Figure 3.20 The users segment (Source: https://www.tokopedia.com/aprilianisurvey/gps-geodetik-hi-target-v90-plus-rtk)

3.4.4 Signals of GNSS

The GNSS system sends its information through various signals. Broadly, it works with three types of signals; L1, L2, and L5. Figure 3.21 shows the modulation of L1 wave and L2 wave. The L1 signals operate at 1575.42 MHz, and carries both the status message and a pseudo random code (PRC) for timing. The L2 signals operate at 1227.60 MHz, and used for the more precise military work. The L5 signal operates at 1176.45 MHz which was turned on April 2009. The L5 frequency is used to improve accuracy for civilian use, such as aircraft precision approach guidance. The GNSS has fifteen satellites with L5 available and Galileo with 24 all of which are currently using L5. In good satellite visibility the GNSS device with L5 will give a 6 ft accuracy, and 10 ft with GPS only.

A civilian GNSS uses the L1 signal in the UHF band. The L1 frequency carries the navigation message and the standard positioning code signals (SPS). Most receivers are capable of receiving and using the SPS signals, and civilian users world-wide use the SPS without restrictions. The SPS accuracy is intentionally degraded by the DoD by the use of Selective Availability (SA). The SPS provides 100 m horizontal, 156 m vertical, and 340 nanoseconds time accuracy. The signals travelling from satellite to receivers will pass through clouds, dust, gas, particles etc., but will not travel through solid objects, such as buildings and mountains (Garg, 2021).

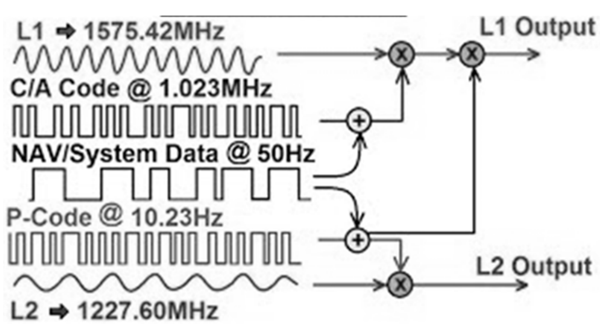

Figure 3.21 L1 and L2 signals

The pseudoranges, which are derived from signal travel time to the receiver, use two pseudorandom noise (PRN) codes. These codes are modulated onto the carrier frequencies. The carrier frequency with PRN codes is modulated for the real-time positioning through GPS signals. The travel time of a PRN signal code can give pseudo ranges. Dual frequency receivers get signals in L1 and L2 carrier wave at 24.45 cm wavelength. But today many of the multi-band receivers operate in L1, L2 and L5, and they eliminate the ionospheric dispersion which is one of the major sources of systematic range error. The structure of the future operational GPS L5 signal will offer a two carrier components signal. Both components– In-phase (I) and quadrature-phase (Q) will have the same signal power level. The minimum received power is defined with -157.9 dBW, which is 0.6 dB more than the L1 C/A code signal. Both components will carry different but nearly orthogonal and time synchronized PRN Codes. The Q channel of the L5 signal will be a data-less channel, transmitting only a pilot signal modulated with the specific satellite PRN, which is useful for a long coherent integration time. On the I channel the navigation message is modulated with 100-symbol per seconds. In addition, the L5 signal uses a NeumanHoffman synchronization code. The usage of two different PRN Codes helps to prevent possible tracking biases. The two channels are only dependent on the same carrier phase.

The L5 signal uses a chipping rate of 10.23MHz and which is 10 times the rate of the C/A and L2C codes. With this chipping rate the signal has 20.46 MHz null-to-null bandwidth which is exactly the same as the legacy P(Y) code signal. Thus the signal features satisfy the requirements for a new Safety of-Life signal with increased bandwidth, higher signal accuracy und robustness under rough conditions. The L5 I Channel NAV Data is very similar to the L2C channel and includes Space Vehicle ephemerides, system time and clock behavior data, status messages and time information. The L5 band signals have the advantages as they have: (i) a higher power (1.5 dB for the pilot channel of the L5 signal compared to the L1 C/A signal, and 2 dB for the E5a/b signals as compared to the E1 signal for the pilot channels), which means that similar detection performance can be obtained with lower integration times; (ii) a pilot channel, whereas the GPS L1 C/A signal does not have one, therefore this must limit its coherent integration time, which can lead to a longer total integration time; (iii) a lower carrier Doppler and Doppler rate (115/154 ≈ 75%), which can reduce the search space and some constraints for the acquisition architecture; and (iv) a secondary code, which on one side complicates the acquisition, but on another side makes the data synchronization much easier, simplifying the transition to the tracking. The L5 is intended to be a "safety-of-life" signal for aircraft navigation but will be useable for all civil users. This makes L5 to a valuable third civil GPS signal beside the C/A and L2C signal.

A simple GPS receiver will make use of only one global navigation satellite system, while multi-constellation GNSS receivers allows them to "see" much more signals at any given time and get information from many such systems. Each one of the GNSS satellites uses one or more frequencies to transmit ranging signals and navigation data. The more signals the receiver can access, the more information it can collect from the satellites, the more accurate and reliable the computed position will be. Navigation GPS in phones, cars and other consumer devices usually uses GNSS signalsinjustone frequency (L1). Dual-frequency receivers can receive two signals from each satellite system, while multi-frequency receivers receive a multi-signals from any GNSS system. Such multi-frequency receivers enhance the GNSS technology to achieve most accurate, reliable, and robust positioning.

A summary of number of satellites and signals from various GNSS system is given in Table 3.3.

Tabkle 3.3 A summary of number of satellites and signals from various GNSS system (Source: https://www.septentrio.com/en/learn-more/about-GNSS/why-multi-frequency-and-multi-constellation-matters)

GNSS	Country	Satellites	Coverage	Signals used
GPS	USA	32	Global	L1CA, L1P, L1C, L2C, L2P, L5
GLONASS	Russia	24	Global	L1CA, L1P, L2CA, L2P, L3CDMA
Galileo	Europe	26+	Global	E1, E1b, E5a, E5b, E6, E5-AltBoc
BeiDou	China	Phase 2: 15+ Phase 3: 25+	Global Phase 2 mostly China regional	B1I, B1C, B2a, B2b, B2I, B3I
QZSS	Japan	4+	Over Japan and Asia Pacific	L1CA, L1C, L1S, L2C, L5, L6
NavIC	India	7+	Over India	L5

Pseudo Random Code (PRC):
The signal that is sent out from GNSS satellites is a random sequence; each part of which is different from every other, called pseudo-random code. It is the prime signal of GNSS, and is physically complicated digital number or complicated sequence of 'on' and 'off' pulses. This random sequence is repeated continuously. All GNSS receivers know this sequence pattern and repeat it internally. Therefore, satellites and the receivers must be in synchronisation. The receiver picks up the satellite's transmission and compares the incoming signal to its own internal signal. By comparing the lag in these signals, the travel time is computed.

There are 2 types of PRC signals generally found.
(a) Coarse Acquisition Code (C/A): The C/A code is made up of sequences called chips, and the sequence repeats itself every millisecond. The C/A code is for the civilians, and is different for every satellite. The L1 code, which is available for civilians, is the C/A-code (Course/Acquisition-code), which has a wavelength of approximately 300 meters. It repeats every 1023 bits and modulates at a 1 MHz rate. The non-availability of C/A-code in L2 allowed the US Government initially to control the level of accuracy available to civilian users.
(b) Precise Code (P): It modulates in both L1 & L2 carries at a 10 MHz rate. The C/A code is made up of sequences called chips, and the sequence repeats itself every millisecond. The C/A code is for the civilians, and is different for every satellite. It is more complicated than C/A code, and is only used by receivers which are designed for PPS (precision positioning service code). The P-code, with a wavelength of approximately 30 meters, is encrypted into the Y-Code in the Anti-Spoofing (AS) mode of operation. The encrypted Y-Code requires a classified AS Module for each receiver channel. The P (Y)-Code is the basis for the PPS. Authorized users with cryptographic equipment & keys, and specially equipped receivers use the PPS. The PPS provides 22 m horizontal, 27.7 m vertical, and 200 nanosecond time accuracy. As the satellite system was fully operational in 1992, access to the P-code was denied to the public by US Government. In order to maintain control over the navigation system, the US military wanted to have most accurate GPS measurements with them only. Therefore, by altering the satellites clocks slightly according to a specific code, civilians used to get some errors in measurements as a result of time error. These signals allowed non-military users to obtain measurements that are accurate to approximately 100 meters.

Later, methods have been developed, where civilians have accurately calculated the receiver's position by comparing the GPS-measured position of a known location with its actual coordinates (e.g., GPS). The corrections were broadcasted to the GPS receiver, and thus it was possible for a civilian to determine the position with an accuracy of millimeters.

3.4.5 Advantages and disadvantages of GNSS

Advantages

- It is easy to navigate with GPS.
- It is available 24 hours anytime
- It has world coverage
- It is independent of weather conditions
- It is independent to visibility conditions: night, fog and dust
- It has open signal
- It requires open to sky clearance
- It is faster and quicker, particularly where Total Station can't be used due to horizontal obstructions.
- Multi-constellations and multi-frequency receivers can provide much accurate results.
- It is independent of visibility of previous points, as all measurements are independent.
- Its data can be easily integrated with Total Station data and GIS.

Disadvantages

- A good visibility for the sky is necessary, as high rise buildings obstruct the signals.
- It can't be used for indoor positioning.
- It can't give precise results in areas like, forest, under a bridge, tunnel, etc.
- Vertical precision is not enough for some applications.
- Extreme atmospheric conditions, storms can contribute to errors in GPS observations.
- With limited number of satellites, accurate results may not be obtained.

3.4.6 Types of GNSS receivers

A wide variety of GPS receivers are commercially available today. Depending upon the type of application, accuracy requirements and cost, the users can select the type of GNSS receiver which best meets the requirements. These receivers cover a wide range from the high-precision receivers with built-in atomic clock, to the hand-held navigation receivers, which can give the precise position to few-metres. Even wrist-watches with built-in GNSS receivers are now commercially available. Three broad categories of GNSS are explained below (Garg, 2021).

(a) Navigation receivers:

Navigation in three dimensions is the primary function of GNSS. Navigational receivers are made for aircraft, ships, ground vehicles, and for hand carried by individuals. These are used for navigation, positioning, time dissemination, measuring atmospheric parameters, surveying, geodetic control, and plate tectonic studies. These receivers are normally single-frequency, C/A code, hand-held light weight receivers, which can give the position with a few metres to few tens of metres accuracy. These receivers are very much portable, weighing only few hundred grams, and are fairly cheap. Single channel receivers, which can track 4 or more satellites, are now being replaced by two or five channel receivers. The accuracies in positioning obtained by these type of receivers are in the range of few tens of metres in absolute positioning 10 (in the absence of SA), and few tens of cm in relative positioning, over short baselines of few km.

(b) Surveying receivers

The surveying type of receivers are single frequency, multi-channel receivers, which are useful for most surveying applications, including cadastral mapping applications, providing tertiary survey control, engineering surveys, etc. They are more expensive than the navigational receivers, but more versatile. The data from many of these receivers can be directly imported to most commonly used GIS software packages. Most of these receivers can also be used in DGNSS mode.

(c) Geodetic receivers

The geodetic receivers are multi-channel, dual-frequency receivers, generally with the capability of receiving and decoding the P-code. They are heavier and more expensive than the navigation and surveying receivers. They are capable of giving accuracies of few cm in absolute positioning with precise post-processed satellite orbit information and of few mm in relative positioning. These receivers are useable for applications related to geodetic, geodynamic, detailed GIS and topographic engineering survey, etc. A modern geodetic receiver should be able to measure accurately and reliably anywhere under any condition.

The GNSS receivers can be classified into two basic types: (i) Code phase receivers, and (ii) Carrier phase receivers (Seeber, 2003; Dhunta, 2001).

(i) Code phase receivers

These receivers are also called *code correlating receivers* as they access the satellite navigational P- or C/A-code signal for their operation. They have a unique capability to begin calculations without having an approximate location and time. Code phase receivers provide real-time navigation data using almanac data from satellite message for operation and signal processing. These receivers have anywhere-fix capability as they can synchronize themselves with GNSS time at a point with unknown coordinates. For this purpose, we need to lock the signals of four satellites to start the survey with a quicker start-up time.

In code based receivers, phase position of the received code sequence is compared with the phase of an identical code replica, generated by the receiver (using the same algorithm as used for the code from the satellites) *via* a correlation technique. Hence, the observable is also called the *code phase*. These receivers can be used for the rapid calculation of baselines where high accuracy is not required, for example, in exploration or offshore work. The two code sequences are shifted stepwise in phase until a maximum correlation is obtained. These receivers have a complete code dependent correlation channel which produces: code phase, carrier phase, change of carrier phase (Doppler frequency), and satellite message.

(ii) Carrier phase receivers

These receivers utilize the actual GNSS signals to calculate a position. Two common types of such receivers are; (i) single frequency, and (ii) double frequency, which are compared together, as given in Table 3.4. The single frequency receivers track L1 frequency signal only, and are cheaper than dual frequency receivers. They can be effectively used in relative positioning mode for accurate baselines of less than 50 km or where ionosphere effects can normally be ignored. The double frequency receivers track both L1 and L2 frequency signals, and are expensive than the single frequency receivers. They can effectively be used to measure longer baselines of more than 50 km where ionosphere effects have a larger impact, as ionosphere effects are eliminated by combining L1 and L2 observations.

Table 3.4 A comparison of single and double frequency receivers

S.No.	Single frequency	Double frequency
1	Access to L1 only	Access to L1 and L2
2	Mostly civilian users	Mostly military users
3	Much cheaper	Very expensive
4	Modulated with C/A and P codes	Not possible for civilian users if Y code is present
5	Affected by ionospheric delay	Almost independent of ionospheric delay
6	Used for short base lines	Used for both long and short base lines
7	Most receivers are coded	Most receivers with dual frequency are codeless

Following factors should be kept in mind while selecting a receiver (Seeber, 2003, Spirent, 2011, https://www.sparkfun.com/GPS_Guide):

(i) Capability of tracking all the signals from each visible satellite at any time (as GPS+GLONASS system needs 20 dual frequency channels)
(ii) Have low phase and code noise
(iii) Contains high data rate (> 10 Hz) for kinematic applications with high memory capacity
(iv) Low power consumption, low weight and small size
(v) Full operational capability under Anti-Spoofing (AS).
(vi) Capability to track weak signals (under foliage, and difficult environmental conditions)
(vii) Able to do multipath mitigation, interference suppression, stable antenna phase centre
(viii) DGNSS and RTK capability
(ix) 1 pps timing output
(x) Ability to accept external frequencies
(xi) Few or no cable connection
(xii) Availability of radio modem
(xiii) Can operate over difficult meteorological conditions
(xiv) Ease of interfacing with other GNSS systems.
(xv) Flexible set up (tripod, pole, pillar, vehicle)

3.4.7 Working of a GNSS

The GNSS operation is based on the concept of ranging and trilateration from a group of satellites, which act as precise reference points. Each of the 24 satellites in GPS emits signals to receivers that determine their locations or ranges by computing the difference between the time that a signal is sent and the time it is received. These signals are captured by a receiver to compute the locations of the satellites and to make accurate positioning. The GNSS satellites carry precise atomic clocks that provide highly accurate time. The time information provided by atomic clocks in a GNSS receiver is placed in the codes broadcast by the satellite so that a receiver can continuously determine the time the signal was broadcasted.

Each satellite broadcasts a navigation message that contains (i) the pseudo-random code, called a Course Acquisition (C/A) code, which contains orbital information about the entire satellite constellation (Almanac), (ii) detail of individual satellite's position (Ephemeris) that includes information used to correct the orbital data of satellites caused by small disturbances, (iii) the GNSS system time, derived from an atomic clock installed on the satellite, with clock correction parameters for the correction of satellite time and delays (predicted by a mathematical ionospheric model) caused by the signal travelling through the ionosphere, and (v) A GNSS health message that is used to exclude unhealthy satellites from the position solution. Once the signals are obtained, the receiver starts to match each satellite's C/A code with an identical copy of the code contained in the receiver's database. By shifting its copy of the satellite's code, in a matching process, and by comparing this shift with its internal clock, the receiver can calculate how long it took the signal to travel from the satellite to the receiver. The distance derived from this method is called a *Pseudo-range* because it is not a direct measure of distance, but a measurement based on time. Pseudo-range is subject to several error sources, including atmospheric delays and multipath errors, but also due to the initial differences between the GNSS receiver and satellite time references. Using trilateration process*,* the GNSS receiver then mathematically determines its position by using the calculated pseudo-ranges and the satellite position information that has been communicated by the satellites.

Trilateration

The GNSS receivers use a technique called *trilateration* which involves computing the distance with the help of known distances (Garg, 2021). In trilateration, three satellites, each with a known position in space, are required. For example, the first satellite broadcasts a signal to a GNSS receiver, and its angle is not known but the distance is known. In 2D space, this distance forms a circle, but in 3D space it forms a sphere (Figure 3.22). If only one satellite is visible, position location is impossible as the receiver location can be anywhere on the surface of a sphere with the satellite at its centre. So, a large error would be present while estimating the location on the Earth with only one satellite.

If two satellites are visible, the receiver location can be anywhere on a circle where the surfaces of the two spheres intercept. So, position location is still impossible as the GNSS position could be anywhere on that circle. But this time, there are two known distances from two satellites. With two signals, the precise position could be any of the two points where these two spheres intersect. The receivers normally select the point out of two, which is closer to the Earth. But, when a third satellite also becomes visible, the GNSS receiver can establish its position as being at one of two points on the previously derived circle where the third satellite sphere intercepts it. So, now position fixing can be done by trilateration, it is almost certain that only one of the two derived points would be near the surface of the Earth. So fixing of location can be done, but only in two dimensions (latitude and longitude). With at least four satellites visible with their good geometry, four spheres will intersect at only one point in space, so receiver position can be accurately fixed in three dimensions (latitude, longitude and altitude). With five satellites visible, it is possible for the system to automatically detect an erroneous signal. With six satellites visible, it is possible for the system to automatically detect an erroneous signal, identify which satellite is responsible and exclude it from consideration. A modern GNSS receiver will typically track all of the available satellites simultaneously, but only a select of them will be used to calculate the receiver's position.

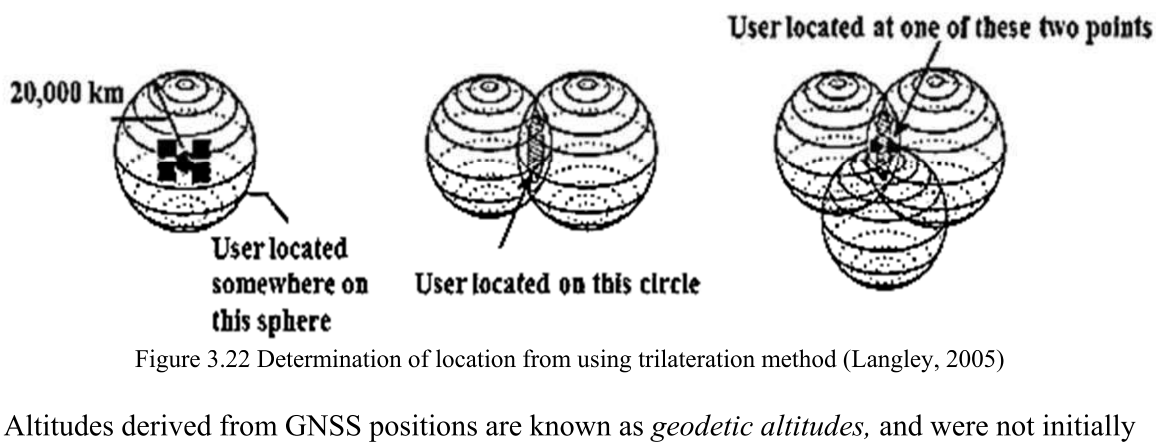

Figure 3.22 Determination of location from using trilateration method (Langley, 2005)

Altitudes derived from GNSS positions are known as *geodetic altitudes,* and were not initially used for aircraft navigation. Performance-based navigation requires that they, and the navigational information presented by the system, are based on the World Geodetic System (WGS-84) coordinate system, established in 1984.

3.4.8 GNSS surveying techniques

There are various methods available for some specific tasks, which may be kept in mind while collecting the data from GNSS (Garg, 2021). The technique used in a given location, would however depend on the (i) accuracy requirements, (ii) time to complete the work, (iii) local terrain conditions, and (iv) available facility. Advantages and disadvantages of some of the techniques are summarized in Table 3.5. Some of the techniques are given below.

(a) Static surveying:

This method is used in surveying that requires reasonable high accuracy, e.g., control surveys from local to state-wide area. It will probably continue to be the preferred method, as the receiver at each point collects data continuously for a defined length of time. The duration of data collection will depend on (i) required precision, (ii) number of visible satellites, (iii) satellite geometry (DOP), (iv) single frequency or dual frequency receivers, and (v) distance between the receivers.

Table 3.5 Advantages and disadvantage of some GPS/GNSS survey methods

Type	**Advantages**	**Disadvantages**
Real-time kinematic (RTK)	Real-time corrected positions in a known coordinate plane. Able to navigate to and compute geometries of data points in the field	Significantly increased equipment cost and logistics. Must have radio connection between base and rover. Must set up base on a known position to use advantages
Rapid Static	Reduced equipment expense and complication compared to PPK. Local base stations not necessary	Requires longer occupation times up to 2 hours, with fewer potential measurements. Lower accuracy than RTK
Static	Higher precision than rapid static, less equipment than RTK or PPK Requires long occupation times to reach similar accuracy to RTK or PPK.	Requires more precise mounting and metadata collection than RTK, PPK, and rapid static
Continuous	Highest possible precision and accuracy (mm)	Requires complex infrastructure, precision mounting, and very long occupation times.

Field data are collected from two or more GNSS receivers, and the line between any two receivers is called a *baseline*. The data are collected for a longer duration of time to achieve the higher accuracy of baseline. Figure 3.23 shows the duration of observations for a given areal extent. Multiple baselines can be established simultaneously by using more than two receivers to save time. When the baseline between a known point and a new point is measured, the new point can be used as a known point for other baselines, and this process continues. To strengthen the network of baselines, control points should be situated at commanding locations. The number and location of control points will depend on the size and shape of network. The larger the constellation of satellites, the better the available geometry, the lower the positioning dilution of precision (PDOP), and the shorter the time of observation needed to achieve the required accuracy. To achieve higher accuracy, the post-processing software is used.

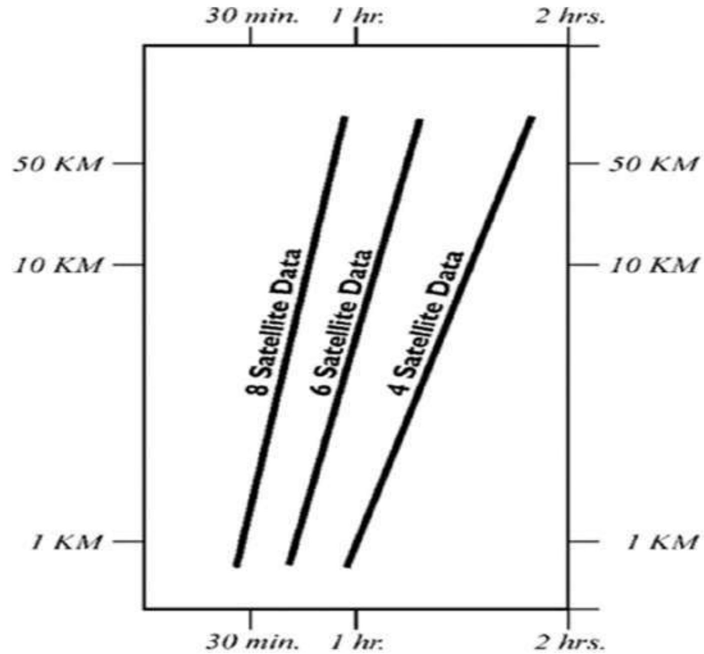

Figure 3.23 Static sessions lengths (Sickle, 2015)

(b) Rapid static surveying:

The rapid static method is a popular method of GNSS surveying where short-time measurements are taken. As the name suggests, it is easy, quick and efficient. The rapid static technique is well suited for short range applications, such as control densification and engineering surveys or surveying many points. It is developed for duel frequency phase measurements or pseudo range measurements. The main basis of this technique is the ability of the software to resolve the ambiguities using a very short observation period.

The required observation time of rapid static observations is mainly a function of baseline length, number of satellites and ionospheric disturbance. Ionospheric disturbance varies with time, day/night, month, year, position on Earth's surface. As ionospheric disturbance is much lower at night, night observation for rapid static technique can often be halved, or the baseline range doubled. Thus at night, it might be advantageous to measure the baselines of 20 to 30 km. Observations with a minimum of 5 satellites above 15° and a good geometric dilution of precision (GDOP < 8) should be used. Table 3.6 provides an approximate guide to baseline length and observation time for mid-latitudes under the ionospheric activity when a dual frequency receiver is used.

Table 3.6 Use of static and rapid static methods (Garg, 2021)

Obs. method	**No. of satellites GDOP ≤ 8**	**Baseline length (km)**	**Approximate time observation**	
			By day	**By night**
Static				
	4 or more	15 to 30	1 to 2 hours	1 hour
	4 or more	Over 30	2 to 3 hours	2 hours
Rapid Static				
	4 or more	Up to 5	5 to 10 mins	5 mins
	4 or more	5 to 10	10 to 20 mins	5 to 10 mins
	5 or more	10 to 15	Over 20 mins	5 to 20 mins

(c) Kinematic surveying
Kinematic surveying uses differential carrier phase tracking to record observations simultaneously. It is used in most surveying applications where the base receiver remains stationary and placed at the known point, while the rover receiver will visit the unknown points for a very short time. The recording interval for static observations could be 10 sec., for rapid static observations 5-10 sec, and for kinematic observations 0.2 sec or more. Kinematic GNSS can use multiple bases and/or multiple rovers in the same survey, if necessary.

Kinematic GNSS surveying is generally suitable for any type of surveying or mapping in areas with no high rise buildings, overhanging trees, dense forest, over-passes or such structures in rover's route. Possible errors in kinematic surveying could be; (i) antenna height may change between points, especially if a prism pole with a sliding mechanism is used, and (ii) improper centering the antenna over the point. This method is undergoing rapid improvement, and OTF-AR (On-The-Fly–Ambiguity Resolution) is making it ideal for surveys, such as road centre line survey, topographic survey, hydrographic survey, airborne applications and many more.

(d) Stop and go kinematic surveying
It is known as stop-and-go technique because only the coordinates of the receiver are used when it is stationary ('stop' part) but the receiver continues to function while it is moving (`go' part) from one stationary station up to the next station. The base receiver remains stationary, while the rover receiver will visit the unknown points for a very short time (< 2 min). This is the kinematic technique because the user's receiver continues to track the satellites while in motion. The software sorts out the recorded data for different points, and differentiates the kinematic or 'go' data (not of interest) from the static or `stop' data (of interest).

The initial ambiguity must be resolved by the software before this survey starts. Once the ambiguities are resolved, the user's receiver is moved from point to point, collecting data just for a minute or so. It is vital that the antenna continues to track the satellites while collecting the data. This method is suitable for details surveys as topographic mapping or boundary survey work when many points close together have to be surveyed, and the terrain poses no problems in terms of signal disruption. This may require special antenna mount on vehicles if the survey is to be carried out over a large area. Speed is the main advantage of the kinematic survey. The technique can also be implemented in real-time if a communication link is provided to transmit the data from the reference receiver to rover receiver. This method also has a limitation that the lock on the same satellites must be maintained during the entire survey. If for any reason a cycle slip occurs, the rover must return to any previous point which had been determined without cycle slip.

(e) Real-time kinematic (RTK) surveying
The RTK method is preferred for many survey applications as it provides positioning in real-time. There is no post-processing of the carrier phase data required. The RTK method provides positional accuracy nearly as good as static positioning method using carrier phase, but it is much faster. It involves the use of at least one stationary receiver (the reference), and at least one moving receiver (the rover), as well as the data link (Figure 3.24). All the receivers involved observe the same satellites (five satellites minimum), simultaneously. Once set up, the reference receiver will continuously transmit its carrier phase measurements to the roving receiver. The rover keeps updating the coordinates of the locations while moving as long as lock on satellites is maintained. The RTK method is most suitable for stakeout surveys, and can provide 0.3-0.5 m accuracy.

Table 3.7 presents the advantages and disadvantages of various GPS survey methods.

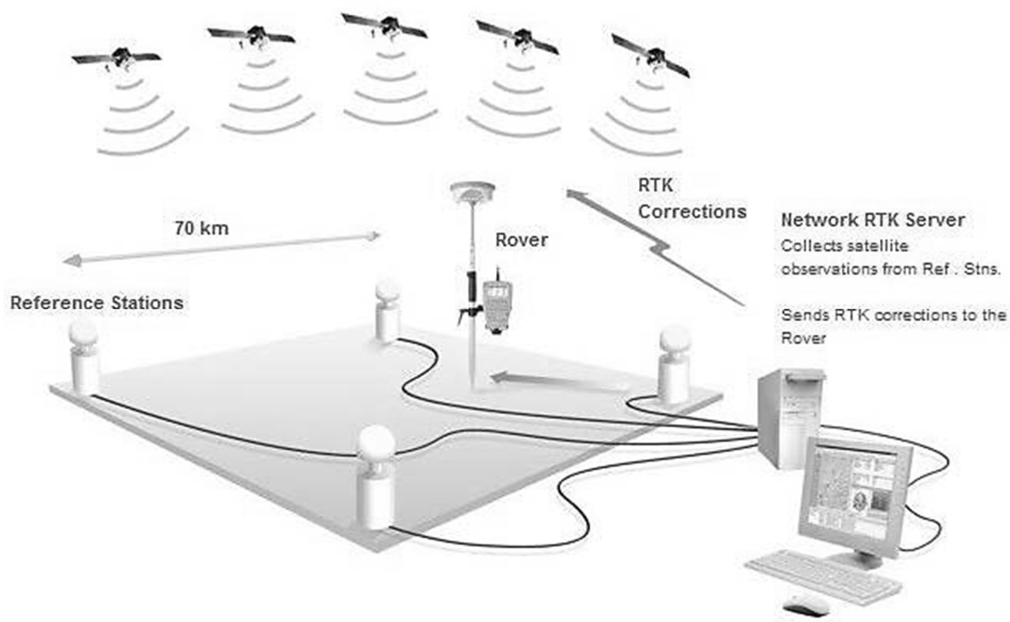

Figure 3.24 Real-time kinematic (RTK) surveys (Source: https://www.smartnetna.com/hiw03_nrtk.cfm)

Table Advantages and disadvantages of various methods (Garg, 2021) :3.7

Conventional static GNSS		**Rapid-static, stop and go, kinematic GNSS**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Highest accuracy Robust technique Ambiguity resolution not critical Minor effect on multi path Undemanding on hardware/software	Long observations session Inappropriate for engineering and cadastral application	Higher accuracy than pseudo range solution Appropriate for many survey applications High productivity Similar procedures to modern terrestrial surveying	Special hardware & software Susceptible to atmospheric and multi path biases Higher capital costs Ambiguity fixed or continuous lock required

(f) Pseudo-kinematic surveying

Pseudo-kinematic GNSS surveying is similar to stop-and-go technique, and is a combination of both static and kinematic methods. The method in pseudo kinematic surveys is somewhat similar to the kinematic surveys, except the process of initialization as in stop-and-go method. This feature offers a more favourable positioning technique for the areas having obstructions to signals, such as bridge overpasses, tall buildings, and overhanging vegetation. It is also suitable for lower order control, such as photogrammetric control etc. Loss of lock of satellites that may result due to these obstructions is more tolerable when pseudo-kinematic techniques are employed. Kinematic method has its advantage of speed, but there is no need to lock 4 satellites (Xu, 2010). This method is less precise of all, but highly productive. Each point is occupied for 5-10 minutes for baselines up to 10 km or less. These points are revisited multiple times; may be after 1 hour but not more than 4 hours. Multiple observations of same point with different times will resolve the integer ambiguity (Tusuat and Turgut, 2004).

(g) Differential GNSS (DGNSS) surveying

The DGNSS technique requires two identical GNSS units, and is used to improve the accuracy of a standard GNSS. It works by placing a GPS receiver at a known location, called a reference station, and another GNSS unit, known as rover station which is kept at unknown points to determine the coordinates (Figure 3.25). The reference station may be a bench mark whose exact location is already known. Thus, the difference between the GNSS derived position and the true position is determined at the bench mark. The reference station actually calculates the difference between the measured and actual ranges for each of the satellites visible from that station. This calculated difference is called the "*differential correction*" for that group of satellites. At rover station, the correction in the observed value can be applied using the differential correction.

The DGNSS technique is based on pseudo ranges and code phase. Although the accuracy of code phase applications has improved a lot with the removal of Selective Availability (SA) in May 2000, yet reduction of the effect of correlated ephemeris and atmospheric errors by differential corrections requires achieving the accuracy better than 2 to 5 m. The DGNSS based on C/A code SPS signals can however offer meter or even submeter accuracy. Pseudo-range formulations can be developed from either the C/A-code or the more precise P-code. These formulations with the C/A-code can provide a precision of around 3 m with a range measurement. Point positioning accuracy for a differential pseudo-range formulated solution is generally found to be in the range of 0.5-10 m.

Differential corrections may be used in real-time, with post-processing techniques. Usually, pseudo-range corrections are broadcasted from the reference to the rover or rovers for each visible satellite. Using the computed satellite position and its own known location, it computes the range to the satellite. The real-time signal is sent to the receiver over a data link. Some systems require two-way, some one-way communication with the base station. Radio systems, internet, radio signal, or cell phone, geostationary satellites, low-earth-orbiting satellites and cellular phones are some of the options available for two-way data communication.

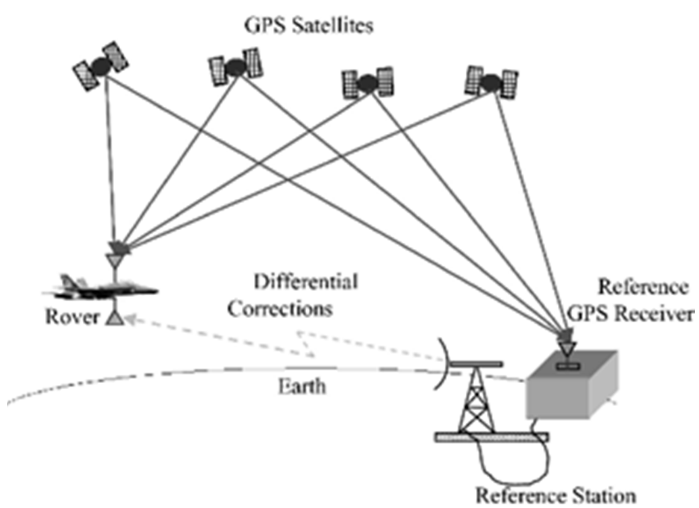

Figure 3.25 The concept of DGNSS survey (Source: http://emitech-infosystems.com/our-services/gps-dgps)

3.4.9 Other satellite based augmentation systems (SBAS)

Most GPS units today are SBAS-enabled. The SBAS are used to augment the GNSS data, and provide higher accuracy, integrity, continuity and availability. Some correction data, like satellite orbit, satellite clock and atmospheric data are broadcasted from communication satellites to get accurate results. It is like a highly advanced real-time DGNSS. There are different types of SBAS, launched by various countries; (i) WAAS, USA, (ii) MSAS, Japan, (iii) EGNOS, Europe, (iv) GAGAN, India, and (v) SDCM, Russia.

1. Wide Area Augmentation System (WAAS) survey:
The WAAS is a combination of ground-based and space-based navigation systems that augments the GNSS Standard Positioning Service (SPS) to improve the accuracy and reliability of location data (Figure 3.26). The WAAS can potentially improve the horizontal accuracy from 5-30 m to 1-5 m. It currently augments the GPS L1 signal providing improved accuracy and integrity. Originally designed for high quality air traffic management in 2003, WAAS signals are broadcasted by geostationary satellites (they remain at the same point over the Earth at all times), and require a clear view of the horizon at higher altitudes. The WAAS is designed to enhance and improve the satellite navigation over the continental United States, and portions of Mexico and Canada, and uses its own geostationary satellites in fixed orbit. There are 25 ground reference stations positioned across the US that monitor the GPS satellite signals. These stations continuously receive and correct the GPS satellite information against their own known precise positions (Garg, 2019).

The WAAS base stations transmit their measurements to a master station where corrections are calculated and then uplinked to two geosynchronous satellites. The WAAS satellite then broadcasts differentially corrected signals at the same frequency as GPS signals. The WAAS signals compensate for position errors measured at WAAS base stations as well as clock error corrections and regional estimates of upper atmosphere errors (Yeazel, 2006). The WAAS-enabled receivers devote one or two channels to WAAS signals, and are able to process the WAAS corrections.

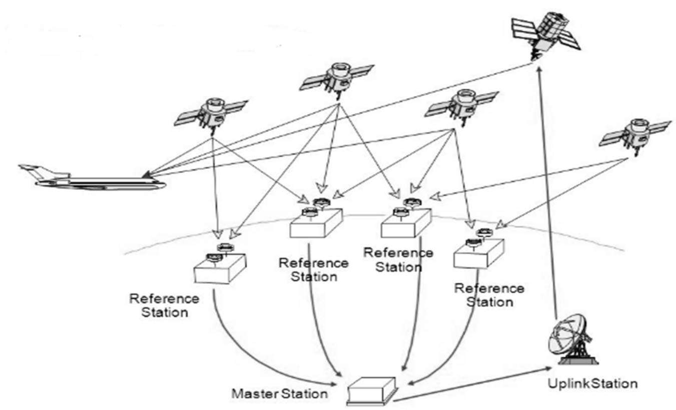

Figure 3.26 Concept of WAAS GNSS survey (Source: https://ifreebsd.ru.com/product_tag/59755354_.html)

2. MSAS Japan:
The MSAS (MTSAT (Multi-functional Satellite) Satellite-based Augmentation System) Japan decided to implement in 1993. Its operation started from September 2007 with the goal of improving its accuracy, integrity, and availability. It augments GPS L1 signals; Two GEOs-MTSAT-1R (PRN129), MTSAT-2 (PRN137), Ground Facility- 2 Master Control Stations (MCSs), 6 Ground Monitoring Stations (GMSs) (Two of them are with the MCSs), 2 Monitoring and Ranging Stations (MRSs), as shown in Figure 3.27. The SBAS signal that is made by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is now transmitted from the QZS-3 GEO satellite using the QZSS SBAS transmission service since April 2020 (https://gssc.esa.int/navipedia/index.php/MSAS_General_Introduction).