}{2(1-e^2)^2}\left(\frac{R_e}{a}\right)^2 \cos i \tag{4.1}$$

where

J_2 is the oblateness coefficient, e is the eccentricity, i is the inclination, a is the semi-major axis of the orbit, n is the mean motion, R_e is the Earth radius.

The drift rate is altitude dependent and decreases with the semi major axis of the orbit. As a consequence, the RAAN drift rate of the GPS orbits is 14.15° per year and that of the Galileo orbits 9.01° per year. Orbits in the same altitude are all affected in the same way, so that the spacing between the orbital planes of one constellation is not affected. The constellations drift as a whole.

Due to the RAAN drift, the phase angle between the constellations will not remain constant. The RAAN offset or “phase angle” between the constellations drifts at a rate of 5.14° per year. Hence the combined constellation will automatically go through several phase angles during the mission.

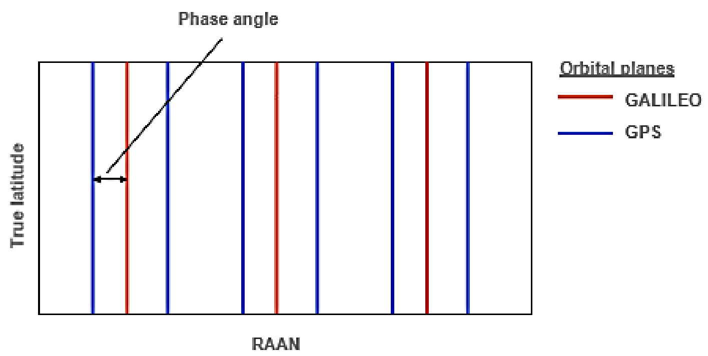


Figure 4.3 : Definition of the phase angle.

In the past, only the nominal constellations have been considered in service volume analysis. However, in reality, at the deployment epoch of Galileo (2008), GPS constellation will have undergone a significant plane drift. It will thus be far away from its nominal status at that time. In addition, it is still open, whether Galileo will be deployed according to its nominal definition. Hence the phase angle (RAAN) between the Galileo and GPS constellation is still an open point.

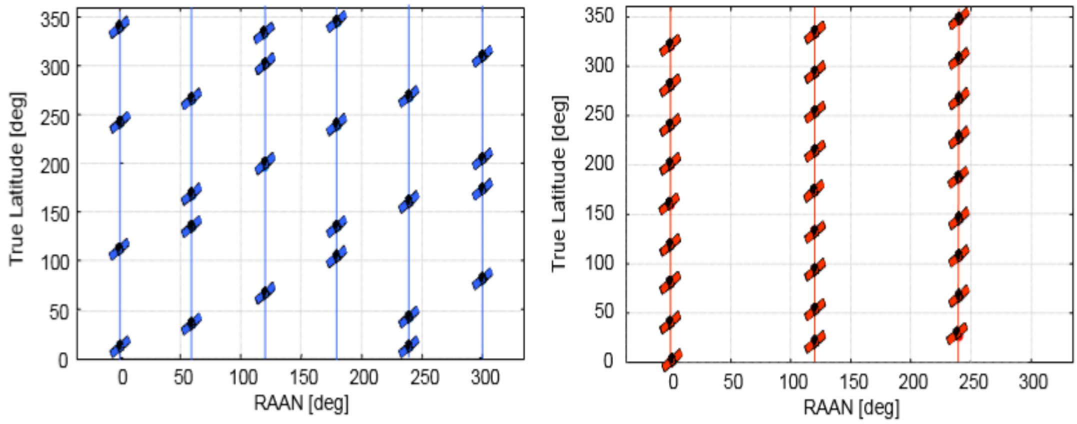


Figure 4.4 : Nominal constell of GPS (left) taken from /0/ and Galileo (right) taken from /0/.

As a starting point, 4 scenarios have been analysed. These scenarios are set up of 2 different phase angles (0° ("in-phase") and 30°) (Galileo planes directly in between two GPS planes, "out-of-phase") . Besides two different masking angles for the reference points on ground have been chosen (10° and 30°) . The combination of these leads to 4 scenarios.

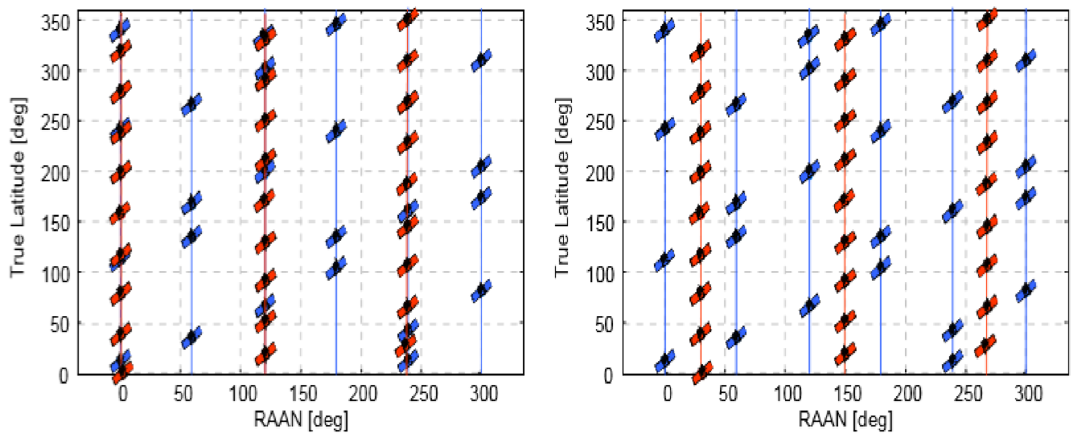


Figure 4.5 : In-phase scenario (left) and out-of-phase scenario (right).

All 4 scenarios have been analysed for two different regions. These are the Canadian region (SimGNSS) and the European region (GSSF). Both regions cover almost the same latitude interval.

The following parameters are of interest:

- HDOP at the 95% percentile.
- HPE at the 95% percentile.
- VDOP at the 95% percentile.
- VPE at the 95% percentile.
- Worst number of visible satellites.

4.5 Simulation and Result of Success Rate

In the statistical sense success rate equals as a probability. So, the value of it lies between 0 and 1. Success rate of 0 means that it can be expected that the ambiguities are never fixed to the correct integer value. On the other hand a success rate of 1 means that the ambiguities are fixed to the correct values in 100% of the cases. This simulation is carried out for Success rate of dual/triple frequency of GPS alone, Galileo alone and combined system.

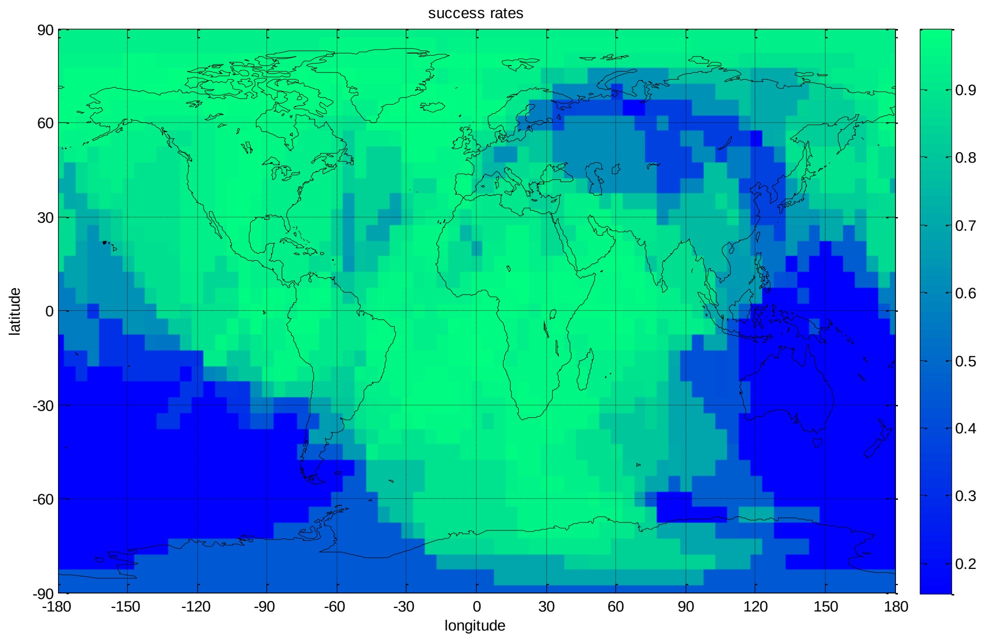


Figure 4.6 (a) : success rate for GPS (dual frequency).

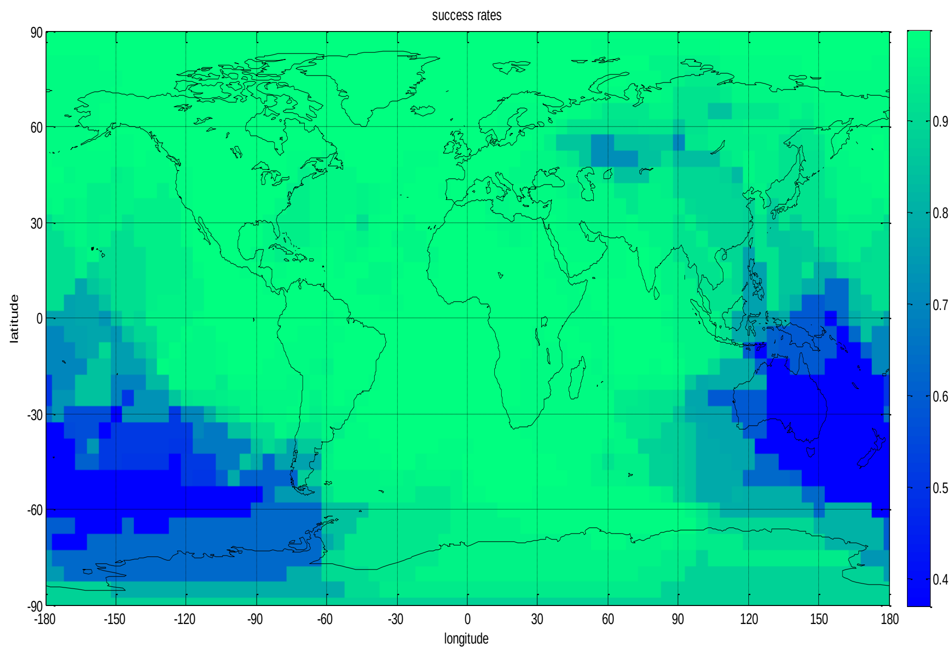


Figure 4.6 (b) : success rate for GPS (triple frequency).

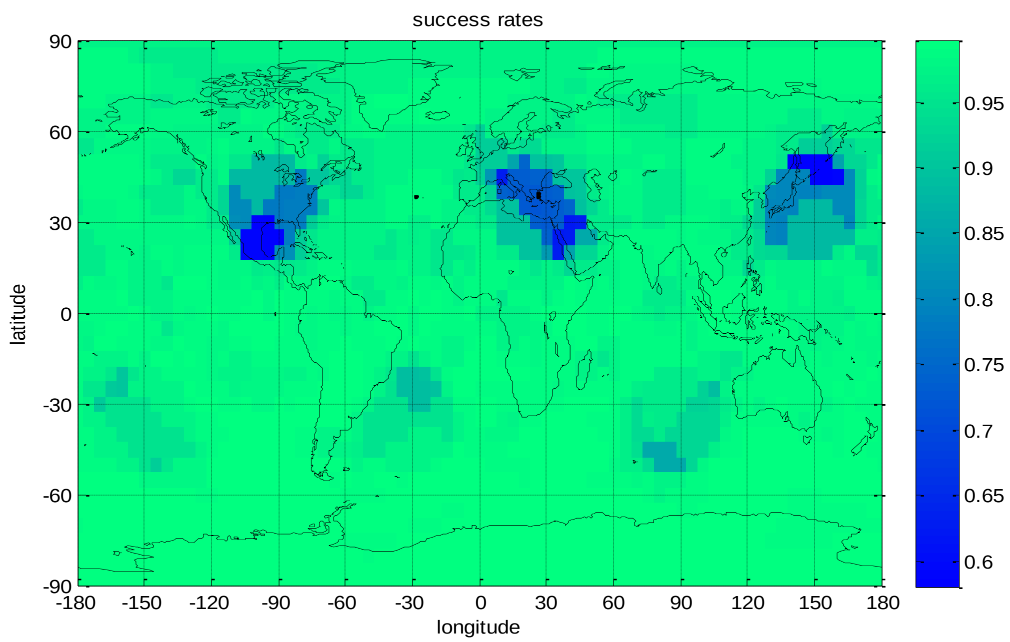


Figure 4.6 (c) : success rate for Galileo (dual frequency).

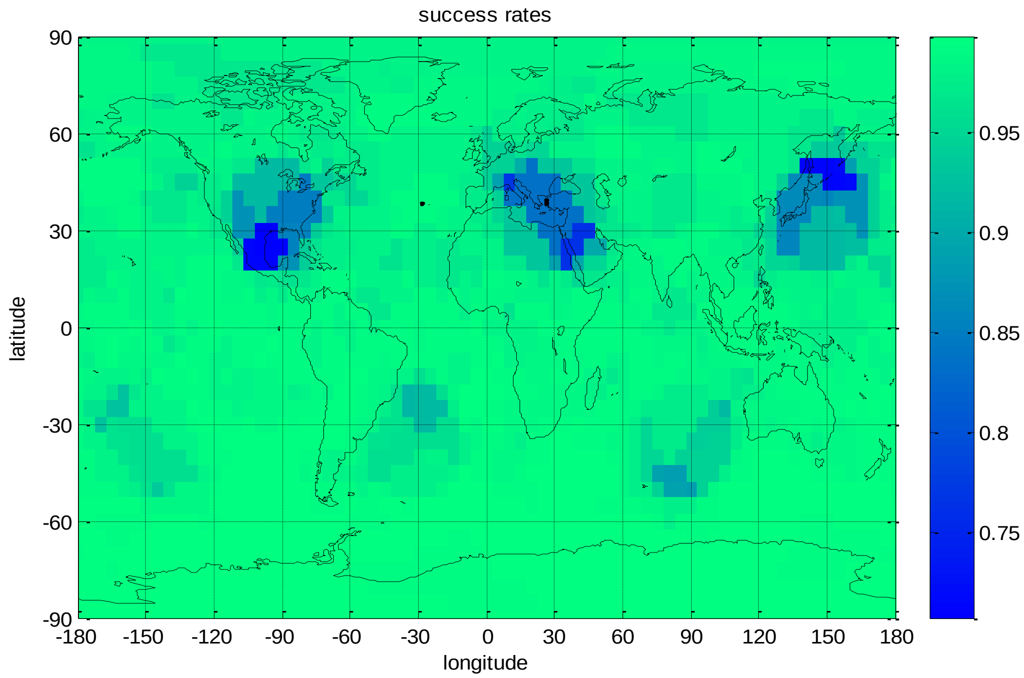


Figure 4.6 (d) : success rate for Galileo (triple frequency).

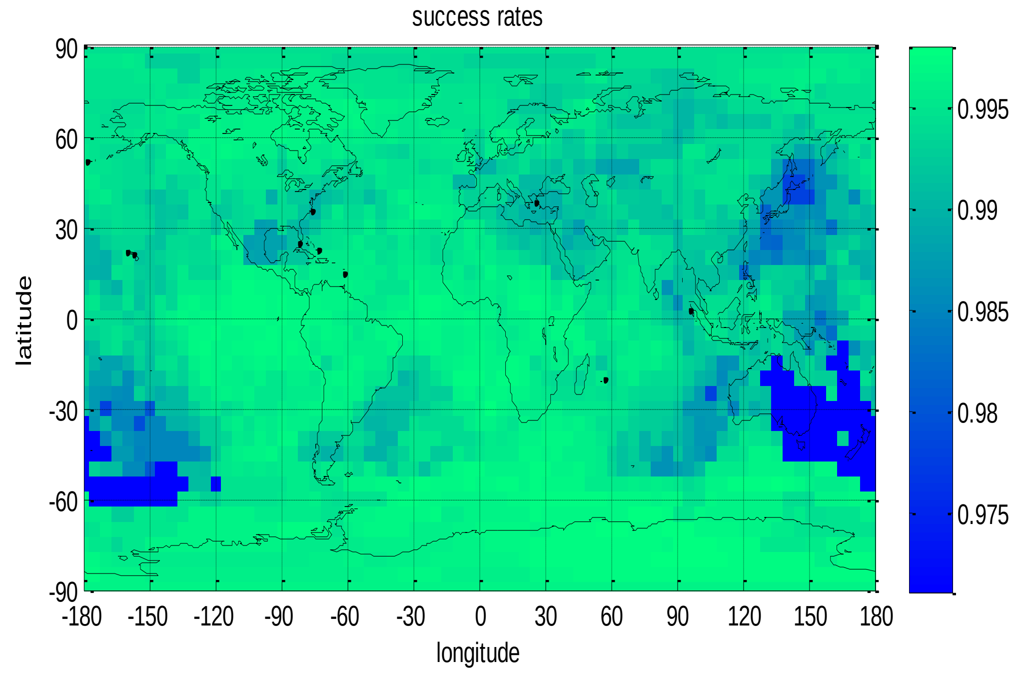


Figure 4.6 (e) : GPS-Galileo combined success rate (dual frequency).

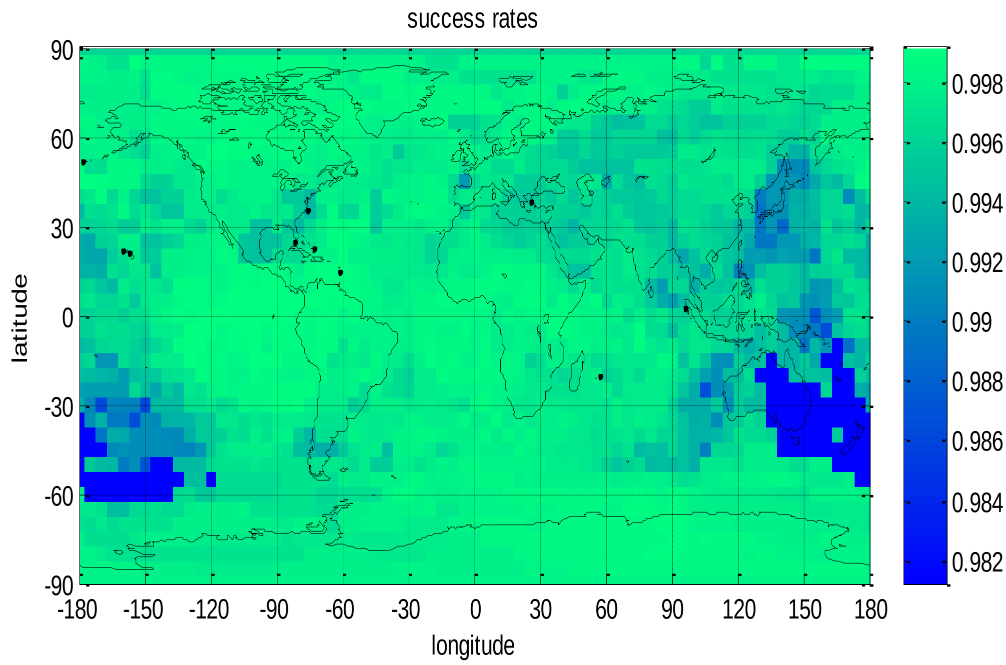


Figure 4.6 (f) : GPS-Galileo combined success rate (triple frequency).

As success rate is a parameter varies from 0 to 1, the value of 1 or close to 1 indicates better success rate. The result indicates that a triple frequency combined GPS-Galileo system provides very good success rate estimation compared to any single system.

4.6 Analysis and Result of Biased Success Rate

Both the underlying model strength and biases are two crucial factors for successful integer GNSS ambiguity resolution (AR) in real applications. In some cases, the biases can be adequately parameterized and an unbiased model can be formulated. However, such parameterization will, as trade-off, reduce the model strength as compared to the model in which the biases are ignored. The AR performance with the biased model may therefore be better than with the unbiased model, if the biases are sufficiently small. This would allow for faster AR using the biased model, after which the unbiased model can be used to estimate the remaining unknown parameters. Any misspecification in the functional model will lead to biases in the least-squares estimator. In case of GPS, in the float solution of the ambiguities such biases could be generated by outliers in the code data, cycle slips in the phase data, multipath, the presence of unaccounted atmospheric delay or any other unmodeled error source. In this context the biased success rates in case of a code outlier or carrier cycle slip can be computed.

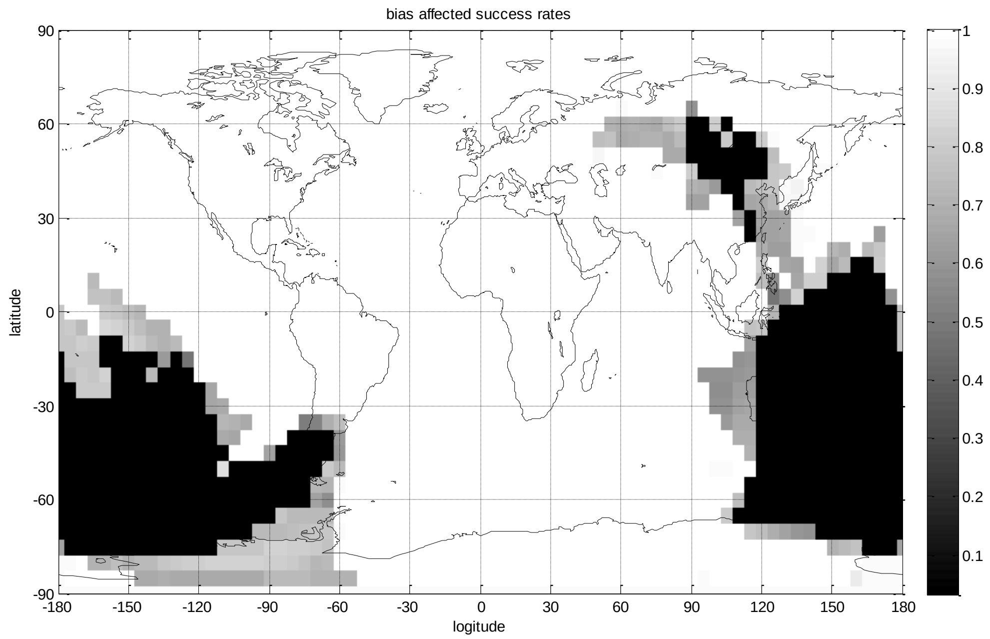


Figure 4.7 (a) : GPS biased success rate.

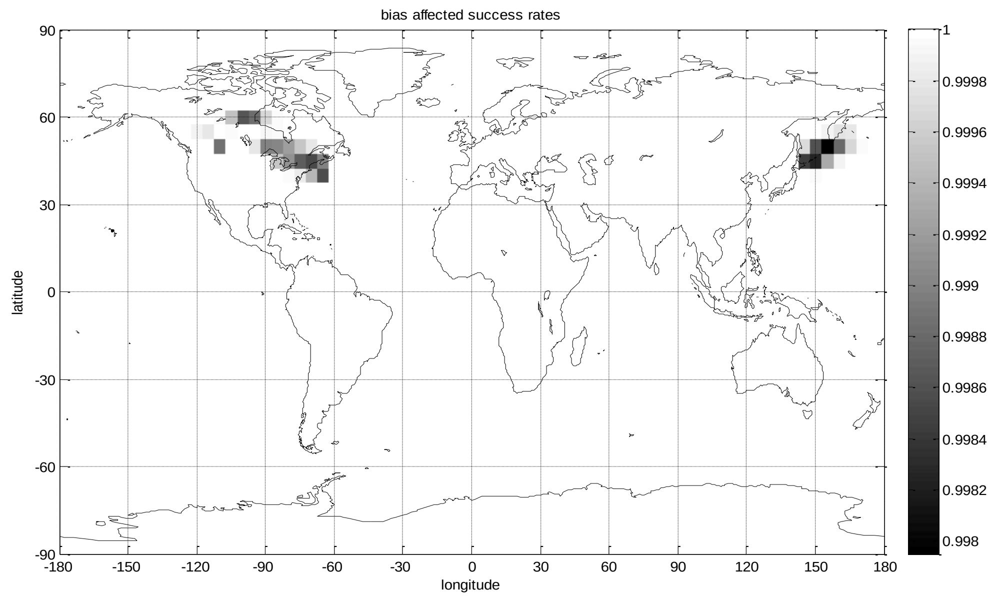


Figure 4.7 (b) : Galileo biased success rate.

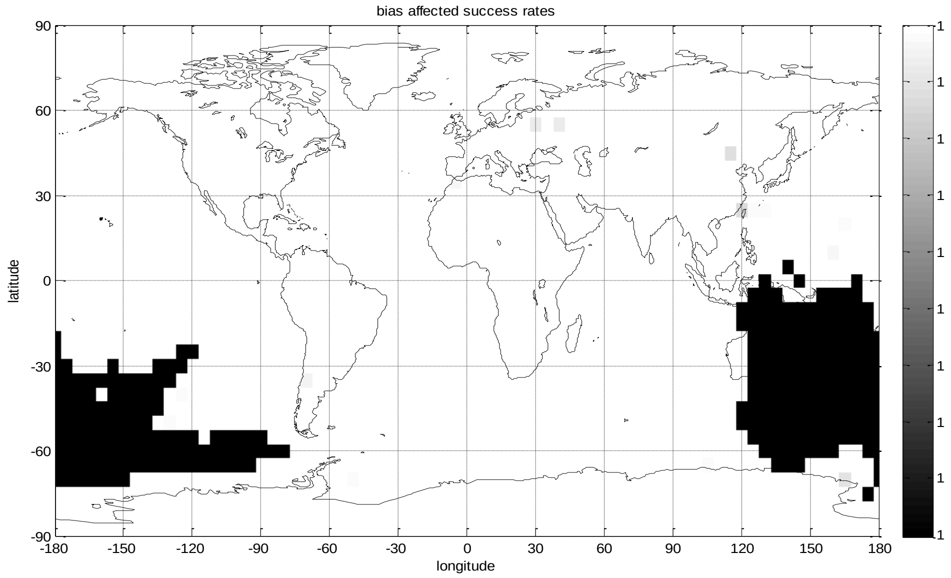


Figure 4.7 (c): GPS-Galileo combined biased success rate.

From the above analysis it is seen that the bias affected success rate provide better performance than the unbiased success rate .Under this affect alone systems provide success rate close to or equal to 1.

4.7 Graphical Analysis

Success rate which are given for the world above can be represent by the graphical analysis. The same result can be obtained for individual area.

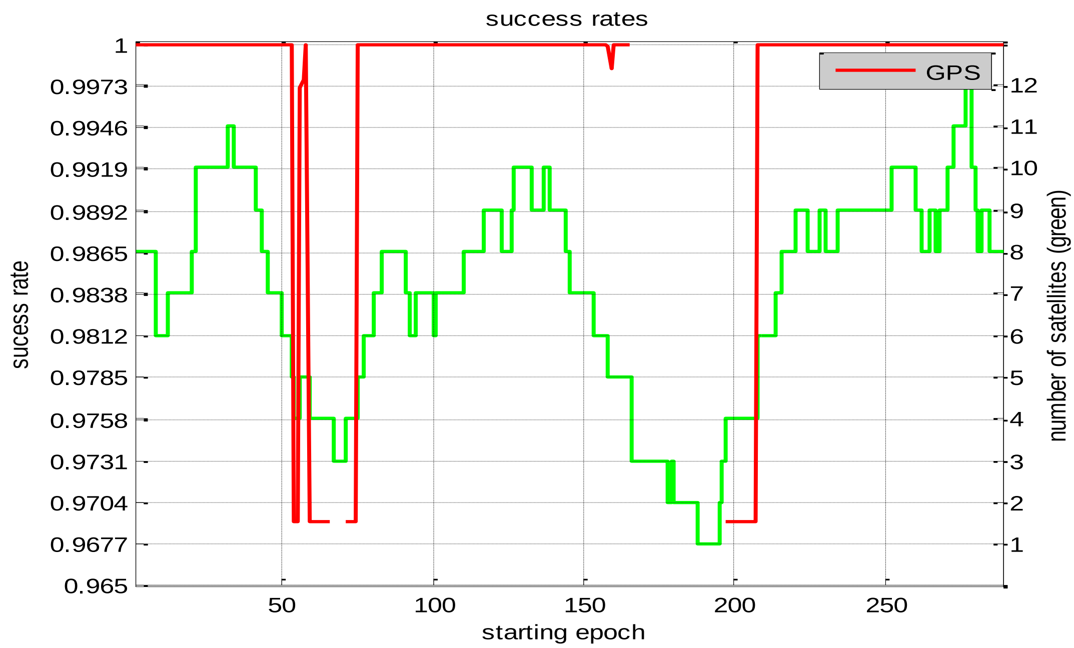


Figure 4.8 (a) : Graphical output of GPS success rate.

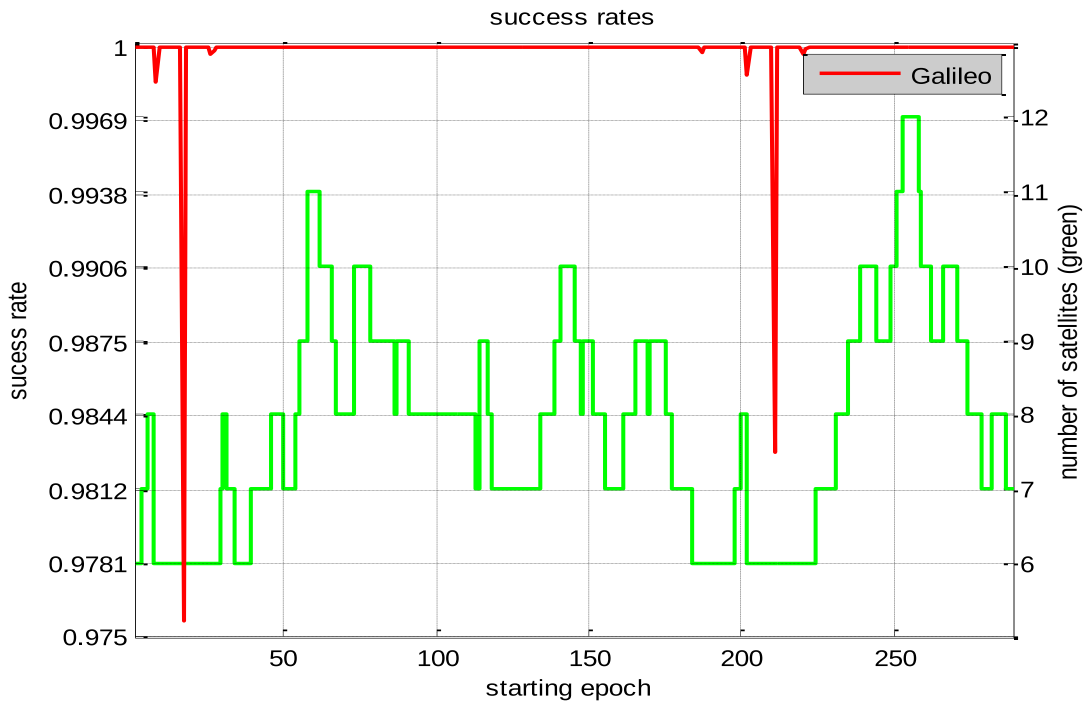


Figure 4.8 (b) : Graphical output of Galileo success rate.

Figure 4.8 (c) : Graphical output of Combined GPS-Galileo success rate.

Since the graphical output represents both the number of satellites tracked and the success rate of systems. From this analysis it is seen that with the increase in satellite number the success rate is also improved and Galileo gives better success rate then the GPS system Combined GPS-Galileo system gives larger number of satellites as well as success rate close to 1.

CHAPTER 5

RECEIVER AUTONOMOUS INTEGRITY MONITORING

5.1 Integrity

Integrity is the measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes the ability of the system to provide timely warnings to users when the system should not be used for navigation. In addition to providing a position, navigation, and timing function, a system such as GNSS must have the ability to provide timely warnings to users when the system should not be used. The integrity function becomes especially critical if GNSS is to be used as a primary navigation system. Monitoring the integrity of a navigation system is essential to ensure that the navigation solution is within tolerable constraints. Integrity includes the ability of a system to provide valid and timely warnings to the user, known as alerts, when the system must not be used for the intended operation.

5.2 Integrity Parameters

In the case of integrity, this is achieved by means of the concepts of Alert limit, Time to alert, Integrity risk and Protection level.

Alert Limit: The alert limit for a given parameter measurement is the error tolerance not to be exceeded without issuing an alert.

Time to Alert: The maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert.

Integrity Risk: Probability that, at any moment, the position error exceeds the Alert Limit.

Protection Level: Statistical bound error computed so as to guarantee that the probability of the absolute position error exceeding said number is smaller than or equal to the target integrity risk. A horizontal (respectively vertical) protection level is a statistical bound of the horizontal (respectively vertical) position error computed so as to guarantee that the probability of the absolute horizontal (respectively vertical) position error exceeding said number is smaller than or equal to the target integrity risk.

The horizontal protection level is the radius of a circle in the horizontal plane (the plane tangent to WGS-84 ellipsoid), with its centre being at the true position, that describes the region assured to contain the indicated horizontal position. It is a horizontal region where

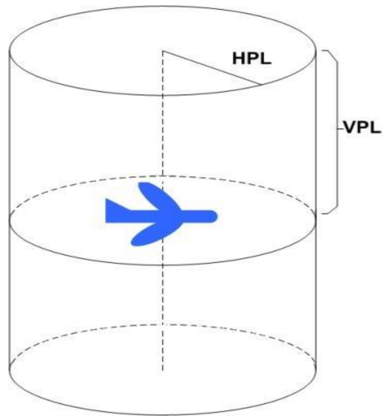


Figure 5.1 : Horizontal and vertical protection levels.

the missed alert and false alarm requirements are met for the chosen set of satellites when autonomous fault detection is used. A horizontal (respectively vertical) integrity event occurs whenever the horizontal (respectively vertical) position error exceeds the horizontal (respectively vertical) protection level.

5.3 Receiver Autonomous Integrity Monitoring (RAIM)

Receiver Autonomous Integrity Monitoring (RAIM) is a GPS integrity monitoring scheme that uses redundant ranging signals to detect a satellite malfunction that results in a large range error. RAIM involves two functions: detection of the presence of a malfunctioning satellite and identification of which satellite (or satellites) is malfunctioning. Receiver autonomous integrity monitoring (RAIM) provides integrity monitoring of GPS for aviation applications. In order for a GPS receiver to perform RAIM or fault detection (FD) function, a minimum of five visible satellites with satisfactory geometry must be visible to it. RAIM has various kinds of implementations; one of them performs consistency checks between all positions solutions obtained with various subsets of the visible satellites. The receiver provides an alert to the pilot if the consistency checks fail. Availability is also a performance indicator of the RAIM algorithm. Availability is a function of the geometry of the constellation which is in view and of other environmental conditions. If availability is seen in this way it is clear that it is not an on–off feature meaning that the algorithm could be available but not with the required performance of detecting a failure when it happens. So availability is a performance factor of the algorithm and characterizes each one of the different kinds of RAIM algorithms and methodologies.

5.4 RAIM Techniques

Traditional RAIM techniques can be decomposed into:

- **FDE (Fault Detection and Exclusion):**
    - **Fault detection:** a process responsible for checking the consistency of the measurements, usually by means of a statistical hypothesis test on the residuals of a least squares position estimation, in which the null hypothesis implies that there are no faulty measurements. If the test fails (in the sense that the null hypothesis is rejected), then a fault detection is declared.
    - **Fault exclusion:** this function is called only if the fault detection function above declares detection. Its purpose is to decide which measurement or group of measurements is more likely to be responsible for the fault detected in the previous step and reject the affected measurements so that they are not used in the navigation solution. Some iterative implementations would then call again the fault detection function to make sure that no further detections occur. The sequence fault detection –fault exclusions may be called iteratively until no further detection occurs, and hence no other exclusions are required.
- **Position and Protection Level (PL) computation:** position (together with a consistent protection level) is re-computed using those measurements that have passed the FDE test successfully. The said protection level can be computed in different ways depending on the assumptions it relies on. Classic RAIM techniques (designed for the civil aviation framework in a GPS-only scenario) assume that only one measurement can be faulty at a given time, but these techniques can be (and have been) generalized to the cases of simultaneous faults. The assumption on the number of faulty measurements that can exist is, of course, linked to the performance level of the FDE mechanism (as well as the quality of the inputs).

The protection levels are used in order to guarantee that the solution error will not be larger than a given value.

An illustration is shown in figure 5.2 that how RAIM protection levels are computed. The horizontal axis represents the value of the test statistic used in the FDE test (usually the root mean square of all individual satellites' estimation residuals). The vertical axis represents the absolute position error in meters.

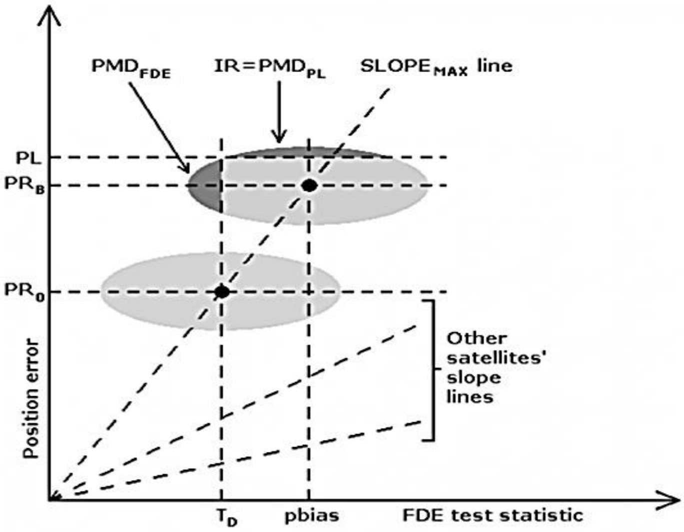


Figure 5.2 : Protection level computation.

Each satellite is associated to a straight line representing the amount of position error induced by a given size of the test statistic caused by a ranging error from that satellite in absence of ranging errors from all other satellites. Assuming that, at the most, one faulty measurement remains after the FDE test, the protection level is computed such as to cover the situation with the most impact in the position error, i.e. the situation where the faulty measurement is the one corresponding to the satellite with the maximum slope.

In the FDE test, the test statistic (root mean square of residuals) is compared with a threshold T_D. If the threshold is not exceeded, then the test is declared successful. However, this does not necessarily imply that all measurements are fault-free. There might be some faulty measurement whose contribution to the test statistic is small enough for the test to pass. Clearly, the most dangerous measurement to be faulty would be the one that produces the largest position error without being detected by the FDE test, that is, the one producing the largest position error with a fixed contribution to the estimation residual or, in other words, the one with the maximum slope in the figure 5.2. Since the test has succeeded (otherwise we would not be computing the protection level), the test statistic is not larger than T_D, and if only one measurement is faulty and all other measurements are perfect, then the resulting position error would be, at the most, that corresponding to a fault in the worst satellite, the one with maximum slope when the test statistic reaches its maximum T_D. Therefore, one would be tempted to set the protection level at PR_0.If it is assumed that the other measurements are not perfect, but are subject of errors which follow some fault-free statistics. In classic RAIM, it is assumed that fault-free measurement errors follow a zero mean Gaussian distribution. Fault-free error statistics are schematically represented in the figure as a coloured ellipse which shows that, even when the FDE test passes (left half of the lower ellipse) it can be the case that position error exceeds PR_0 (upper left quarter of the lower ellipse). Actually, the left half of the ellipse represents FDE misdetection probability.

Since the points in that region represent situations in which the test passes, but the measurement with maximum slope is faulty. An infinitesimal increment of that error would be above the detection threshold, but due to the compensating effects of other satellites errors, the test statistic would not exceed the threshold and the fault would not be detected. Actually, since the ellipse is symmetric, this situation would imply an FDE misdetection rate of 50%. Since FDE misdetection rate is an input to the design, it is essential to move along the maximum slope line up to the point in which the probability mass on the left of TD is smaller than or equal to the target FDE misdetection rate, PMD_{FDE}, represented with the upper ellipse in the figure 5.2. The displacement in the horizontal axis that is needed to reach this point is called pbias in RAIM literature, and can be computed using the statistics of the fault-free ranging errors. At this point, if PR_B would be used as the protection level, then the upper half of the new ellipse would still represent position errors above the protection level. The target Integrity Risk (IR) is then used by the algorithm to displace the final protection level upwards, to a value PL, so that the probability mass (of the fault-free ranging error statistic represented by the ellipse) left above PL is smaller than or equal to the target integrity risk which is also called protection level misdetection rate, PMD_{PL}.

5.5 Principles of RAIM Detection and Identification

RAIM performance is based on two quantities: the position error and a test statistic. The test statistic is the quantity that the user avionics uses to make an integrity decision. In a normal condition, that is, with no satellite having an unusually large error, the distribution of position error versus the test statistic would typically look like Figure 5.3 (a).

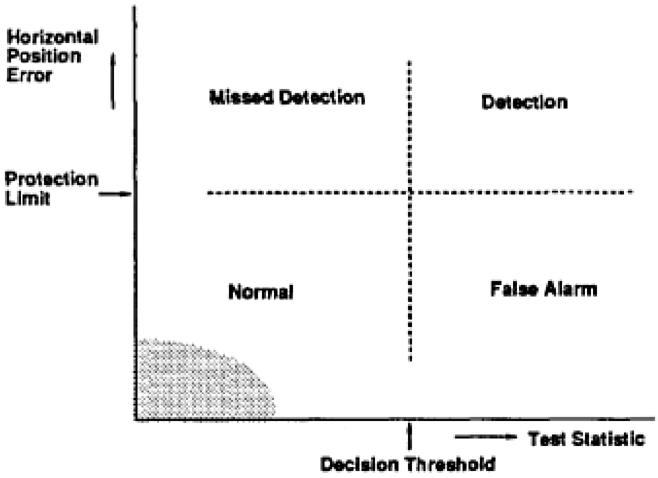


Figure 5.3 (a) : Position error vs. test statistic in a normal condition.

In this case, almost all of the points would be well within the region defined by the protection limit and decision threshold. In contrast, if any one of the satellites has an unusually large range bias error, the distribution would be like Figure 5.3 (b).

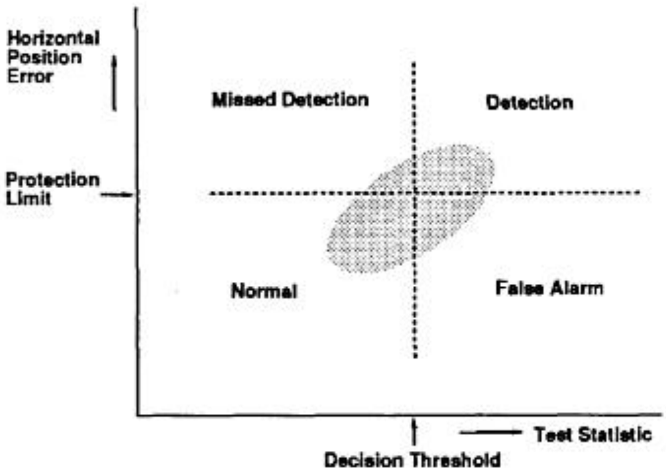


Figure 5.3 (b) : Position error vs. test statistic in an abnormal condition.

In these figures, each data point is represented in one of the following four quadrants defined by the decision threshold and the protection limit:

Normal (N) - region: no alarm and no violation of protection limit.

Missed detection (MD) - region: no alarm and violation of protection limit.

Detection (D) - region: alarm and violation of protection limit.

False alarm (FA) - region: alarm and no violation of protection limit.

Where an alarm condition corresponds to the decision statistic being at or beyond the decision threshold.

Ideally, it is desired to have all the points in either the N-region or D-region; that is, to raise an alarm if and only if the protection limit is coloured. These false alarms may be acceptable provided that they do not significantly increase the overall alarm rate. Therefore, for the detection function, it is sufficient to ensure that the missed detection probability (P_m) defined as follows, is smaller than a certain specified value considered to be acceptable:

$$P_m = P \text{ [protection limit coloured with no alarm]}.$$

If a satellite malfunctions in such a way that its range error starts to increase, the effect on the position error and the test statistic would follow either one of the paths shown in Figure 5.3 (c).

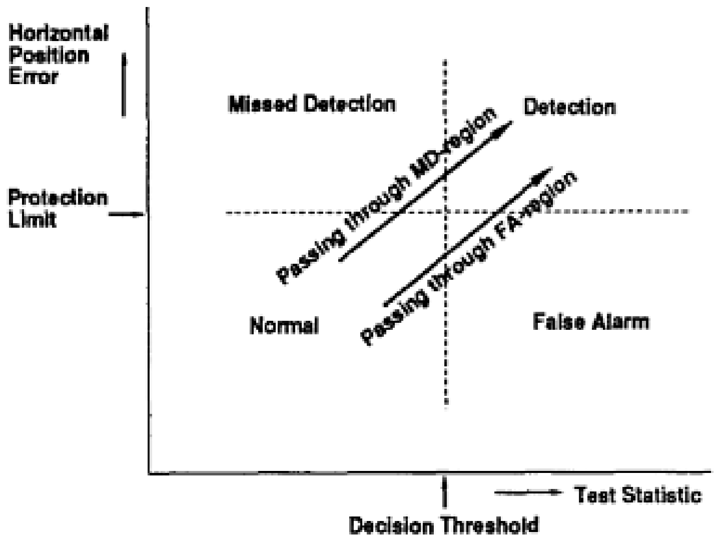


Figure 5.3 (c) : Possible paths taken vs. range error increases.

For the detection function, a tight decision threshold may be used in order to minimize the missed detection probability so that a data point would pass through the FA-region rather than the MD-region. In case the identification function is also required, a false alarm is undesirable as a missed detection. The alarm might be followed by identification of a wrong satellite and navigation continued using the faulty satellite, with an unacceptably large position error for the remainder of the flight.

5.6 New Detection/Identification Algorithm

Any RAIM identification function requires at least six satellites in view. The principle used in the identification scheme proposed can be explained using Figure 5.4 (a). First, a detection algorithm is applied to the test statistic for the full set (set of six, in this example). If an alarm is raised, that would indicate the presence of a malfunctioning satellite. In this case, subsets of (N-1) satellites are taken and the same detection algorithm is applied to these subsets separately. As shown in Figure 5.4 (a), if alarms are raised for all subsets except for one, the subset with no alarm is identified to be the subset not including the malfunctioning satellite. In this scheme, the decision threshold is fixed regardless of the user-satellite geometry (The threshold varies only as a function of the number of satellites in view).

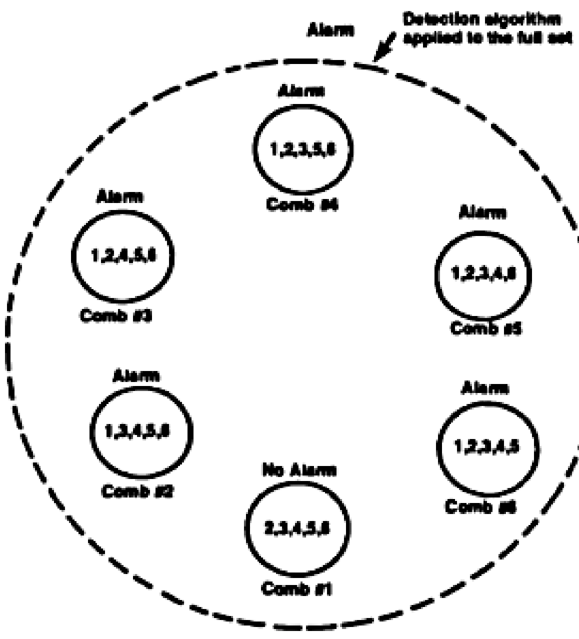


Figure 5.4 (a) : Existing detection /identification scheme (example of a six-satellite case).

The new D/I procedure proposed is to minimize not only missed detections but also false alarms and false identifications. The new D/I algorithm proposed here takes advantage of an approximation valid only with a much larger protection limit, which is the case for the oceanic phase of flight.

5.7 Approximate Linear Relationship between Position Error and Test Statistic

First, the x and y components of the user position estimation error d can be expressed as a linear combination of the satellite range errors:

$$\Delta x = a_1\Delta R_1 + a_2\Delta R_2 + ... + a_N\Delta R_N \quad (5.1)$$

$$\Delta y = b_1\Delta R_1 + b_2\Delta R_2 + ... + b_N\Delta R_N \quad (5.2)$$

Where N is the number of satellites used for position determination.

Second, each range residual can also be expressed as a linear combination of the satellite range errors:

$$\in_1 = c_{11}\Delta R_1 + c_{12}\Delta R_2 + ... + c_{1N}\Delta R_N$$

$$\in_2 = c_{21}\Delta R_1 + c_{22}\Delta R_2 + ... + c_{2N}\Delta R_N$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\in_N = c_{N1}\Delta R_1 + c_{N2}\Delta R_2 + ... + c_{NN}\Delta R_N \quad (5.3)$$

With the least squares residual algorithm, the test statistic is obtained as

$$m = (\in_1^2 + \in_2^2 + ... + \in_N^2)^{1/2} \quad (5.4)$$

Now, if the range error of the malfunctioning satellite is much larger than the range errors of the other satellites, then it dominates over all of the other errors. Then, the following approximations are possible for the position error d, and the test statistic m. Assume that satellite i is malfunctioning and its error ΔR_i dominates.

Then, from (5.2)

$$d = (\Delta x^2 + \Delta y^2)^{1/2}$$

$$= [(a_1\Delta R_1 + a_2\Delta R_2 + ... + a_N\Delta R_N)^2 + (b_1\Delta R_1 + b_2\Delta R_2 + ... + b_N\Delta R_N)^2]^{1/2}$$

$$= [a_i^2 + b_i^2]^{1/2} \Delta R_i \quad (5.5)$$

And

$$m = (\epsilon_1^2 + \epsilon_2^2 + \dots\dots\dots + \epsilon_N^2)^{1/2}$$

$$= [(c_{11}\Delta R_1 + c_{12}\Delta R_2 + \dots\dots + c_{1N}\Delta R_N)^2 + \dots (c_{N1}\Delta R_1 + c_{N2}\Delta R_2 + \dots. + c_{NN}\Delta R_N)^2]^{1/2}$$

$$\cong [c_{1i}^2 + c_{2i}^2 + \dots + c_{Ni}^2]^{1/2} \Delta R_i \tag{5.6}$$

The above approximations are valid when the coefficients for the different satellites are of comparable magnitude.

The ratio of the position error d and the test statistic m may be approximated as

$$d/m \cong [a_i^2 + b_i^2]^{1/2} / [c_{1i}^2 + \dots + c_{Ni}^2]^{1/2}$$

$$\cong K_i \tag{5.7}$$

On the basis of this observation, the following D/I procedure is proposed:

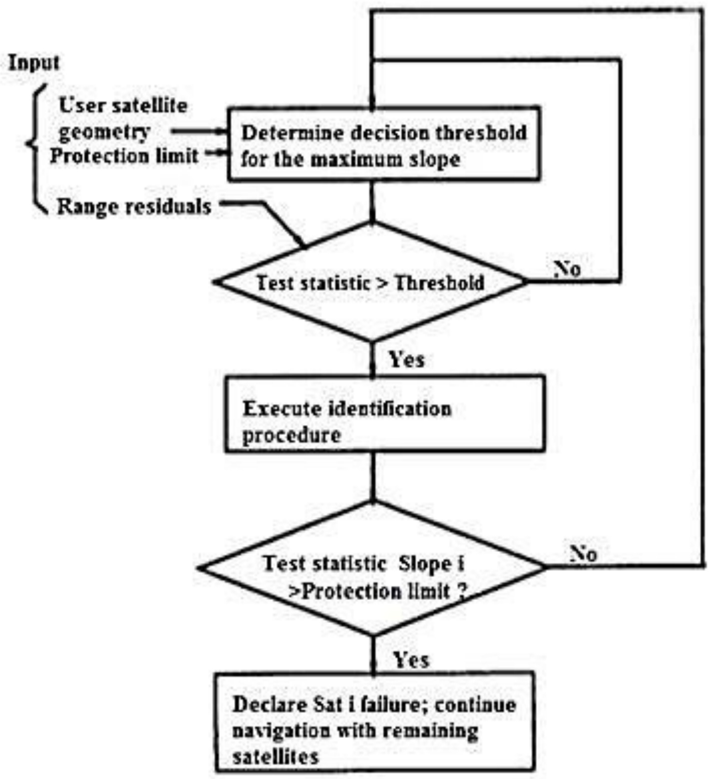


Figure 5.4 (b) : Proposed D/I procedure

Step 1: From the user-satellite geometry, calculate the k_i slopes. Then, from the maximum slope and the protection limit, derive a threshold that will be used in Step 2 for initiation of the identification function (Threshold = protection limit / maxk_i).

Step 2: Continue checking the test statistic to see if it exceeds the threshold derived in Step 1. That is,

- Take each subset of (N-1) satellites out of a total of N satellites. For each subset, derive the test statistic (e.g. least-squares residuals).
- Identify the subset that gives the smallest test statistic and determine it as the subset in which the satellite with the dominating range error is missing.
- However, if any other subset gives an almost equally small test statistic value (this value to be chosen via experiment), then no identification decision is made.

Step 3: Calculate the position error caused by the malfunctioning satellite identified in Step 2 and determine if the protection limit is coloured. If it is, an alarm is raised, the identified satellite is no longer used, and navigation is continued with the remaining satellites.

5.8 Concluding Remark

It is widely known and accepted that, even with the advent of Space and Ground Based Augmentation Systems for Global Navigation Satellite Systems (GNSS) Integrity Monitoring, users still require a final and independent indication of the integrity of the navigation solution. Without RAIM the GNSS solution is susceptible to errors such as multipath, signal obscuration and software and hardware failures. Currently the GNSS world is dominated by the U.S. GPS with marginal support from the restoring Russian GLONASS. However, the future of GNSS is now almost certain to include Modernized GPS, the developing Galileo System of the European Union (EU) and possibly the fully restored GLONASS. With such a rich future of satellite availability the single outlier assumption will be unrealistic under system augmentation.

CHAPTAR 6
GNSS RECEIVER

6.1 A Basic GPS Receiver

In the basic GPS receiver, the signals transmitted from the GPS satellites are received from the antenna through the radio frequency (RF) chain. The input signal is amplified to proper amplitude and the frequency is converted to a desired output frequency. An analog to digital converter (ADC) is used to digitize the output signal. The antenna, RF chain, and ADC are the hardware used in the receiver. After the signal is digitized, software is used to process it, and that is why we have taken a software approach. Acquisition means to find the signal of a certain satellite. The tracking program is used to find the phase transition of the navigation data. In a conventional receiver, the acquisition and tracking are performed by hardware. From the navigation data phase transition the subframes and navigation data can be obtained. Ephemeris data and pseudoranges can be obtained from the navigation data. The ephemeris data are used to obtain the satellite positions. Finally, the user position can be calculated for the satellite positions and the pseudoranges. Both the hardware used to collect digitized data and the software used to find the user position.

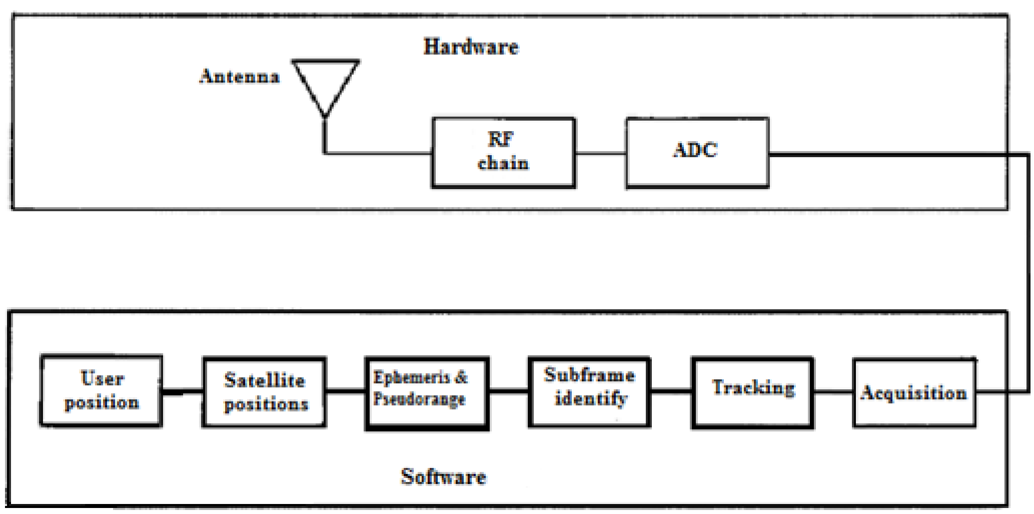


Figure 6.1 : A fundamental GPS receiver.

6.2 Platforms for a Future GNSS Receiver

GNSS receiver technology has changed dramatically since the first reception of a GPS signal. It evolved from complex electrical circuits - partly analog - tracking only one satellite at a time to today's sophisticated, small multichannel receivers. The core of a modern receiver is contained in one or more highly sophisticated chips that perform all the receiver's tasks, starting with signal processing, followed by positioning, and often ending at application processing. The technology to build these chips is called application-specific integrated circuit (ASIC) technology. GPS modernization and Galileo are now changing the environment of GNSS receiver design, and new signal processing algorithms are being developed.

6.2.1 ASIC Technology

The general approach used in ASIC-based receivers has provided a well-engineered partitioning of the required computations across fixed and programmable logic. High-speed digital correlation operations are performed in ASIC with parallel hardware-based digital signal processing manner. In typical ASIC-driven GNSS receiver design, a programmable microprocessor is responsible for controlling code and carrier tracking loops as well as for decoding and processing the navigation data bit stream to provide the user's position solution. Additional correlators increase receiver sensitivity and lower the CPU load. Current ASIC technology makes it possible to integrate tens of thousands of parallel hardware correlators into a single, small chip. This obsoletes the need for separate acquisition and tracking stages.

- The first is chip-level integration, which provides a variety of benefits to manufacturers and system integrators, for example, reducing size and power consumption, improving reliability and performance, and saving cost. The goal of chip-level integration is development of a single-chip solution that includes the RF and digital processing components. Nonetheless, chip-level integration may require a certain amount of development time and cost.
- The second ASIC trend is the design of a GNSS receiver as a form of IP (for example, RF IP and baseband IPs for each GNSS). This design approach is considered as one of the potential solutions for mobile applications in the form of PDAs, cell phones, and so

on. Successful adoption of GNSS IP into cell phones requires that the technology meets new demands such as indoor operation with low power consumption.

- The third trend that we will discuss is system on a chip (SoC) technology. Today's SoC designs are hardware/software systems on silicon rather than just gates on a chip. SoC-based system development combines tightly integrated software and hardware using ASIC or FPGA technology as the main hardware platform. This approach is currently helping to narrow the gap between the design methods of software and hardware designers.

6.2.2 FPGA Technology

A modern Field Programmable Gate Array (FPGA) receiver will have their place in the GNSS control segment, where development costs are the dominant factor. Additionally the control segment receiver algorithms can be continuously updated resulting in a steadily improving overall GNSS performance.

6.2.3 Software Defined Radio

The software defined radio (SDR) approach has evolved. SDR incorporates digitization closer to the receiver antenna front end so as to develop systems that work at increasingly higher frequencies and wider bandwidth. SDR accomplishes all digital signal processing using a programmable microprocessor, such as a DSP or a general purpose CPU, rather than an ASIC. This completely separates analog signal conditioning in hardware from all digital signals processing in software and results in significant gains, most notable flexibility. The SDR approach is expected to become more and more important, particularly in the design of multi-mode GNSS receivers (GPS + Galileo and soon).

6.2.4 Digital Signal Processors (DSPs)

The sole purpose of a digital signal processor (DSP) is to modify and manipulate the numbers in a digital data stream and it is "trimmed" to perform these tasks the quickest fashion possible. Hence, the DSP can perform its tasks by relying on many fewer transistors than a CPU, which translates into much lower power consumption, and thus makes DSPs ideal for mobile devices that have to be powered by batteries or power cells. Multi-issue DSPs use very simple instructions that typically encode a single operation, so that a high level of parallelism can be achieved. Fortunately the multi-channel concept employed in a GNSS receiver is parallel in nature and can be readily transferred to a multi-core chip.

6.2.5 General Purpose CPU

Although a general purpose CPU does not represent a primary platform for GNSS receiver development, this situation has been changing for some years, due to the continual increases in processing power driven in part by computer multimedia applications.

A DSP-based software receiver has a good chance to be used in applications where a DSP already exists and processing time is available (e.g., in an embedded system). A highly sophisticated DSP or general purpose CPU might even be a cost-efficient platform for a high-end receiver. A genuine software receiver (running on a PC) is the ideal teaching and research tool and might prove to be valuable for monitoring applications due to extremely flexible data inspection, monitoring and logging possibilities.

6.3 Theoretical Analysis of GNSS Receiver

The next generation of miniaturised GNSS space receivers compatible with the new and improved GNSS signals from Galileo and modernized GPS. A quick review of applications like Precise Orbit Determination (POD) and Radio Occultation (RO) is provided together with the performance achieved in current satellites. It will provide robustness and miniaturization altogether.

6.3.1 GNSS Receiver Architecture Overview

Our vision regarding future GNSS space receivers for POD and RO is summarised in Figure 6.2, which shows three key blocks in the GNSS receiver: the antenna, the RF chain and the baseband processing based on AGGA-4.

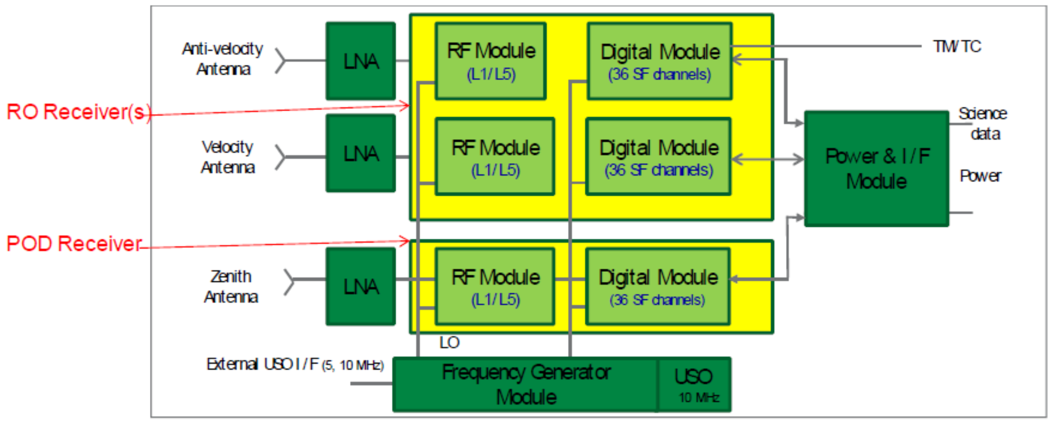


Figure 6.2 : Modular architecture of the next generation of GNSS receivers.

Key architectural trade-offs in the design of GNSS space receivers, that have a substantial impact on performance and complexity are:

- Number of frequency bands: two bands allow for compensation of ionospheric delays and result in subdecimeter accuracy at the expense of additional RF chains and complexity in the software to be implemented. Currently, the preferred bands are L1 and L2, but in the future it is expected that L1/E1bc and L5/E5a will be the chosen bands because most of the new GNSS constellations offer open signals at these frequencies that can be processed with the same hardware and because of the increased signal bandwidth on L5/E5a. Three GNSS frequencies close to each other will not bring benefits for ionospheric corrections.
- Acquisition timing: cold start, warm start or hot start differ in the a priori knowledge of several parameters like almanac, PVT solution, etc. and result in slower or faster acquisition, at the expense of software complexity.
- In RO with very low SNR, all kind of optimizations are needed at the expense of higher complexity, such as:
  - High gain directive antennas
  - Use of open loop tracking processing techniques when closed loop is no more possible, resulting in for example more observations or longer measurements in lower troposphere heights.

- Although nor related to low SNR, in RO it is also important to have high performance of the RF Front End with short term stability of the receiver through the use of ultra-stable oscillators (USO) with very low phase noise and clock drift.

6.3.2 Building up from AGGA-2

The development of the first AGGA (Advanced GPS/Galileo ASIC) device was initiated within ESA's Earth Observation Preparatory Programme (EOPP) in order to support the Earth observation applications of navigation signals. After prototyping iterations, the flight component known as AGGA-2 was manufactured as the Atmel product T7905E . The AGGA-2 is a space-qualified digital integrated circuit providing all the high-speed digital signal processing functionality for GNSS Earth Orbit (EO). applications and includes novel techniques for which international patents were assigned to the agency. AGGA-2 is available to all European space industries and is flying or will fly in a large number of ESA missions (e.g. Metop-GRAS for RO, GOCE, Swarm, EarthCare, GMES Sentinels 1, 2, 3 for POD) and non-ESA missions (e.g. Radarsat-2, Cosmo-Skymed for POD, Oceansat2-ROSA for RO).

The need for a new generation of AGGA (AGGA-4) was driven by:

- The understanding of the processing functionality that is optimal for atmospheric sounding, in particular through the development and exploitation of the GRAS instrument in MetOp.
- New requirements regarding geodetic-quality receivers (e.g. for GMES Sentinel of second generation).
- Enhanced GNSS signals from a larger number of GNSS systems (GPS / Galileo / GLONASS/ Compass) calling for extra functionality (e.g. memory codes, BOC modulation, secondary codes, pilot and data components) in the signal processing.
- Advances in space ASIC technology that allows on-chip integration of much more functionality than for AGGA-2.

6.3.3 Next Generation AGGA-4 GNSS Core

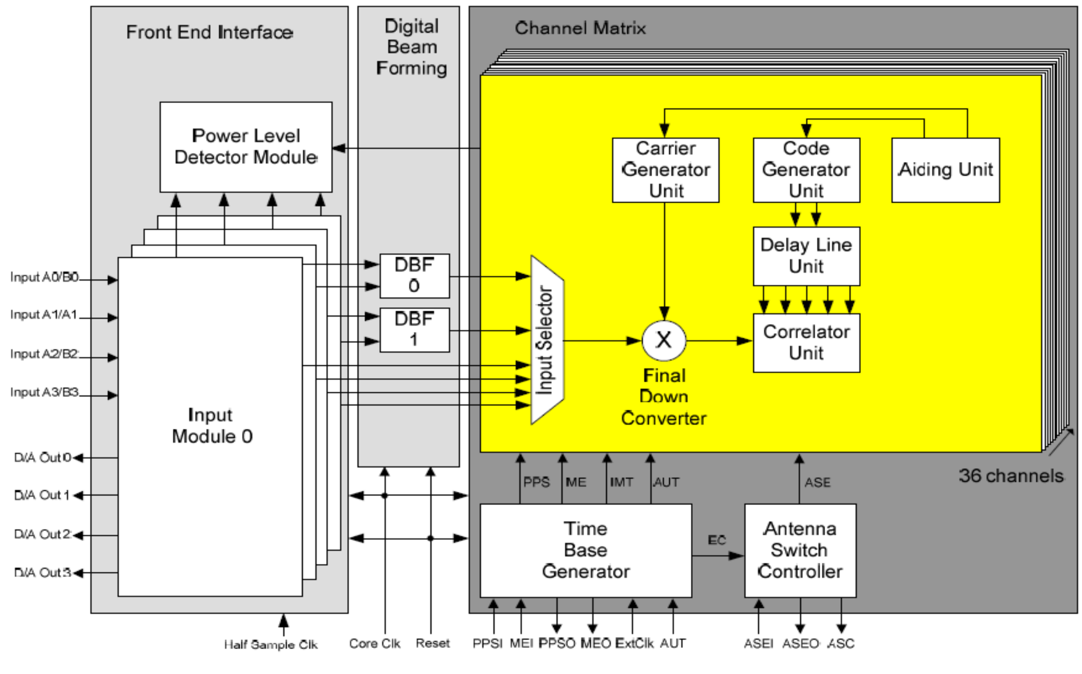


Figure 6.3 : AGGA-4 GNSS Core.

As shown in Figure 6.3, the Channel Matrix in the GNSS Core includes 36 (target) highly configurable single-frequency (SF) / double code GNSS channels. 36 SF channels correspond to 18 dual-frequency (DF) channels. Each SF channel includes:

- Double-code generators: the Linear Feedback Shift Register (LFSR) is needed to generate very long codes (e.g. for L2CL with 767,250 chips), whereas the memory-based generator is needed for very specific signals like E1bc. In addition, secondary code and BOC (Binary offset carrier) modulation capabilities are included. This very flexible architecture allows processing of any known GNSS open service signals in just one SF channel for both signal components (data/pilot), a2s indicated in Table 6.1.

Table 6.1 : Modernized GPS and Galileo Signals and Possible AGGA- 4 Configuration

Band	Freq. (MHz)	Component	Code Rate (Mcps)	Primary code length (chips)	Secondary code length (chips)	Symbol/ Data Rate sps / (bps)	Modulation in AGGA-4	LFSR/ Memory (config. AGGA4)	AGGA4 nb. channels
E1	1575.42	E1 B	1.023	4,092	No	250/125	BOC(1,1)	Memory	1 SF
		E1 C	1.023	4,092	25	Pilot	BOC(1,1)	Memory	
E5a (E5b)	1176.45 (1207.14)	E5a-I (E5b-I)	10.23 (idem)	10,230 (idem)	20 (4)	50/25 (250/125)	BPSK(10) (idem)	LFSR (idem)	1 SF (idem)
		E5a-Q (E5b-Q)	10.23 (idem)	10,230 (idem)	100 (idem)	Pilot	BPSK(10) (idem)	Memory (idem)	
L1c	1575.42	L1Cd	1.023	10,230	No	100/50	BOC(1,1)	Memory	1 SF
		L1Cp	1.023	10,230	1800	Pilot	BOC(1,1)	Memory	1 SF
L1	1575.42	L1 C/A	1.023	1,023	No	50	BPSK(1)	LFSR	1 SF
L2C	L2C	L2CM	10.23	10,230	No	50/25	BPSK(0.5)	Memory	1 SF
		L2CL	10.23	767,250	No	Pilot	BPSK(0.5)	LFSR	
L5	1176.45	L5-I	10.23	10,230	10	100/50	BPSK(10)	LFSR	1 SF
		L5-Q	10.23	10,230	20	Pilot	BPSK(10)	Memory	

- Code and carrier loop aiding in each channel to support the high but predictable range dynamics experienced by Low Earth Orbit (LEO) satellites and launchers. Typically the aiding frequencies are computed immediately after a new navigation solution has become available, either at each Measurement Epoch (ME) or at each Pulse Per Second (PPS) event.
- Optimized signal raw sampling or retrieval of observables via Direct Memory Access (DMA) at the output of the correlators, which is useful for example for RO applications in open loop tracking.
- A code delay unit with two configurable delay lines, which allow the tracking of double - component (pilot/data) signals in one channel.
- Five complex (I/Q) code correlators (Early-Early, Early, Punctual, Late, Late-Late), which is important for the processing of BOC (Binary Offset Code) signals.
- Ten (5I, 5Q) 29 bit integration accumulators.

Like in AGGA-2, all the channels in the AGGA-4 Channel Matrix share one Antenna Switch Controller (ASC) to support four antennas in attitude determination and a Time Base Generator

(TBG). The TBG produces the Measurement Epoch (ME) strobe, the Pulse Per Second (PPS) strobe for synchronizing external equipment and the Epoch Clock (EC). It also provides the Instrument Measurement Time (IMT) counter. It is possible to select between an internally generated ME signal and an external input, which allows slaving of multiple AGGA-4's, hence increasing the number of available channels if needed.

AGGA-4 provides four slave able input modules that support multiple input formats at baseband (complex format) and intermediate frequency (real format) at sampling frequencies up to 250 MHz (target). Each input module contains two Digital Down Converters (DDC) chains allowing to process up to eight GNSS bands at a time. Implementation losses are reduced through pre-processing (I/Q mixer, FIR decimation and re-quantization) which also converts all input formats into a common 3-bit I and 3-bit Q output format. The front-end also provides Power Level Control functionality, including Digital to Analogue (DAC) conversion to support Automatic Gain Control (AGC).

Each of the two Digital Beam-Forming (DBF) modules performs digital phase shifting and combination of two antenna signals prior to the channel correlations. In total, the two DBF modules can process the inputs from up to four antennas.

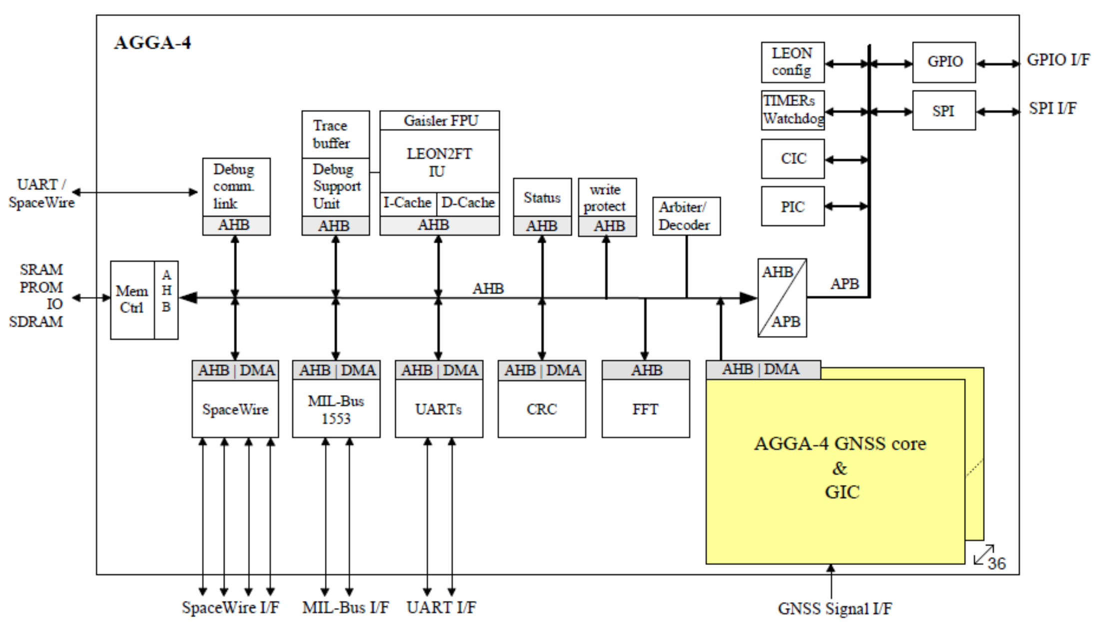


Figure 6.4 : AGGA-4 System overview.

As shown in Figure 6.4, the GNSS Core and other AGGA-4 modules access memory by direct memory access (DMA) via the AMBA (Advanced Microcontroller Bus Architecture) High-performance Bus (AHB). Data is shared through AHB and AMBA Peripheral Bus (APB). AGGA-4 includes on-chip the LEON-2 FT (Fault Tolerant) processor based on the SPARC V8 standard. The LEON-2 processor and periphery consist of a cache sub-system, a memory controller, interrupt controller (With GIC: GNSS Interrupt Controller; CIC: Communication Interrupt Controller and PIC: Primary Interrupt Controller).

The main AGGA-4 external interfaces are:

- Two DMA capable UARTs.
- SpaceWire interfaces: AGGA-4 has four bidirectional SpaceWire interfaces implemented with single-ended IO's (no LVDS) for general communication purposes (e.g. connection to EGSE, booting, extracting observables, etc.), at a rate per link related to the LEON-2 clock.
- Mil-Std-1553 bus.
- External SRAM memory interface with the on-chip LEON-2 FT microprocessor.
- Debug Support Unit (DSU) with debug Interface (UART and SpaceWire).
- Serial Peripheral Interface (SPI) for communicating e.g. with RF Front End.

The RF chain performance is a very important part for the overall performance of the GNSS receiver. This is particularly true for Radio Occultation (RO) applications, where parameters like phase noise, local oscillator stability and clock coherency with multi - frequency plans based on integer ratios between the different domains (e.g. digital, intermediate frequency, carrier) and components serving the relevant bands (L1, L2 or L5), are crucial to the observation science. Stringent out-of-band filtering requirements are also required due to emitted signals close to the GNSS spectrum (e.g. Search and Rescue – S&R – on - board payload) or due to ground interference in the L - band. New technology can also be used to improve the receiver frontend. Specifically, very low noise amplifiers (LNA), integrated close to the antenna when no S&R payload is considered, can be used to improve the receiver system noise, which allows improving SNR.

Antenna gain is not critical for POD applications in LEO geometry although precautions have to be taken into account for example to minimize multipath. Antenna gain is much more important for RO applications, however the rather large wavelength (around 25 cm at L5) imposes a serious constraint on the antenna size (e.g. 86 x 46 cm in Metop- GRAS) required to achieve the expected gain (e.g. 9 dB at 45 degree azimuth angle) that can only be slightly improved with new technology.

In short, it is expected that the new GNSS signals will bring higher robustness and similar accuracy in the next generation of GNSS space receivers for POD. Under very low SNR in RO, there is a potential accuracy improvement because the losses in semi-codeless processing will not be present and thanks to pilot signals. This allows a simplification of the receiver and improves the tracking limits with the two frequencies under unfavorable conditions. In addition, the higher code bandwidths could help when only code tracking is possible.

6.4 Multi-Constellation & Dual-Frequency Single Chip GNSS Receiver

Multi-constellation multi-band global navigation satellite system (GNSS) receivers can efficiently exploit the advantages derived from the modernization of existing GNSS constellations, such as GPS and GLONASS, as well as from the launch of new ones like Galileo and BeiDou. Utilizing multiple systems can significantly improve the availability of a navigation solution in urban canyons and heavily shadowed area. Increased satellite availability also guarantees higher measurement redundancy and improved reliability. Moreover, the excellent inherent noise and multipath mitigation capabilities of the new and modernized wideband signals in the L5/E5a band, combined with the ionosphere error mitigation given by frequency diversity, significantly improves the accuracy in both measurement and position domains.

The purpose of the NAPA project (Navigation chip for Pedestrian navigation and higher precision Applications) is to close this gap by providing a fully integrated, compact, low-power, and low-cost solution in which the analog and digital parts of the GNSS receiver are integrated together on the same chip. The NAPA receiver offers all the advantages of multi-constellation reception with additional dual-frequency support. Combining different chips for the analog front-end and the digital baseband is one of the solution. One fully integrated single-chip analog multi-band front-end for the simultaneous reception of GPS L1/L5, Galileo E1/E5 and GLONASS G1 signals with 40 tracking channels have been presented. However, this chip included only the front-end and requires an additional, separate digital-baseband solution.

6.4.1 Structural Design Exploration

The GNSS receiver is composed of two separate blocks integrated on the same silicon die: the analog core provides the functionality of a two-frequency radio-frequency (RF) front-end, whereas the digital part implements the main GNSS processing tasks, including the correlator channels and an embedded processor and takes care of the RF front-end control. The interface between the two blocks is completely digital and provides synchronizers to ensure a valid clock domain crossing (CDC).

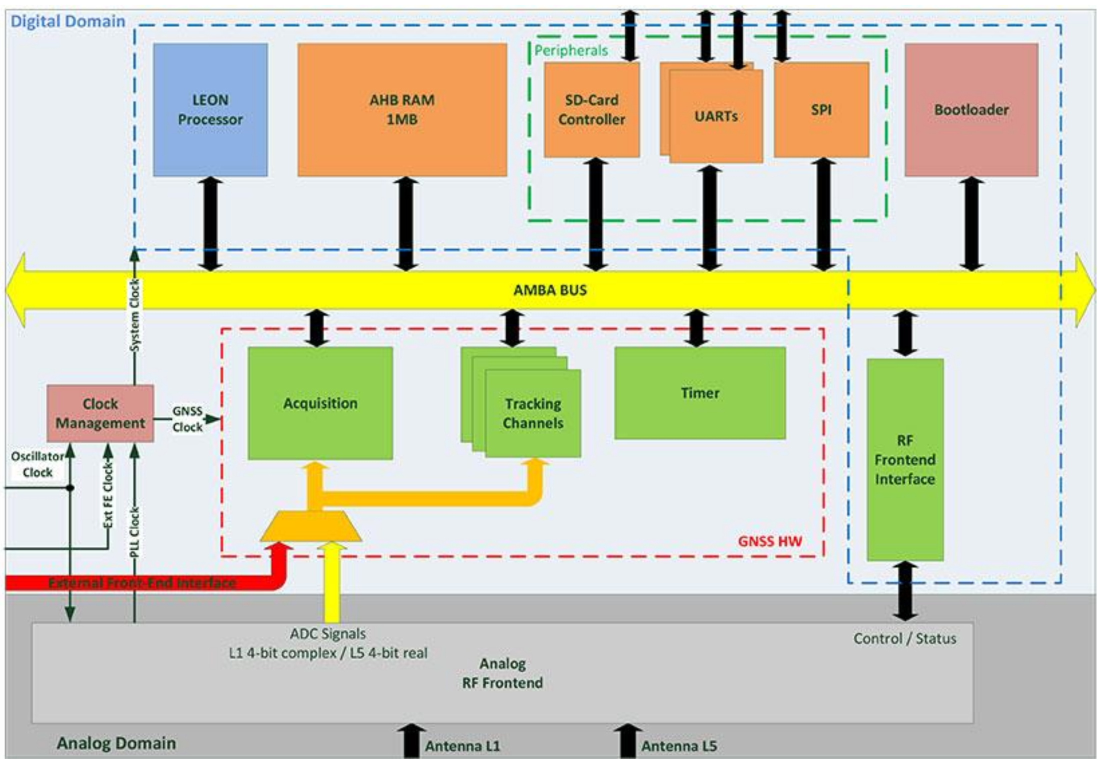


Figure 6.5 : GNSS Receiver.

6.4.2 Analog Front-End

The analog RF front-end supports the simultaneous reception of GPS L5 / Galileo E5a and GPS L1 / Galileo E1 / GLONASS G1 signals as well as modes where only one reception path is activated. Both passive and active GNSS antennas are supported, thanks to integrated low noise amplifiers (LNA). There are two separate signal reception paths for the two frequency bands. The real-valued analog signal is controlled by an AGC and converted to the digital domain using a single 4-bit ADC. A common phase locked loop (PLL) is used with specific L1/E1/G1 and L5/E5a dividers to generate the mixers' local oscillator (LO) frequencies. The PLL loop filter is integrated on-chip to minimize external elements. Moreover, automatic filter and voltage-controlled oscillator (VCO) calibrations are included to mitigate process tolerances. The PLL can handle input clock frequencies between 10 and 80 MHz with a recommended clock frequency of 36.115 MHz. An SPI core was implemented on the front-end part to facilitate control of the different front-end features. This means it is possible to tune the PLL, to switch off a complete front-end path if the second frequency band is not used and to activate different on-chip calibration procedures. The ADC clock is also directly connected to the baseband digital core and is used as the main clock for the GNSS hardware modules. The embedded processor in the digital core receives a second clock, which is twice as fast as the GNSS hardware one.

6.4.3 Digital Baseband SoC

The baseband is characterized by a system-on-chip (SoC) architecture based on a SPARC-compatible 32-bit LEON2 microprocessor running at approximately 150 MHz. The processor's primary functions are to correctly configure the RF front-end and control the different parts of the receiver. In particular, it triggers acquisition, initializes, and starts the tracking channels with the signals detected during acquisition and takes care of closing the frequency/phase/delay locked loops (FLL/PLL/DLL) used for signal tracking. The tracking loops have strict real-time constraints; communication between the channels and the processor features a high-speed infrastructure. The processor is connected to a hierarchical on-chip Advanced Microcontroller Bus Architecture (AMBA) composed of a high-performance bus (AHB) and a peripheral bus (APB). In addition to the processor, there are four additional AHB masters: the bootloader, the SD-card controller, the real-time GNSS modules, and the on-chip processor debugger.

6.4.4 Generic Peripherals

The digital core is equipped with several peripherals that enable the communication with the outside world. The two separate universal asynchronous receiver/transmitter (UART) interfaces can run at 115.2 kbps. A dedicated serial peripheral interface (SPI) master is also provided with a maximum of 10 - MHz clock frequency. The SD-card interface facilitates the loading and storage of large amounts of data. In addition, 10 general-purpose I/O pins (GPIO) are provided. They can be controlled via software and can provide a very basic interface. Using the chip as a simple snapshot receiver without having to use the on-chip dedicated GNSS hardware is also a possibility. For this purpose, the integrated peripherals like UART and SPI ports are provided as interfaces. External RF Front-End Interface is provided to allow for more flexibility.

CHAPTER 7

GPS TRACKING SYSTEM

7.1 GPS Tracking System

A GPS tracking unit is a device that uses the Global Positioning System to determine the precise location of a vehicle, person, or other asset to which it is attached and to record the position of the asset at regular intervals. The recorded location data can be stored within the tracking unit, or it may be transmitted to a central location data base, or internet-connected computer, using a cellular, radio, or satellite modem embedded in the unit. This allows the asset's location to be displayed against a map backdrop either in real time or when analyzing the track later, using GPS Tracking Software. GPS tracking system is method to locate the exact location of a receiver (tracking unit) on the earth.

In the developed world the miniaturisation and proliferation of Information and Communications Technologies (ICT) such as mobile phones, personal wireless laptop computers and personal GPS systems are rapidly and constantly evolving. We are a society constantly on the move, in a world that is becoming smaller by the day, wanting access to all forms of information wherever we are. That's why a new approach to GPS tracking system is proposed. The person will be able to use this system to navigate to a destination, obtaining the information about their location or destination. The system can also be used as an emergency aid.

The prototype is a system comprising a handheld/mobile device, Information and Communications Technologies (ICT), indoor and outdoor positioning technologies and Server Software that gives person information about where they are and how to get to where they want to go. Furthermore, a lot of location related information can be provided by such a proposed system. This is an excellent example of a "location-based service", which has been slated as the largest area of growth for ICT in the coming decade. This product is an additional device to enable the individual to enjoy mobility and have an improved sense of confidence and self-assurance.

7.2 Approaches to the GPS Tracking System

Any all-purpose navigation system must incorporate a variety of technologies in order for it to be useful

- Usable and location relevant information
- A viable user interface
- Comfortable method of carriage and
- An accurate location system, especially in an indoor environment.

7.2.1 Location-Based Services (LBS)

The proposed system can be seen as enabling a very specific application of location-based services (LBS). In general, LBS are services that exploit knowledge of where the user is located or where the query for information is directed in a geographic sense. These applications cover nearly every aspect related to human mobility. A critical component of LBS is the positioning technique(s) required to provide the location of the mobile user at an acceptable accuracy level. In general, GPS (or more generally the Global Navigation Satellite System - GNSS) is usable everywhere where there is clear sky. However it fails to operate where it's impossible or difficult to receive the satellite signals, such as inside most buildings, in ‘urban canyon’ environments and underground. For indoor application other technologies are used.

7.2.2 Assisted-Global Positioning Systems (A-GPS)

Assisted-Global Navigation Satellite Systems (A-GNSS), or Assisted-Global Positioning Systems (A-GPS) in particular, are now commonly accepted as an effective way to reduce the time-to-first-fix (TTFF) in GNSS-unfriendly environments, e.g. in areas of weak GNSS signals. Today’s location-based service (LBS) devices such as GPS-enabled mobile phones and personal digital assistants (PDA) rely on A-GPS. The development of the Open Source GNSS Reference Server (OSGRS) provides an alternative to commercial A-GPS reference data solutions. Tests in urban environments have demonstrated that A-GPS can significantly reduce the waiting time for a positioning and increases the number of tracked satellites. The OSGRS is an Open Source Java application that provides data for A-GPS/GNSS clients. The client may be an A-GPS/GNSS handset or an application that serves a network of A-GPS /GNSS handsets.

The OSGRS can be configured to connect to one or more sources of GNSS data (data sources) in order to cache it and serve it up to clients on request. The data is provided to the client in a format that is useful for A-GNSS satellite acquisition and calculating the location of handsets.

7.2.3 Wireless Wide Area Network (WiFi)

Utilising deployed infrastructure for wireless communications for positioning purposes is more attractive as it is much cheaper and it can be deployed much faster. Mobile phone network and WiFi are examples. WiFi is a very attractive alternative positioning technology due to the widely deployed WiFi access points (WiFi APs). Currently there are several companies that provide WiFi-based indoor positioning systems, however the accuracy is not very high.

7.2.4 The Global Positioning system (GPS) / Global System Mobile Communication (GSM) Based System

The GPS/GSM Based System is one of the most important systems, which integrate both GSM and GPS technologies. It is necessary due to the many of applications of both GSM and GPS systems. This system is designed for users in land construction and transport business, provides real-time information such as location, speed and expected arrival time of the user in a concise and easy-to-read format. This system may also be useful for communication process among the two points.

7.3 System Design

The proposed system consists of three parts:

- positioning technology,
- user interface and
- dynamic information provision (including information database structure).

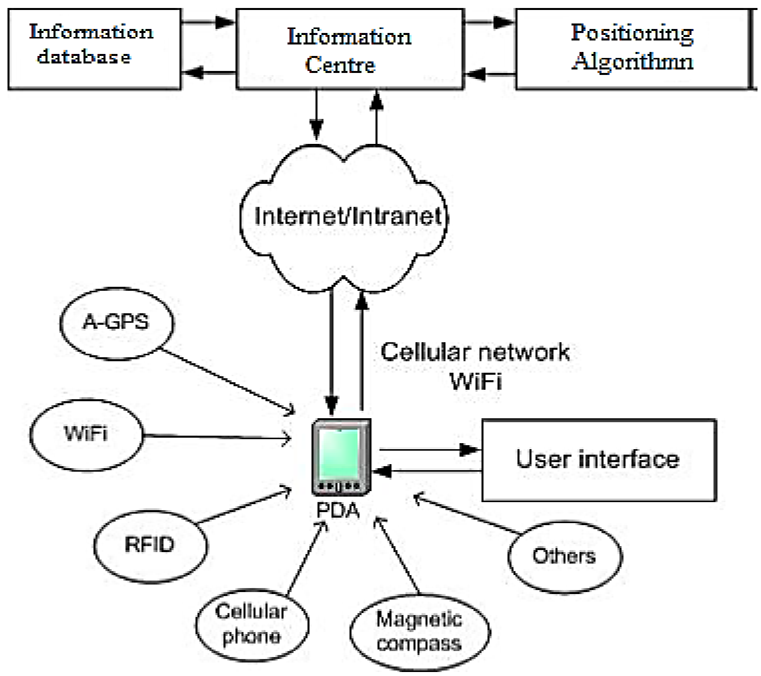


Figure 7.1 : The structure of the proposed system.

7.3.1 Positioning Technology

Many researchers have focused on the development of positioning technologies for indoors and outdoors. For example, Microsoft's Place Lab software allows devices such as notebooks, PDAs and mobile phones to locate themselves using radio beacons such as WiFi APs or GSM mobile phone towers. The positioning system that combines GPS, WiFi and mobile phone positioning is required. However, it will trilaterate signals from WiFi APs and mobile phone towers to find position; and GPS is used to map the WiFi and cellular landscape. The combination of GPS, WiFi and mobile phones remains a challenge for accurate positioning and navigation. The positioning technology integration is done by integrating several technologies such as A-GPS, WiFi Aps, Radio Frequency Identification (RFID), Inertial Navigation System (INS), etc. It can go some way to addressing the global positioning. Location information would be delivered by combining A-GPS and ICT technologies. In an outdoor environment A-GPS will be used, while in an indoor environment other technologies such as WiFi APs or RFID will be used. During the transition from one of these environments to the other a combination of all the methods may be used.

Figure 7.2 : Integrate several positioning technologies to provide location.

7.3.2 User Interface

People require an easy-to-use Human User Interface (HUI) to submit requests and connect to a server through the cellular network or WiFi. For a person, visualisation is an ideal way to display where facilities are, how to access them and other location based information. Keyboard entry, vibro-tactile, etc., are all possible interfaces.

7.3.3 Dynamic Information Provision

In this proposed system the dynamic information provision will consists of information database structure, information center and positioning algorithm. The information will be linked to location, other location-related data will be classified and the server can be accessed via the cellular network or WiFi.

The output of this system will be the data obtained from the GPS receiver. The data contains information which is position of the user. The data from the GPS receiver will be sent using

GSM module to the receiving end. On the receiving end, the GSM modem will receive the data and displayed it on the screen of the mobile phone. The mobile phone also can be used to send command to the GPS receiver through the GSM module.

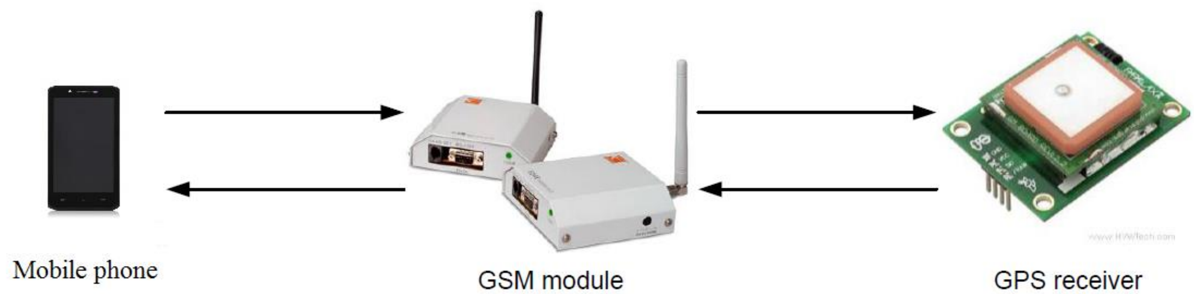


Figure 7.3 : The proposed system.

Our proposed idea is to implement this system at Military Institute of Science And Technology. Any outsider visits MIST can easily find his destination by using this tracking system. The mobile phone will act like a GPS receiver and it will guide him towards his destination showing his position in the campus. All required information will be available in the information database. The server can be accessed via the cellular network or WiFi. Positioning technologies will help the individual to reach his exact location by providing precise position data and suitable user interface.

We have prepared a hypothetical view on the mobile screen of this system which is implemented for the 4^{th} floor of tower building 1 of MIST, in which the user position is indicated by a red dot. This dot will move with respect to the user position showing on the mobile screen in the form of map.

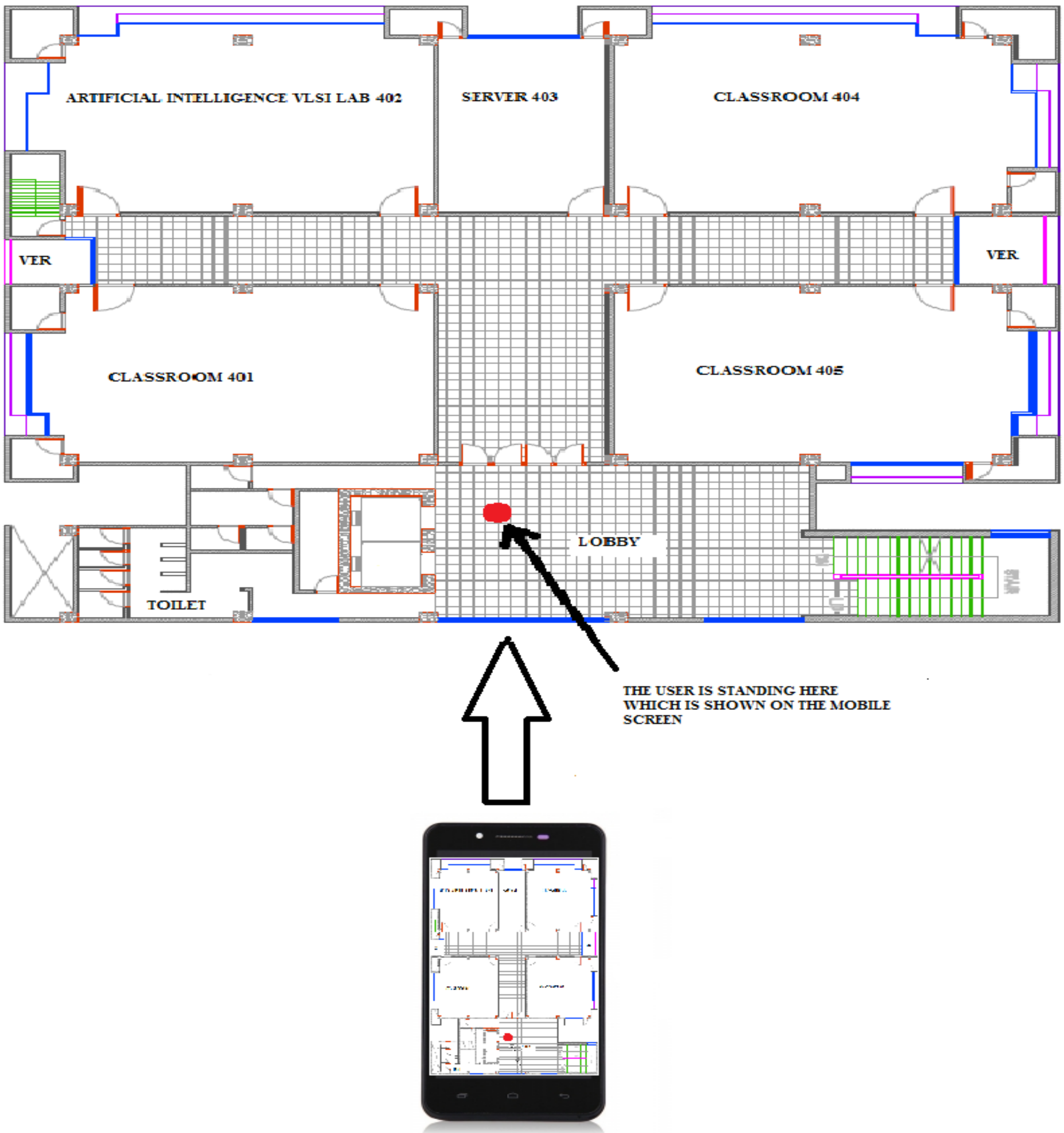


Figure 7.4: The hypothetical output on mobile screen.

7.4 Concluding Remarks

The proposed navigation and information system will create a prototype device that improves the mobility and independence of the individual. Furthermore, the proposed system will generate an innovative design for an indoor/outdoor positioning and information delivery system. This design can then be used for many other applications, from personal navigation to location-based services.

CHAPTER 8

CONCLUSION AND SCOPE OF FUTURE WORK

8.1 Results and Discussion

Chapter 1 gives the basic idea of our thesis topic that is GNSS. Here its history, evolution through time, classification and working principle is discussed. Subsequently the GNSS user architecture and its classification are described. Currently major four types of GNSS navigation system exists. They are GPS, GLONASS, Galileo and BeiDou navigation system. GPS and Galileo are incorporated because of very less deviation between their coordinate reference frame and frequency compatibility. GPS and GLONASS combination is avoided because of complexity they offer due to not having any frequency band common. Also their co-ordinate reference frame offer a deviation of 5 ~ 10 m. Thus it is less effective to interoperate GPS - GLONASS than GPS - Galileo.

Chapter 2 describes satellite constellation and availability. Constellation can be considered as a number of satellites with coordinated ground coverage while they are operating together under shared control and synchronized so that they overlap well in coverage and complement rather than interfere with other satellites coverage. LEO, GPS, Galileo and GLONASS satellite constellation is elaborated. Satellite availability depends on basically the geometry of satellites. In order to determine satellite availability, different cases are considered. One is the tracking of the satellites and the another is for spatial variation where the simulation is done for the entire world.

Chapter 3 presents satellite geometry specifically Dilution of Precision (DOP). Dilution of Precision (DOP) often called as Geometric Dilution of Precision (GDOP) is a dimensionless number, which is a measure of satellite geometry. DOP is basically a value of probability for the geometrical effect on GPS accuracy. The computed position can vary depending on which satellites are used for the measurement. Different satellite geometries can magnify or lessen the position error. A greater angle between the satellites lowers the DOP, and provides a better measurement. The brief and illustrated calculation of DOP especially GDOP is done in this chapter. At the end various figures for GDOP under different conditions are given. In figure 3.6

DOP analysis of GPS system for different cut-off elevations are shown. In figure 3.7 DOP analyses of different GNSS systems are shown.

Chapter 4 shows interoperability and compatibility of different GNSS systems. Interoperability refers to the ability of global and regional navigation satellite systems and augmentations and the services they provide to be used together to provide better capabilities at the user level than would be achieved by relying solely on the open signals of one system. Compatibility refers to the ability of global and regional navigation satellite systems and augmentations to be used separately or together without causing unacceptable interference and other harm to an individual system and service. GPS and Galileo orbital plane drifts are briefly explained in this chapter. The simulation is done to better understand interoperability and the success rate is also determined.

Chapter 5 describes Receiver Autonomous Integrity Monitoring (RAIM). Receiver Autonomous Integrity Monitoring (RAIM) is a GPS integrity monitoring scheme that uses redundant ranging signals to detect a satellite malfunction that results in a large range error. Traditional RAIM technique includes Fault Detection and Exclusion (FDE). A FDE test is also mentioned in this chapter. Principle of RAIM detection and identification is elaborated briefly. At last a new detection/identification algorithm is introduced.

Chapter 6 is basically written on GNSS receivers. At first various GNSS receiver architectures are discussed. Platform for a future GNSS receiver is introduced. ASIC, FPGA technologies are described. At first AGGA-2 is given then next generation AGGA-4 GNSS core is brought up in this chapter. The chapter is concluded with Multi constellation and dual frequency single chip GNSS receiver.

Chapter 7 proposes a new GPS based tracking system. A GPS tracking system, for example, may be placed in a vehicle, on a cell phone, or on special GPS devices, which can either be a fixed or portable unit. A GPS tracking system uses the Global Navigation Satellite System (GNSS) network. This network incorporates a range of satellites that use microwave signals that are transmitted to GPS devices to give information of location, vehicle speed, time and direction. So, a GPS tracking system can potentially give both real-time and historic navigation data on any kind of journey. In this chapter, we proposed various aspects of GPS tracking system and proposed an idea to implement for the Tower Building 1 of MIST.

8.2 Scope of Future Work

The GPS tracking system will be very useful to the user and it will also contribute for the betterment of the accurate positioning technologies. But still there are many further scopes for improving it. We have only considered GPS and Galileo system. If we can integrate the two other GNSS systems having global coverage such as GLONASS and BeiDou, the accuracy can be more improved.

On the other hand the proposed GPS tracking system is an imaginary idea. So, costing can be a very important factor. This costing can be a great limitation. That is why further improvisation is required. The more the system is refined, the more will be the system precision.

The system will be complicated as many positioning technologies are integrated. We have come to know that standalone GPS is not enough for accurate positioning as it works better for outdoor application. But we must keep in mind that indoor positioning system is also required. So, we are using WiFi /RFID for indoor application. The integrated system must also work during transition from one of these environments to the other. Integration of A-GPS, WiFi, cellular networks, RFID and near-field communications positioning is a core research challenge.

For more advanced use, Differential GNSS system or Multisensor Integrated Navigation system can be used. To attain high precision level, the positioning data provided by the GPS tracking system need to be corrected one. Design of such system could be a new era of research work for the future generation.

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