UNIT 5
GPS AUGMENTATION SYSTEMS

SYLLABUS

Differential GPS (DGPS)
Local Area DGPS (LADGPS)
Wide Area DGPS (WADGPS)
GPS Augmentation systems
Need for augmentation
Types of augmentation systems
Space Based Augmentation system (SBAS)
GPS Aided GEO Augmented Navigation (GAGAN)
Ground Based Augmentation System (GBAS)

DIFFERENTIAL GLOBAL NAVIGATION SATELLITE SYSTEM (DGNSS)

DGNSS is a technique for reducing the error in GPS-derived positions by using additional data from a reference GNSS receiver at an accurately known position.

The most common form of DGNSS involves determining the combined effects of navigation message ephemeris and satellite clock errors (including the effects of SA) and, usually, atmospheric propagation delay errors at the reference station and transmitting delays corrections, in real time, to a user's receiver.

The receiver applies the corrections in the process of determining its position.

They include Corrections for:
(1) selective availability (if present)
(2) satellite ephemeris and clock errors.
(3) ionospheric delay error and
(4) tropospheric delay error.

Other error sources that cannot be corrected with DGNSS:
(1) multipath errors and
(2) user receiver errors.

A separate GPS receiver (called a reference station) is placed at a pre-surveyed point and turned on.

Because the location of the base station is already known with great accuracy, the base station is able to compare the position measurement generated by its own GPS receiver with the known co-ordinates.

By Dr.Swapna Raghunath
Professor, Dept. of ECE

Any difference means the signal from one or more satellites is being delayed.

All the system has to do then is work out how much correction should be applied to each satellite in order to correct the GPS position measurement.

Once the base station knows how the signal from each satellite needs to be corrected, it can share this information with any other GPS receivers (often called rovers) in the area.

This is often achieved using radio modems.

The roving receiver checks if corrections are available for the satellites it is seeing and applies them where applicable—improving the accuracy of its pseudo-range measurements even though it is not at a known location.

There are also other ways to achieve DGPS. Rather than using your own local base-station (that you set-up on your own site), it is possible to receive differential corrections via a web-based service and data connection.

In this case, your receiver (the rover) works out where it is in the normal way.

It then transmits its location to a central server that works out where the nearest reference station is to you, before sending back the differential corrections from that location.

The beauty of systems such as these is that you could drive from one end of a country to the other and receive valid corrections for the entire journey.

LOCAL-AREA DIFFERENTIAL GPS (LADGPS)

LADGPS is a form of DGPS in which the user's GPS receiver receives real-time pseudorange and, possibly, carrier phase corrections from a reference receiver generally located within the line of sight.

The corrections account for the combined effects of.

With the assumption that these errors are also common to the measurements made by the user's receiver, the application of the corrections will result in more accurate coordinates.

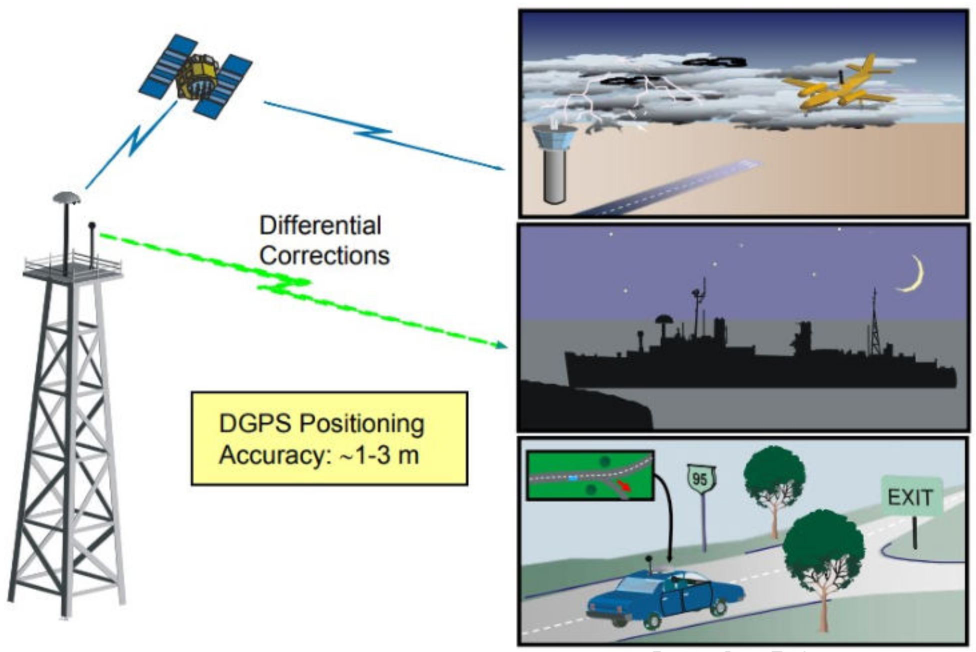

Fig. 5.1 DGPS Applications

WIDE-AREA DIFFERENTIAL GPS (WADGPS)

GPS has proven to be an extremely accurate positioning sensor for a wide variety of applications.

However, in some situations, such as aircraft approach and landing, higher accuracy is required.

Wide Area Differential GPS (WADGPS) is a system that could be used to meet such requirements.

The WADGPS system comprises a master station, and local monitor stations distributed across the United States.

The system calculates and transmits a vector of error corrections to users.

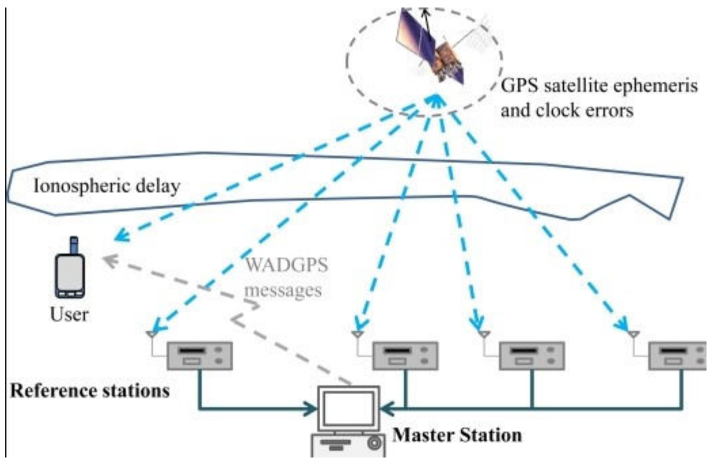

Fig. 5.2 DGPS Block Diagram

This correction vector consists of parameters describing the three-dimensional ephemeris errors, satellite clock offsets, and ionospheric time delay parameters.

The master station gathers GPS measurements made at each of the local stations, and estimates the errors

WADGPS services are designed to support safety of life applications.

Therefore, GNSS signal availability and reliability is of prime importance.

As the GPS L1 C/A code is currently the only GPS signal formally recognized for public access, it is the fundamental measurement used in augmentation systems such as the Coast Guard DGPS service and the FAA Wide Area Augmentation System (WAAS).

L1-only augmentation systems are less precise as first-order ionospheric errors cannot be fully corrected.

DGPS base stations observe L1 pseudoranges and compute corrections for transmission to maritime users from high-frequency radio-beacons.

As a GNSS satellite signal footprint covers an area of several hundred kilometres on the Earth's surface, common view is generally achieved over baselines of up to a couple of hundred kilometres.

While error cancellation from observation differencing becomes less effective as the distance between the base and rover increase, metre-level precision is routinely achieved with good satellite geometry.

With base stations performing autonomous integrity monitoring functions, users can be notified when system performance does not meet service specifications.

While DGPS base stations are independent from each other and autonomous, WADGPS references are part of a network of tracking stations that all report to a master station where wide-area corrections are computed and relayed to satellite uplink stations.

The uplinks ensure that communication satellites with footprints covering different regions of North America reliably broadcast augmentation messages to all WADGPS users.

WADGPS is a form of DGPS in which the user's GPS receiver receives corrections determined from a network of reference stations distributed over a wide geographic area.

Separate corrections are usually determined for specific error sources, such as satellite clock, ionospheric propagation delay, and ephemeris.

The corrections are applied in the user's receiver or attached computer in computing the receiver's coordinates.

The corrections are typically supplied in real time by way of a geostationary communications satellite or through a network of ground-based transmitters.

Corrections may also be provided at a later date for post processing collected data.

SPACE-BASED AUGMENTATION SYSTEMS (SBAS)

WIDE-AREA AUGMENTATION SYSTEM (WAAS)

WAAS enhances the GPS SPS and is available over a wide geographic area.

The WAAS developed by the Federal Aviation Administration, will provide WADGPS corrections, additional ranging signals from geostationary (GEO) satellites, and integrity data on the GPS and GEO satellites.

The primary mission of WAAS is to provide a means for air navigation for all phases of flight from departure, en route, arrival, and through approach.

WAAS provides improved en route navigation and PA capability to WAAS certified avionics.

The safety critical WAAS system consists of the equipment and software necessary to augment the Department of Defense (DOD)-provided GPS SPS.

WAAS provides a signal in space (SIS) to WAAS-certified aircraft avionics using the WAAS for any FAA-approved phase of flight.

The SIS provides two services:
(1) data on GPS and GEO satellites and
(2) a ranging capability.

The GPS satellite data is received and processed at widely dispersed wide-area reference stations (WRSs), which are strategically located to provide coverage over the required WAAS service volume.

Data are forwarded to wide-area master stations (WMSs), which process the data from multiple WRSs to determine

- the integrity,
- differential corrections, and
- residual errors

for each monitored satellite.

Multiple WMSs are provided to eliminate single-point failures within the WAAS network.

Information from all WMSs is sent to each GEO uplink subsystem (GUS) and uplinked along with the GEO navigation message to GEO satellites.

The GEO satellites downlink these data to the users via the GPS SPS L-band ranging signal (L1) frequency with GPS-type modulation.

Each ground-based station/subsystem communicates via a terrestrial communications subsystem (TCS).

In addition to providing augmented GPS data to the users, WAAS verifies its own integrity and takes any necessary action to ensure that the system meets the WAAS performance requirements.

WAAS also has a system operation and maintenance function that provides status and related maintenance information.

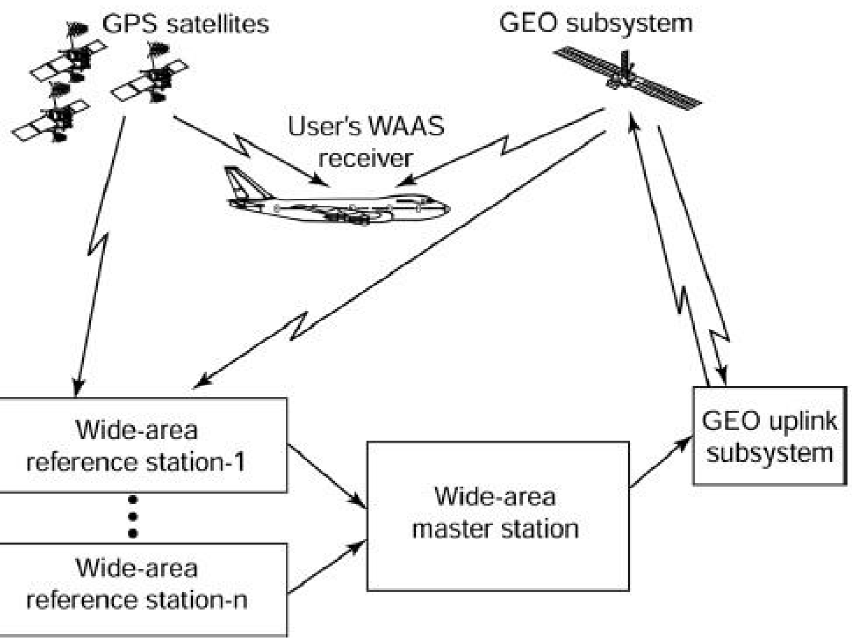

Figure 5.3 WAAS Top-level View

Correction and Verification (C&V) processes data from all WRSs to determine for each monitored satellite.

- integrity,
- differential corrections,
- satellite orbits and residual error bounds
- ionospheric vertical delays and their residual error bounds

C&V schedules and formats WAAS messages and forwards them to the GUSs for broadcast to the GEO satellites.

Wide-area reference stations (WRSs)
Each WRS collects raw pseudorange (PR) and accumulated delta range (ADR) measurements from GPS and GEO satellites selected for tracking.

Each WRS performs smoothing on the measurements and corrects for ionospheric and tropospheric delays.

These smoothed and atmospherically corrected measurements are provided to the WMS.

Wide-area master stations (WMSs)
WMS is capable of

- real-time processing,
- computation of delay correction,
- determination of satellite integrity status and
- WAAS message formatting.

This processing is done at a 1-Hz rate.

The WMS background processing consists of algorithms that estimate slowly varying parameters.

These algorithms consist of

- WRS clock error estimation
- Broadcast ephemeris computation
- Satellite orbit determination
- Satellite ephemeris error computation
- Satellite visibility computation.

GNSS AUGMENTATION SYSTEMS

A GPS augmentation is any system that aids GPS by providing accuracy, integrity, availability, or any other improvement to positioning, navigation, and timing that is not inherently part of GPS itself.

GBAS and SBAS are the augmentation systems that have been incorporated into GNSS to overcome its limitations.

Ground Based Augmentation System (GBAS)

A Ground Based Augmentation System (GBAS) augments the existing Global Positioning System (GPS) used in U.S. airspace by providing corrections to aircraft in the vicinity of an airport in order to improve the accuracy of, and provide integrity for, these aircrafts' GPS navigational position.

GBAS comprises a constellation of satellites, ground station and the aircraft receiver.

A group of three to four reference receivers placed at predetermined locations, a central processing station and a very high frequency (VHF) data broadcast (VDB) transmitter operating over 108 - 117.975 MHz together form the ground station.

GNSS data is received by the reference receivers which they relay to the processing facility.

The differential corrections are computed by the processing facility and transmitted to the VDB transmitter which in turn is delivered to the aircraft receiver.

The aircraft receiver employs these corrections for reducing GNSS error.

If two airports are in close proximity, a single GBAS installation can provide service to both of them.

GBAS Architecture

A GBAS Ground Facility typically has three or more GPS antennas, a central processing system (i.e., a computer), and a VHF Data Broadcast (VDB) transmitter all locally situated on or near an airport.

GBAS airborne equipment consists of a GPS antenna, a Very High Frequency (VHF) antenna, and associated processing equipment.

On board the aircraft, GBAS avionics within the Multi-Mode Receiver (MMR) technology allows simultaneous implementation of GPS and GBAS using common antennas and hardware.

The GBAS Ground Facility uses the VHF radio link to provide aircraft with GPS corrections, integrity, and approach path information.

The GBAS, with reference antennas in known surveyed positions, receives signals from GPS satellites.

The reference receivers measure the time of transmission between the GPS satellite and the reference antennas to estimate the distance the signal travelled.

The GBAS Ground Facility then compares the measured/ estimated distance with the actual distance based on the broadcast satellite position and the true GPS reference receiver position, and determines the error in the measurement.

The average error measured by all operational reference receivers represents the correction term the GBAS avionics needs to apply to the satellite ranges measured by the GBAS avionics.

The GBAS Ground Facility also monitors general GPS satellite performance.

The GBAS avionics only use GPS satellites for which it receives valid ground corrections.

When the GBAS Ground Facility determines there is a potential problem with a GPS satellite or when it cannot monitor a GPS satellite, it stops broadcasting corrections for that particular satellite, effectively preventing the GBAS avionics from using the satellite.

The GBAS Ground Facility broadcast also includes integrity parameters which permit the GBAS avionics to compute vertical and lateral error bounds on their calculated GPS position.

This bound is commonly referred to as a protection level.

The broadcast integrity values are set such that the likelihood of the actual error being larger than the computed protection level is less than 1 in 10 million.

The avionics compares these computed vertical and lateral bounds to a corresponding set of alert levels.

If either of the computed bounds is larger than the corresponding alert levels, the avionics determines that the aircraft positioning accuracy is not suitable for the operation.

The alert limits are defined in ICAO standards and are based on the amount of allowable error for a given operation.

The VDB broadcasts the GBAS signal throughout the GBAS coverage area to avionics in GBAS-equipped aircraft.

GBAS provides its service to a local area (approximately a 23 nautical mile radius).

The GBAS service volume is designed to support aircraft throughout the transition from en-route airspace to precision approach and landing.

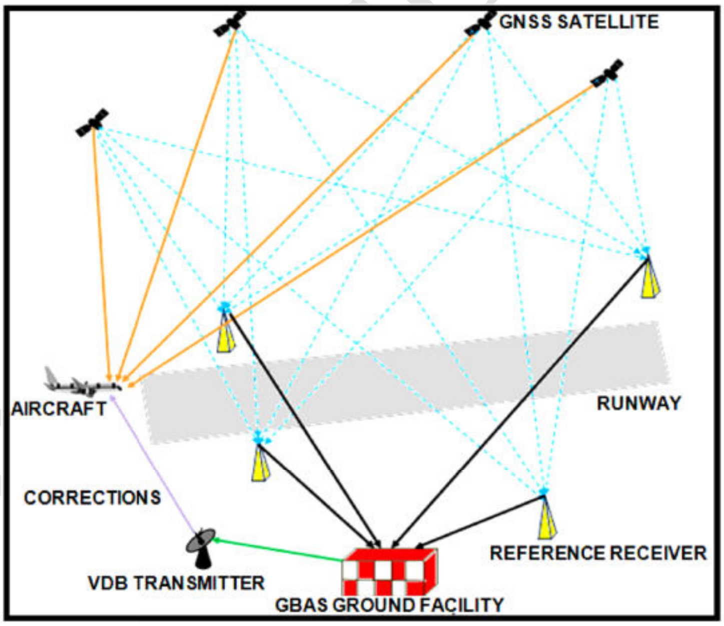

Fig. 5.4 GBAS Architecture

SATELLITE-BASED AUGMENTATION SYSTEM (SBAS)

A Satellite-based Augmentation System (SBAS) is a civil aviation safety-critical system that supports wide-area or regional augmentation – even continental scale - through the use of geostationary (GEO) satellites which broadcast the augmentation information.

A SBAS augments primary GNSS constellation(s) by providing GEO ranging, integrity and correction information.

While the main goal of SBAS is to provide integrity assurance, it also increases the accuracy with position errors below 1 meter (1 sigma).

The ground infrastructure includes the accurately-surveyed sensor stations which receive the data from the primary GNSS satellites and a Processing Facility Center which computes integrity, corrections and GEO ranging data forming the SBAS signal-in-space (SIS).

The SBAS GEO satellites relay the SIS to the SBAS users which determine their position and time information.

For this, they use measurements and satellite positions both from the primary GNSS constellation(s) and the SBAS GEO satellites and apply the SBAS correction data and its integrity.

The augmentation information provided by SBAS covers corrections and integrity for satellite position errors, satellite clock/time errors and errors induced by the estimation of the delay of the signal while crossing the ionosphere.

For the errors induced by the estimation of the delay caused by the troposphere and its integrity, the user applies a tropospheric delay model.

SBAS compensates for the shortfalls in the performance of GNSS throughout every phase of flight of an aircraft.

SBAS detects and quantifies the errors and provides error bounds and confidence intervals to the aircraft receiver.

The SBAS implemented by the US Federal Aviation Administration (FAA) is the Wide Area Augmentation System (WAAS).

European Geostationary Navigation Overlay Service (EGNOS) is European SBAS.

Japan and India have developed their own SBAS known as Multi-functional Satellite Augmentation System (MSAS) and GPS-Aided Geo Augmented Navigation (GAGAN) respectively.

GAGAN was developed as a joint venture by ISRO and Airports Authority of India (AAI).

It has been in operation since 30th December, 2013 with an accuracy of 3m.

The intension behind the conception of SBAS is to reduce the dependency on the terrestrial based infrastructure and to rely mostly on the super precise satellite technology.

SBAS components include a ground network of precisely located reference stations, master stations, the Geostationary Earth Orbit (GEO) communication satellites and SBAS sensor systems in the user receiver.

The ground reference stations observe, receive and process GNSS data from where the data is transmitted to master stations, also located on Earth.

The master stations determine the error component and propose corrections which are then transmitted to the GEO satellites and broadcasted to the SBAS receiver.

In aircraft navigation, the corrected message from the GEOs is received by the SBAS receiver in the Flight Management System (FMS).

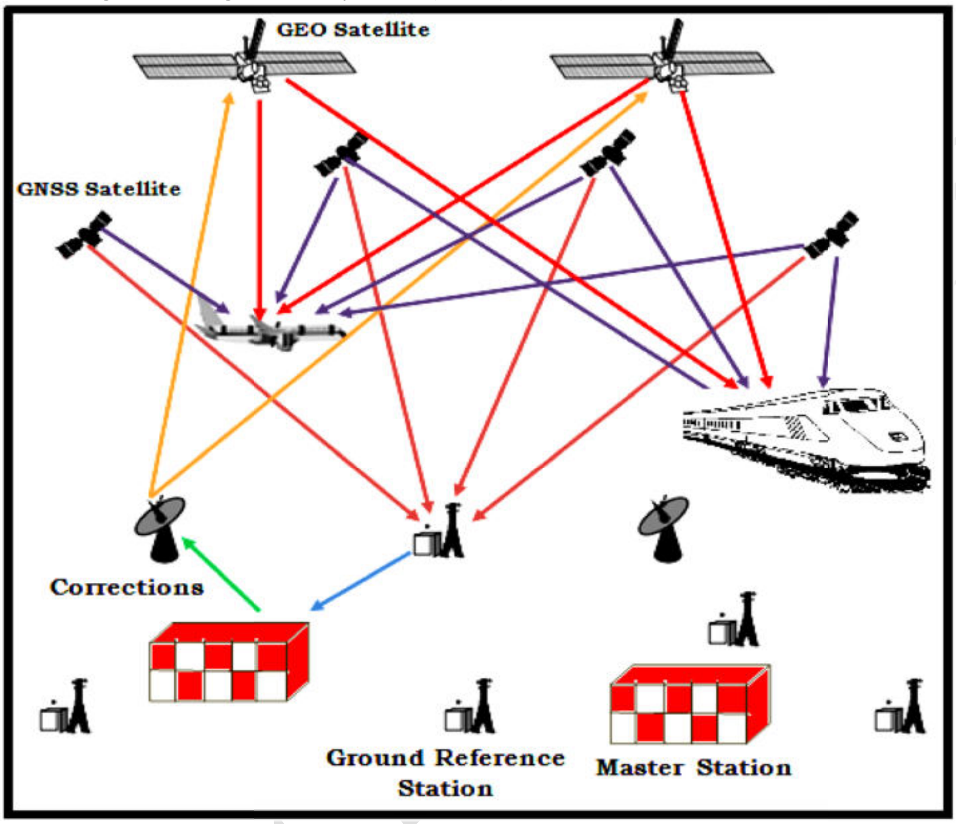

Fig. 5.5 SBAS Architecture

GPS AIDED GEO AUGMENTED NAVIGATION (GAGAN)

The GPS Aided Geo Augmented Navigation (GAGAN) system was developed by the Indian Space Research Organization (ISRO), together with Airports Authority of India (AAI), to deploy and certify an operational satellite-based augmentation system (SBAS).

The system's service area covers the Indian Flight Information Region (FIR), with the capability of expanding to neighbouring FIRs.

GAGAN provides a civil aeronautical navigation signal consistent with International Civil Aviation Organization (ICAO) Standards and Recommended Practices (SARPs) as established by the GNSS Panel.

The system is interoperable with other international SBAS systems such as

- the U.S. Wide Area Augmentation System (WAAS)
- the European Geostationary Navigation Overlay Service (EGNOS)
- the Japanese MTSAT Satellite Augmentation System (MSAS)

and provides seamless air navigation across regional boundaries.

GAGAN Components

The GAGAN system consists of the following elements for the effective implementation of SBAS over India.

1. Indian Reference Station (INRES) — at 15 locations across India
2. Indian Master Control Center (INMCC) —two at Bangalore
3. Indian Land Uplink Station (INLUS) —three stations, two at Bangalore and one at New Delhi
4. Geostationary satellites (GSAT8/GSAT10) in orbit and one on-orbit spare in GSAT-15 launched on November 10, 2015
5. A data communication subsystem —two optical fiber communication (OFC) circuits and two very small aperture terminal (VSAT) circuits.

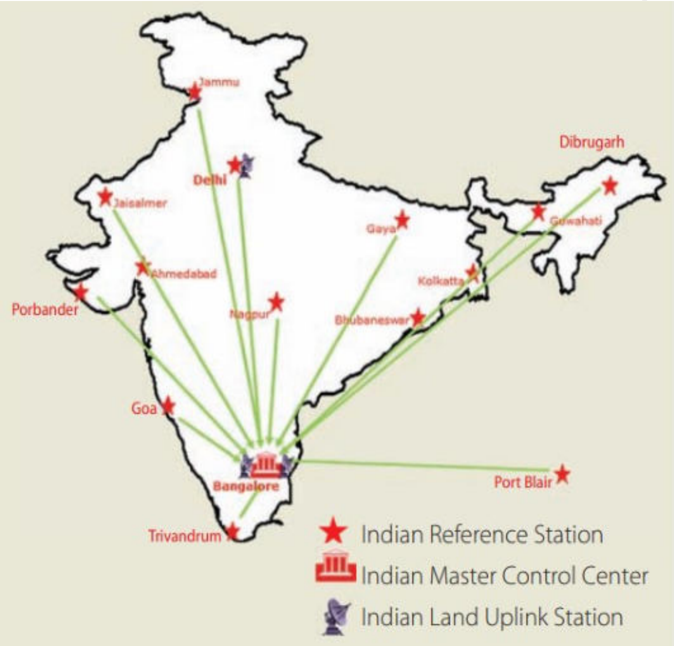

Fig. 5.6 GAGAN Ground Segment

The following sections describe each element in greater detail.

INRES – Indian Reference Station

The INRES stations collect measurement data and broadcast message from all the GPS and GEO satellites in view and forward them to the INMCC for further processing.

The 15 INRES stations are established at

1. Ahmedabad
2. Bangalore
3. Jammu
4. Guwahati
5. Kolkata
6. New Delhi
7. Port-Blair

8. Trivandrum
9. Jaisalmer
10. Goa
11. Porbandar
12. Gaya
13. Dibrugarh
14. Nagpur
15. Bhubaneshwar

INMCC – Indian Master Control Center

The data collected by each INRES across the country are transmitted to INMCC in real time (every second) and processed for the generation of correction and integrity parameters, in the form of SBAS messages.

The SBAS messages contain information that allows SBAS receivers to remove errors in the GPS position solution, thereby allowing for a significant increase in location accuracy with reliability.

Along with the corrections, the confidence parameters (integrity) are also computed and provided to the users as messages.

The generated SBAS messages are sent to INLUS for further processing.

INLUS – Indian Land Uplink Station

The INLUS receives the SBAS messages from INMCC, formats them for GPS compatibility and uplinks the SBAS messages to GEO Stationary satellite for broadcast to the user community.

The messages are up linked in C-band to GSAT-8/GSAT-10 GEO satellite through Indian Land Uplink Station (INLUS) which are down linked in L1 & L5 band to the users.

The broadcast messages are used by SBAS compatible receivers which compute its position while applying corrections over GPS signals.

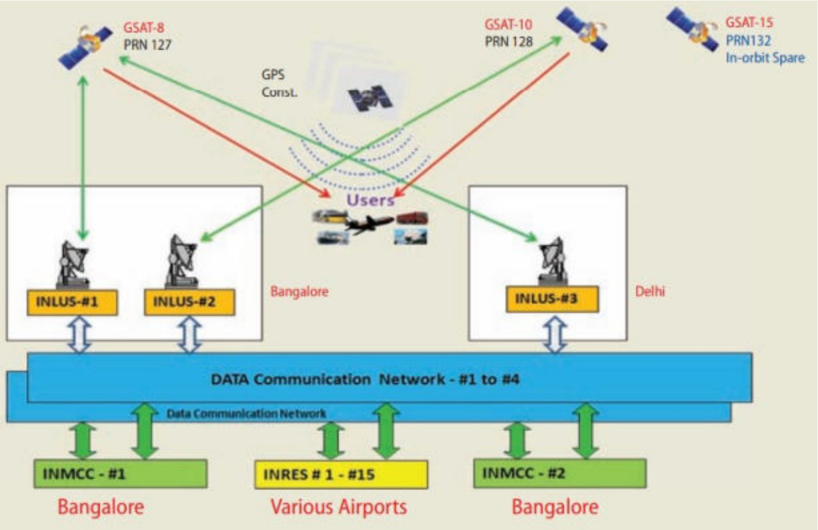

Fig. 5.7 Schematic Overview of GAGAN Final Operational Phase (FOP) Configuration

GEO Satellite

ISRO is responsible for providing GEO Satellites (SPACE segment) to the GAGAN program.

Three GEO satellites GSAT-8, GSAT-10, and GSAT-15 carry the GAGAN payload.

Table 5.1 Location of GAGAN GEO Satellites

GSAT	Location	PRN
GSAT-8	55 degrees East	127
GSAT-10	83 degrees East	128
GSAT-15	93.5 degrees East	132

GSAT-8 and GSAT-10 are already transmitting GAGAN SIS (Signal in Space).

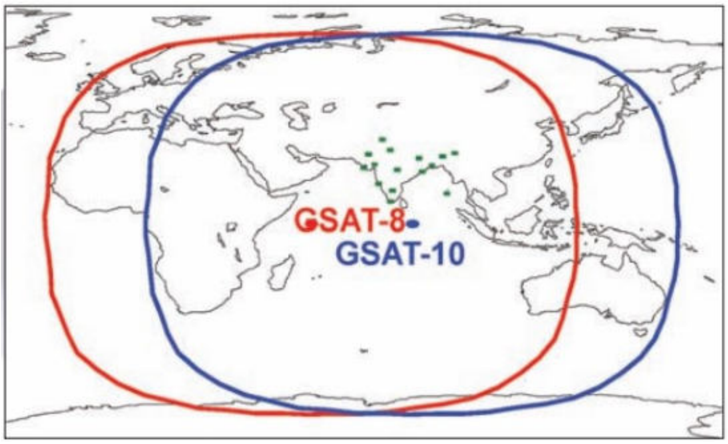

Fig. 5.8 GAGAN Signal Coverage

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