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# The Global Navigation Satellite System (GNSS) and Indian Satellite Based Augmentation System (GAGAN)

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**Abstract**— The Global Positioning System (GPS) has been used extensively for providing navigation, positioning and time information across the world for air vehicles, ships, missiles and Geographic Information System (GIS). The Global Navigation Satellite System (GNSS) of Russia (GLONASS) is also getting momentum in terms of civilian and military applications. In the series of satellite constellation GALILEO is getting ready for full fledge deployment. The GNSS alone is not sufficient for high precision position applications such as approach and landing of air vehicles. Hence, to achieve the appropriate level of accuracy these constellations need to be augmented. This paper describes the various methods of augmentation along with detailed description of Indian Satellite based augmentation system. The GAGAN system is an Indian Satellite Based Navigation Augmentation System. The GAGAN will provide a civil aeronautical navigation signal consistent with International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPS) as established by the GNSS Panel.

Index Terms—GAGAN, GALILEO, GLONASS, GPS, GBAS, ABAS, SBAS

## 1 Introduction

IN the modern world, satellite-based radio systems are being used in aviation as well as non-aviation sectors for communication, navigation, surveillance, air traffic management and various other purposes. The past decade has seen a rapid development of several GNSSs. Some of them are already in service such as GPS & GLONASS [1]-[3]. However, some GNSSs are still under development e.g. GALILEO by European Union [2] and Compass by China. The position accuracy achievable with these core constellations are not good enough for various service requirements such as accurate positioning and precision approach and landing of aircrafts. Hence to achieve the appropriate level of accuracy these constellations need to be augmented. Three types of augmentation techniques are used to enhance the position accuracy: Ground Based Augmentation System (GBAS), Aircraft Based Augmentation System (ABAS), and Space Based Augmentation System (SBAS).

GPS Aided Geo-Augmented Navigation (GAGAN) system is a planned implementation of a regional satellite based augmentation system by the Indian government. This system will help in up gradation of communication, navigation and surveillance systems. This will also help in landing of aircrafts in adverse weather conditions and uneven terrain. Once completely implemented, GAGAN will be the fourth operational Satellite Based Augmentation Systems after American Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS) and the Japanese MTSAT Satellite-based Augmentation System (MSAS). Since the GAGAN is an aiding system to GPS, therefore, in this paper GPS is considered a representative of GNSS family.

This paper describes the GPS and illustrates the limitations posed by GNSS for precise positioning applications in section 2. Section 3 deals with various augmentation techniques. Section 4 describes an Indian SBAS (GAGAN) in great detail. Finally, conclusion is presented in section 5.

## 2 Global Navigation Satellite System (GNSS)

### 2.1 Global Positioning System (GPS)

GPS is developed and maintained by the Department of Defense (DoD), USA and is officially named Navigation Signal Timing and Ranging (NAVSTAR) Global Positioning System. The GPS system uses receivers to calculate position by measuring the distance between the receiver and three or more GPS satellites. The distance to each satellite is measured by the time delay between transmission and reception of each GPS radio signal. The calculated distance is called pseudo range. The GPS signals also carry information about the satellite's location. By determining the satellite's position and pseudo ranges to the receiver, the receiver can compute its location using trilateration. Because receivers do not have perfectly accurate clocks, an extra satellite is tracked to account for clock error.

The GPS has architecture of three segments: 1) Space segment, 2) Control Segment, and 3) User segment [1]-[3]. The space segment includes 24 satellites at 20,000Km altitude, with six orbital levels as shown in figure 1 and a 12 hour period. The second segment includes the earth stations to control the satellite trajectories. The third segment includes GPS receivers using two frequencies in L1 and L2 band.

GPS satellites broadcast navigation data, modulated on the L1 (1575.42 MHz) and L2 (1227.60 MHz) band carrier frequencies. The data contains coarse ephemeris data for all satellites in the constellation, precise ephemeris data for this particular satellite, timing data and model correction parameters needed by a GPS receiver to make a correct ranging measurement. This data is included in the 37,500 bit navigation message, which

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takes 12.5 minutes and is send at 50 bps rate.

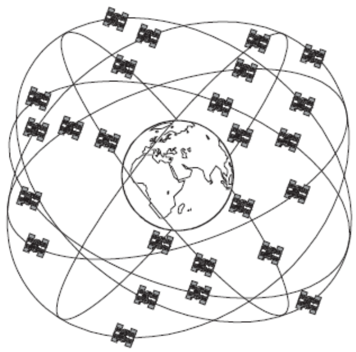


Fig.1 GPS Satellite Constellation

The satellites broadcast two forms of ranging codes: the Coarse/Acquisition (C/A) code, which is freely available to the public and the restricted Precise code (P-code), which is usually reserved for military applications specifically for US defense and allied forces only. Each satellite has a different C/A code. The C/A code is a 1,023 bit long pseudo-random code, broadcasts at 1.023 MHz and repeating every millisecond. Each satellite sends a distinct C/A code which allows it to be uniquely identified. Similarly the P-codes are broadcast at 10.23 MHz, but it repeats only once a week.

The U.S. government is committed to providing GPS to the civilian community at the performance levels specified in the GPS Standard Positioning Service (SPS) Performance Standard [4]. The accuracy users attain depends on various factors that include propagation delay, multipath, low accuracy receiver clock and the receiver noise. Some of the error sources and its effects are tabulated in table-1 [5].

Table- 1 Sources of Error

| Sl. No. | Source of Error | Effect |
|---|---|---|
| 1 | Ionospheric effects | ± 5 meter |
| 2 | Ephemeris error | ± 2.5 meter |
| 3 | Satellite clock error | ± 2 meter |
| 4 | Multipath distortion | ± 1 meter |
| 5 | Tropospheric effects | ± 0.5 meter |
| 6 | Numerical errors | ± 1 meter or less |

## 2.2 GNSS Limitations

In addition to accuracy consideration, there are other factors also which limit usage of GNSS such as [6], [9]:

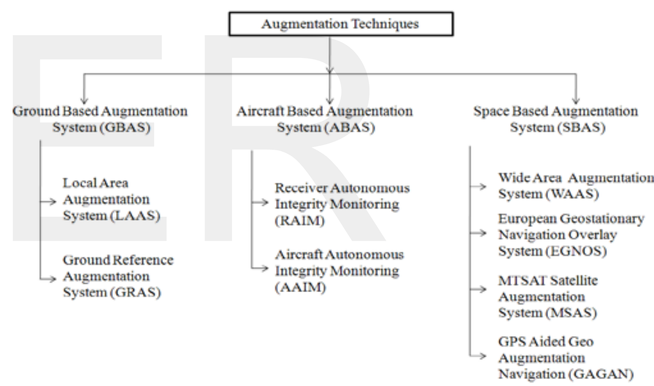
- GPS standalone cannot satisfy the integrity, accuracy and availability requirements for all phase of flight.
- Integrity is not guaranteed, since all satellites may not be satisfactorily working all times.
- Time to alarm could be from minutes to hours and there is no indication of quality of service.
- Accuracy is not sufficient even with selective availability (S/A) off for cat-I landing.
- For GPS & GLONASS standalone systems availability & continuity are not assured.

# 3 GNSS Augmentation

All the limitations mentioned in section 2.2 requires an immediate attention to address all the issues. Higher accuracy is available today by using GPS in combination with augmentation systems. These enable real-time positioning to within a few centimeters, and post-mission measurements at the millimeter level. The U.S. government is committed to modernizing the GPS constellation to enable higher civilian accuracy without augmentations.

The ongoing GPS modernization program is adding new civilian signals and frequencies to the GPS satellites, enabling ionospheric correction for all users. In turn, the accuracy difference between military and civilian GPS will disappear. But GPS with P-code will continue to provide important advantages in terms of security and jam resistance.

Augmentation of GNSS is a method of improving the navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process. There are many such systems in place and they are generally named or described based on how the GNSS receiver uses the external information. The augmentation techniques are classified as:




## 3.1 Ground Based Augmentation System (GBAS)

The GBAS supports local augmentation (at airport level) of the primary GNSS constellation(s) by providing enhanced levels of service that support all phases of approach, landing, departure and surface operations. The GBAS is intended primarily to support precision approach operations. The GBAS describes a system that supports augmentation through the use of terrestrial radio messages. The GBAS composed of one or more accurately surveyed ground stations, which take measurements concerning the GNSS, and one or more radio transmitters, which transmit the information directly to the end user. Generally, GBAS networks are considered localized, supporting receivers within 20 km, and transmitting in the very high frequency (VHF) or ultra high frequency (UHF) bands. The United States Local Area Augmentation System (LAAS) and Nationwide Differential GPS System (NDGPS) are examples of Ground Based Augmentation Systems.

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### 3.2 Aircraft Based Augmentation System (ABAS)

The ABAS augments the information obtained from GNSS with information available on-board the aircraft by using separate principles realized for GNSS. Due to this reason, it is not necessarily subjected to the same sources of error or interference. Receiver Autonomous Integrity Monitoring (RAIM) and Aircraft Autonomous Integrity Monitoring (AAIM) are the techniques used in ABAS.

RAIM is a technique used to provide a measure of the trust which can be placed in the correctness of the information supplied by GNSS. It uses redundant measures of GNSS pseudoranges, when more satellites are available than needed to produce a position fix.

AAIM uses the redundancy of position estimates from multiple sensors, including GNSS, to provide integrity performance. Inertial Navigation Systems (INS) on board is used as an integrity check on GNSS data when RAIM is unavailable. INS uses different motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously calculate via dead reckoning the position, orientation, and velocity of the aircraft without the need for external references.

### 3.3 Space Based Augmentation System (SBAS)

The SBAS supports wide-area or regional augmentation even continental scale through the use of GEO satellites which broadcast the augmentation information. A SBAS augments primary GNSS constellation(s) by providing GEO ranging, integrity and correction information [6]. While the main goal of SBAS is to provide integrity assurance, it also increases the accuracy with position errors below 1 meter. Such systems are commonly composed of multiple ground stations, located at accurately surveyed points. The ground stations take measurements of one or more of the GNSS satellites, the satellite signals, or other environmental factors which may impact the signal received by the users. Using these measurements, information messages are created and sent to one or more satellites for broadcast to the end users. There are already three operational (WAAS, MSAS, EGNOS), three under implementation (GAGAN, SDCM, SNAS) while others are under feasibility studies, for instance SACCSA systems in the world.

## 4 THE GPS AIDED GEO AUGMENTED NAVIGATION (GAGAN)

The GAGAN system is jointly developed by Indian Space Research Organization (ISRO) and Airports Authority of India (AAI), to deploy and certify an operational SBAS over Indian Flight Information Region. When commissioned for service, GAGAN will provide a civil aeronautical navigation signal consistent with International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPS) as established by the GNSS Panel. GAGAN implementation is carried out in two phases [7]-[10]:

- Technology Demonstration System (TDS): The objective of TDS phase was to demonstrate feasibility of SBAS implementation over Indian region with minimum set of elements, and to study the ionosphere over the Indian region & to collect data for system development and necessary modifications for the Indian region for the Final Operational Phase. The infrastructural configuration required for TDS phase is shown in figure 2.

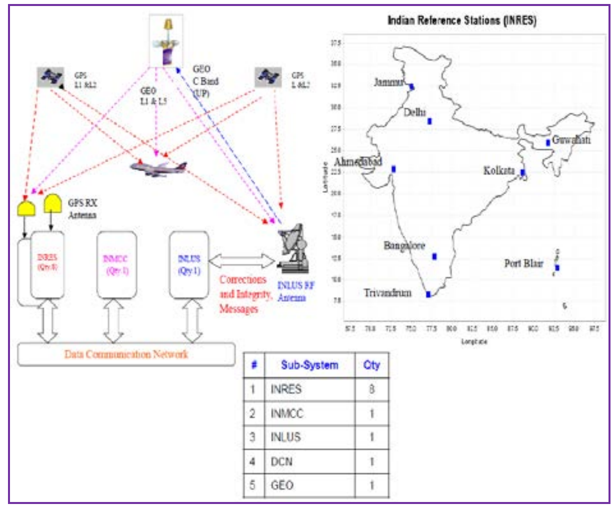


Fig.2 GAGAN TDS configuration [10]

- Final Operational Phase (FOP): The FOP intended for providing a certified satellite based navigation system for all phases of flight by augmenting the TDS system suitably. Further to provide redundancies, Implement Suitable region specific IONO model, Get safety Certification for the system for the Civil Aviation use from DGCA, the regulatory authority in India. The GAGAN satellite configuration and required ground infrastructure for FOP is shown in figure 3.

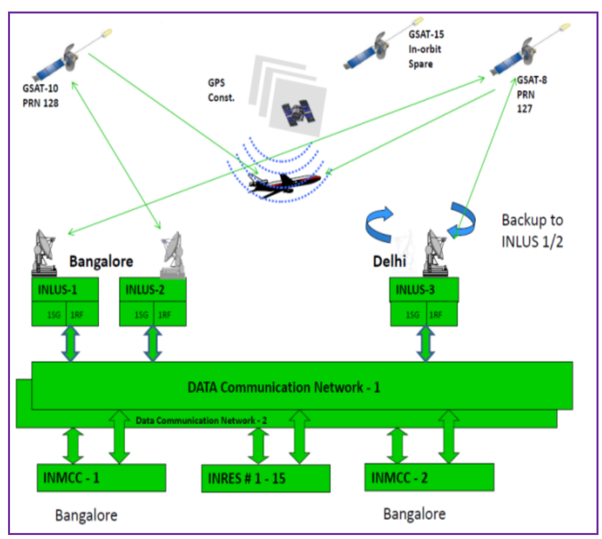


Fig.3 GAGAN FOP configuration [10]

The final GAGAN network involves the establishments of 15 Indian Reference Stations (INRES), 3 Indian Land Up-link Stations (INLUS), 2 Indian Master Control Centers (INMCC), 2

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Geo-Stationary Navigation Payloads (GSAT-8 & GSAT-10) in C & L bands and with all the associated software and communication links [10]. All INRESs are integrated with redundant communication links (which include 2 OFC & 2 VSAT links) to transfer data to INMCC.

GPS satellites data is received and processed at widely dispersed Indian Reference Stations (INRESs), which are strategically located to provide coverage over the required service volume. Data is forwarded to the Indian Master Control Center (INMCC), which processes the data from multiple INRESs to determine the differential corrections and residual errors for each monitored GPS satellite and for each predetermined Ionospheric Grid Point (IGP). Information from the INMCC is sent to the INLUS and uplinked along with the GEO navigation message to the GAGAN GEO satellite. The GAGAN GEO satellite downlinks this data to the users via two L-band ranging signal frequencies (1 MHz, BPSK signal at 1575.42 MHz of L1 band and 10 MHz, BPSK signal at 1176.45 MHz of L5).

The Final System Acceptance Test (FSAT) was completed during July 2012 and the GAGAN signal in space was evaluated using SBAS receivers at various locations across the country and the system performance was verified [10]. SBAS user receivers were deployed at various locations within India, and the performance in terms of accuracy and integrity were monitored and were found to be within specifications.

GSAT-8 is providing GAGAN signal at PRN-127, while GSAT-10 is providing GAGAN signal at PRN128. GSAT-15 will serve as an in-orbit spare once it is launched in the near future [10].

Further, GAGAN is the first system in the world that is being developed to serve the equatorial anomaly region with its unique IONO algorithm designed and developed by scientists and experts from ISRO & AAI in collaboration with Raytheon.

The GAGAN is designed to provide the additional accuracy, availability, and integrity necessary to enable users to rely on GPS for all phases of flight, from en route through approach for all qualified airports within the GAGAN service volume. GAGAN will also provide the capability for increased accuracy in position reporting, allowing for more uniform and high-quality Air Traffic Management (ATM).

In addition, GAGAN will provide benefits beyond aviation to all modes of transportation, including maritime, highways, railroads and public services such as defense services, security agencies, telecom industry and personal users of position location applications.

## 5 Conclusion

The Satellite constellation based Global Navigation Satellite Systems (GPS, GLONASS & GALILEO) are meant for providing navigation, positioning and time information across the world for various applications. However, for precision positions and safety critical applications the GNSS alone cannot meet the requirements in terms of accuracy, integrity and availability. Hence, various augmentation methods are adopted to improve the accuracy of GNSSs. The GAGAN is a SBAS designed to provide the additional accuracy, availability, and integrity necessary to enable users to rely on GPS for all phases of flight. This will enable Cat-I landing at Indian regional airports under the GAGAN service range.

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