Introduction to GPS

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GNSS Overview

- GNSS - Global Navigation Satellite Systems. The first project was born in the 70s with the first launch of satellites by the UAS Department of Defense of the Global Positioning System (GPS) program

- Main applications:
  - Navigation
  - Detection
  - Geodynamics and geophysics
  - Remote sensing (Troposphere and ionosphere)
  - etc.

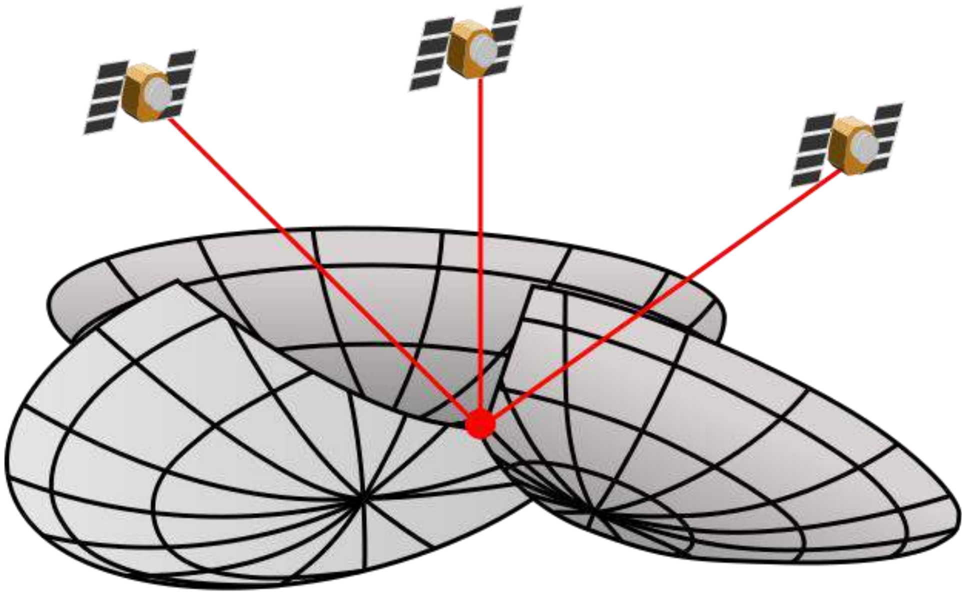
- Current GNSS systems:
  - GPS (USA)
  - GLONASS (Russia)
  - Galileo (EU)
  - BeiDou (China)

Basic Principle

- The satellite transmits a signal that contains the position of the satellite (note) and the time of transmission of the same signal (atomic clock)

- The receiver compares the transmission time with that measured by its own internal clock, thus obtaining the time taken by the signal to arrive from the satellite.

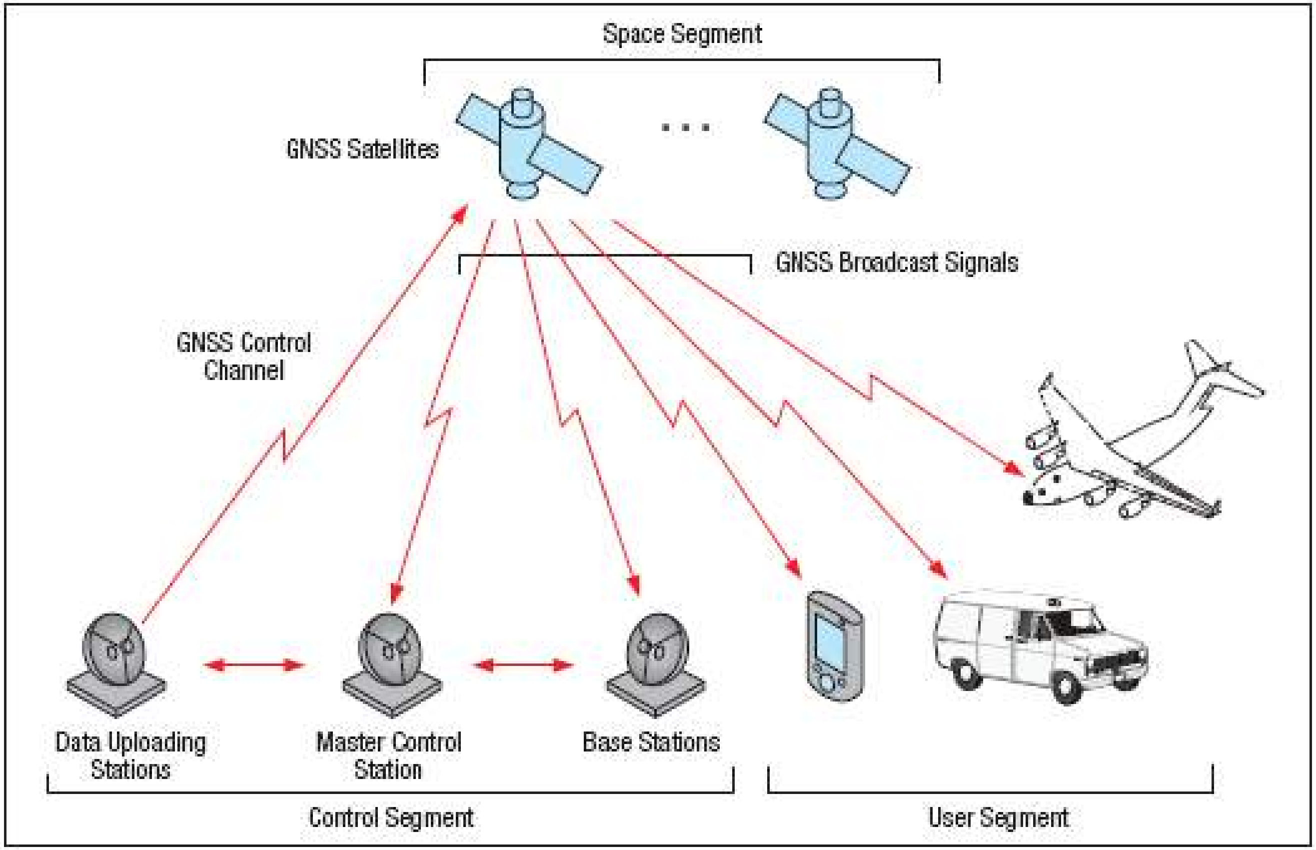
- Different measures can be performed simultaneously with different satellites, thus obtaining the positioning in real time.



Architecture

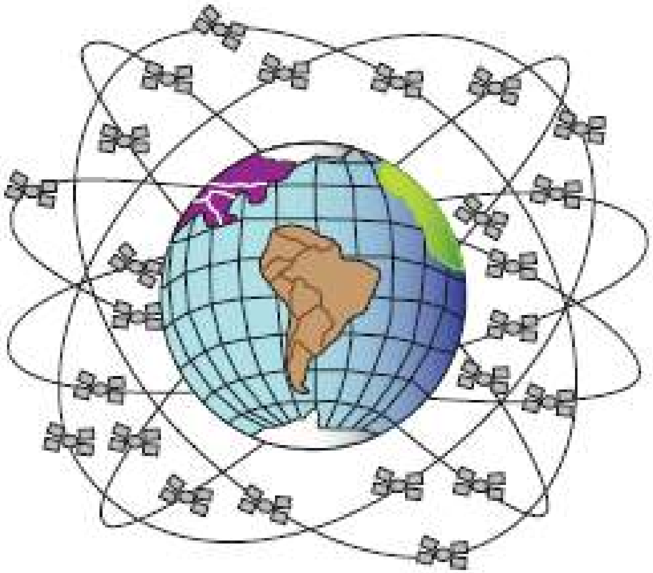
GNSS systems are composed of three main components ("segments")

- Space segment
- Control segment
- User Segment



Space segment

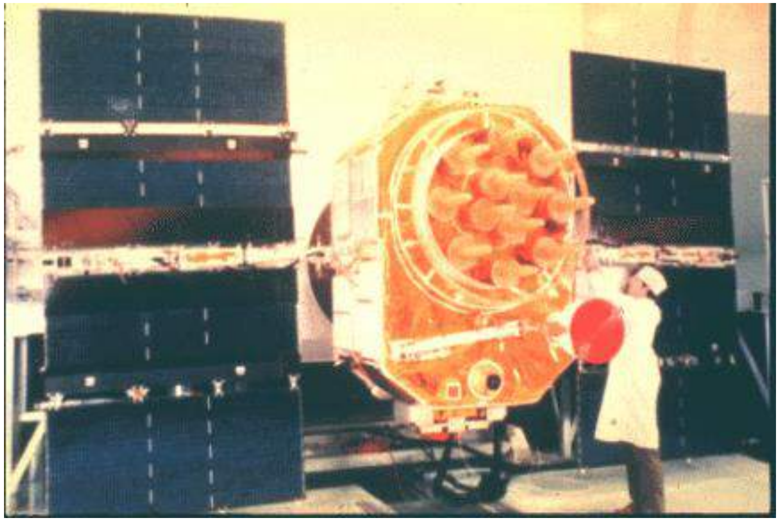
It consists of GNSS satellites, which orbit at about 20,000 km from the earth. Each GNSS system has its own constellation of satellites.



The GPS satellite system

- Nominally 24, arranged on 6 orbital planes;
- the average inclination of each orbital plane with respect to the equatorial plane (i) is 55 °.
- The orbits are almost circular (e≅0), have radius (a) of ≅ 26,000 km, the period is 12 sidereal hours; each satellite moves at about 4 km / sec.
- Atomic clock
- Emitters and signal receivers

The system has been designed in such a way as to guarantee the visibility of at least 4 satellites at each point of the Earth



Space segment

The mass of a satellite is about 800 kg

The estimated life of a satellite is 7.5 years

The main purpose of the satellites is to generate signals:

2 carriers (L1, L2) + 2 codes (C / A, P) + 1 message (D)

The satellites have been launched in various blocks:

- block I: experimental and launched from 1978 to 1985 (now all out of use)
- block II, SVN 13-21: launched from 1989 to 1990
- IIA block, SVN 22-40: launched from 1990 to 1997
- block IIR, SVN 41-62: launched from 1997 to 2003
- IIR-M block with third frequency and third code launched since 2005 (will be fully operational in 2014)

Space segment

- GPS - 32 satellites of which 31 operating The oldest works since 1990
- GLONASS - 28 satellites of which 24 are operational
- GALILEO - 6 satellites none yet operational
- BEIDOU - 15 operational satellites (35 by 2020)

	GLONASS	GPS	GALILEO
Number of nominal satellites	24	24	30
Number of orbital planes	3	6	3
Orbital Inclination	64°8'	55°	56°
Orbital altitude	19.140 km	20.180 km	23.222 km
Period of revolution	11h 15m	11h 58m	14h 22m
Launch site	Baikonur/Plesetsk	Cape Canaveral	Kourou (French Guiana)
Date of first launch	02/10/82	22/02/78	N/A
Satellites for launch	1/3	1	2
Datum	PZ-90.11	WGS-84	GTRF

Source: GLONASS System Description at glonass.it web site

Control segment

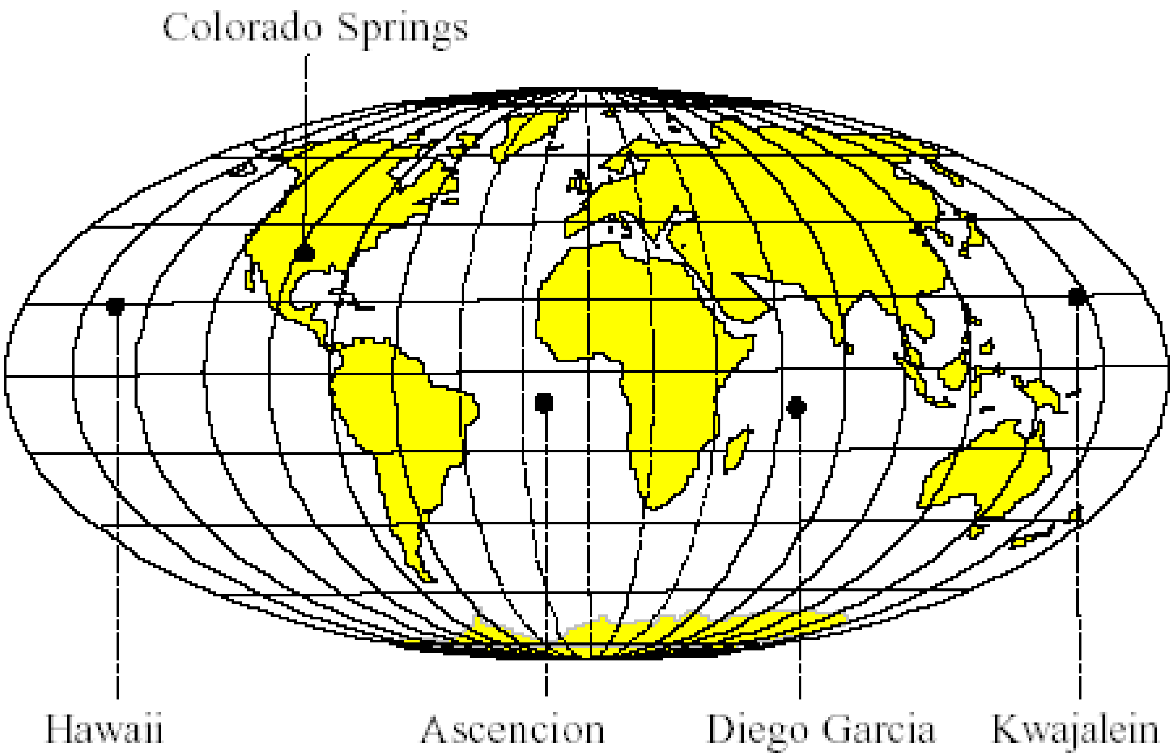
- The control system consists of a network of ground stations (control stations, data monitor stations, data uploading stations)

- Control stations are equipped with atomic clocks with greater precision than those on board the satellites and control the orbits of the satellites and the position (ephemeris) of each satellite as well as the atomic clocks aboard the satellites to maintain a high precision in the measure

- Monitoring stations (monitors) monitor the status of the signal

- Modifying stations (uploading) perform maintenance and send control signals to the satellites as well as periodically sending to each satellite its ephemeris

For the GPS system, the control segment consists of 5 master stations that continuously track the satellites and process the received data in order to determine the position in time of the satellites (efemeridi)



Control segment

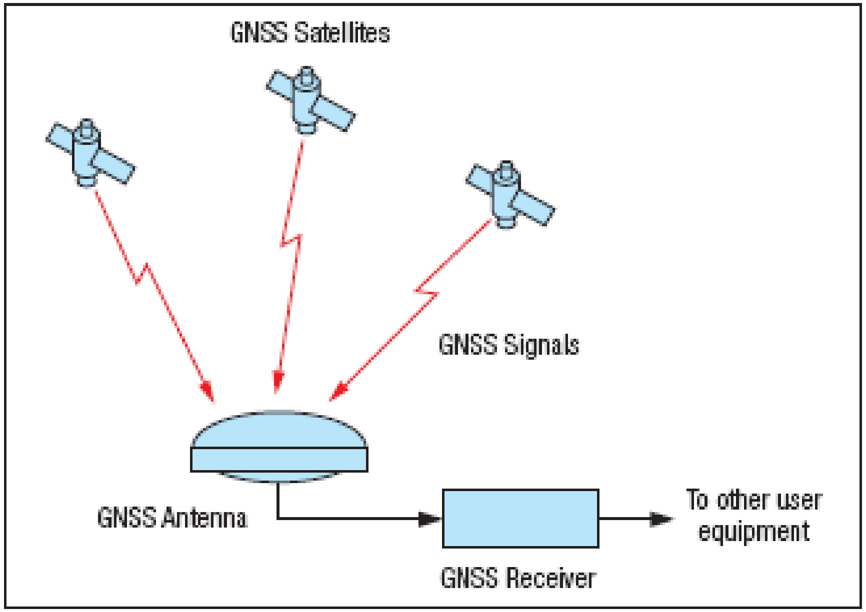
- The Control Segment follows the route of the GPS satellites, updates their orbital position, calibrates and synchronizes their clocks.

- The Control Segment determines the orbit of the satellites and predicts the route for the following 24 hours. This information is updated by the control stations, sent to the satellite and subsequently transmitted by the same. This makes it possible, for any GPS receiver, to know where the satellites will be for the next 24 hours.

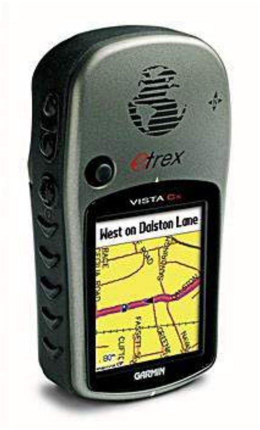
- The Ascension stations, Diego Garcia and Kwajalein receive the satellite signal, and then send the measurements to the master control station, which is located in Colorado Springs, where all possible errors of satellite signals are calculated. Finally, this correct information is sent to the 4 stations equipped with terrestrial antennas that send them to the satellites

User segment

- The user segment consists of antennas and GNSS receivers used to determine information about position, speed, etc.
- GPS receiver (passive antenna)
- Battery for operation
- Memory for storing the received signals
- 10 or more contemporary reception channels (one per satellite)
- Controller for receiver management
- Possible ground transceiver system (GMS or similar)



The user segment is made up of every user, both civil and military, in possession of a receiver capable of receiving and processing data sent by the satellites



Several GPS receivers are currently available on the market, with different functions and prices

Prices range from a few tens to several thousand euros, and depend mainly on the type of signal that the receiver can process and store

The accuracy of the measurements depends on the type of signal used

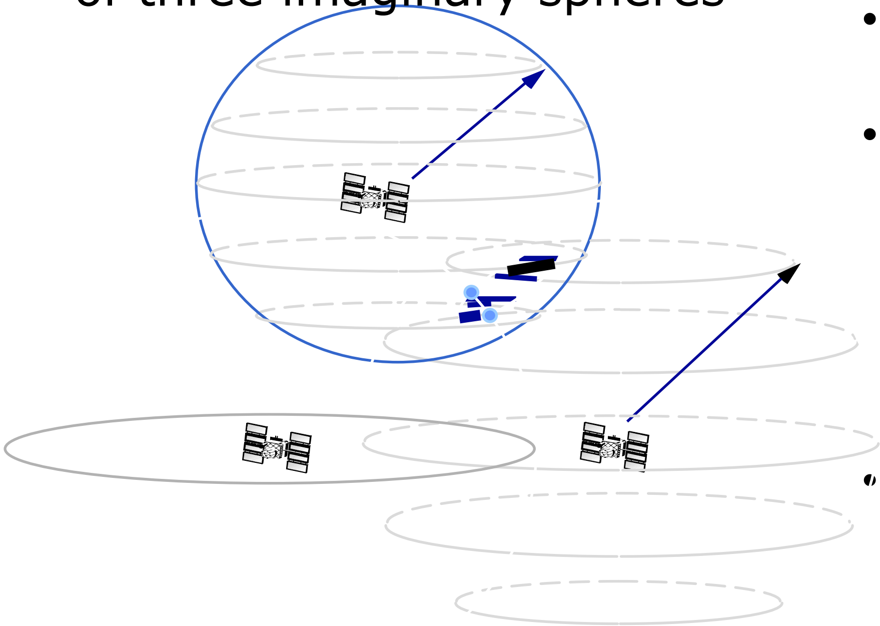
In real time the precision is of the order of a few meters, while a post-processing ensures an accuracy of a few millimeters

GNSS Basic concept

- All GPS positions are based on the calculation of the distance between the satellites and the GPS receiver on the ground. The basic idea is that of the intersection: if one knows the distance of one point with respect to three others, one can calculate the relative position of the point with respect to the known points.

- Note the distance of a point from a satellite, we know that the position of the point must be included in the imaginary sphere that has center in the satellite and radius equal to the distance itself.

- The position of the receiver can be uniquely identified by the intersection of three imaginary spheres



Intersection between three imaginary spheres

- The position of the GNSS satellites is known in an extremely accurate manner (ephemeris)
- The measurement accuracy of time is extremely important as the receiver satellite distance is calculated as:

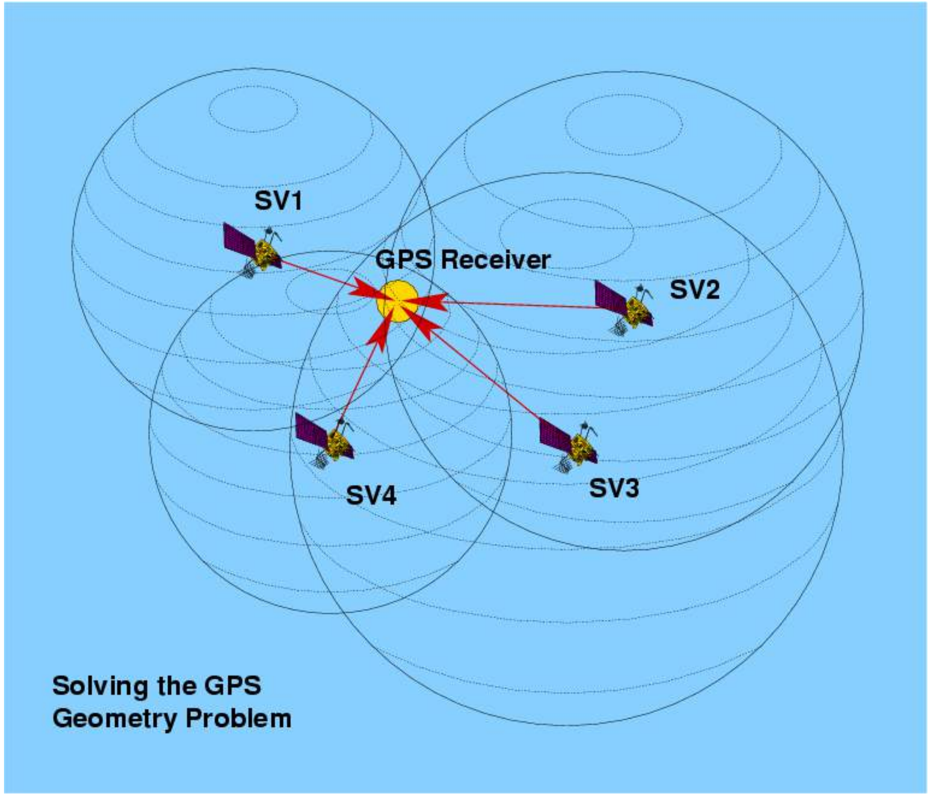
$$\mathbf{D = v * \Delta t}$$

v = vel. light (300000 km/s); Δt = t (arrival)- t (depart)

- Attention to speed: 1 microsecond = 300m, 1 nanosecond = 30 cm => Small errors in determining the time measurement can cause significant errors in the position !!!

GNSS Basic concept

- Fundamental element for the functioning of the system
- Atomic clocks on satellites and in the control section (σt = 10-12), clocks on receivers (σt = 10-9)
- Time measurement is also assumed as unknown, but another satellite must be observed
- Offset = difference in accuracy of time measurement ("delay" different to each measurement)



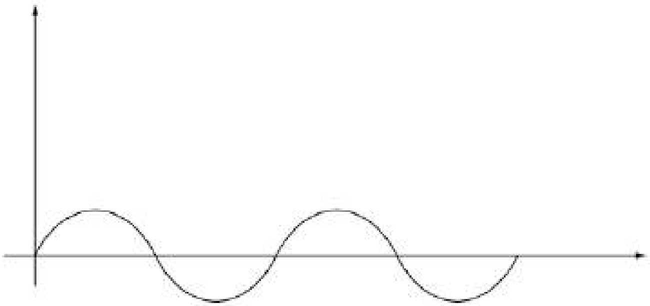
4 measurements are needed for 4 unknowns:

1. X
2. Y
3. Z
4. “Offset”

GPS signal

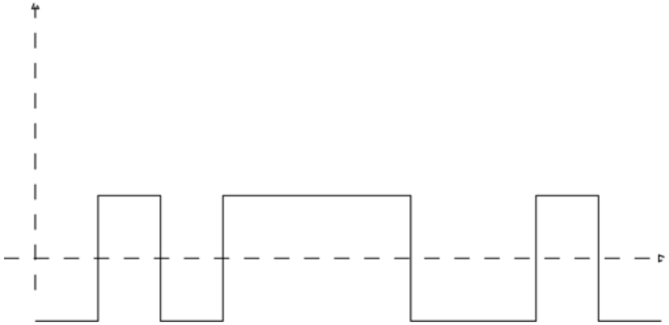
- The oscillators on board the satellites produce a frequency signal f0 = 10.23 MHz, characterized by high stability over time
- Starting from this fundamental frequency (f0) two sinusoids (or carriers) are generated: L1 and L2;

Nome	f (MHz)	λ (cm)
L1	$154f_0$=1575.42	$\cong$ 19
L2	$120f_0$=1227.60	$\cong$ 24



- and two binary codes (Pseudo Random Codes): C / A (Coarse Acquisition Code) and P (Precise Code)

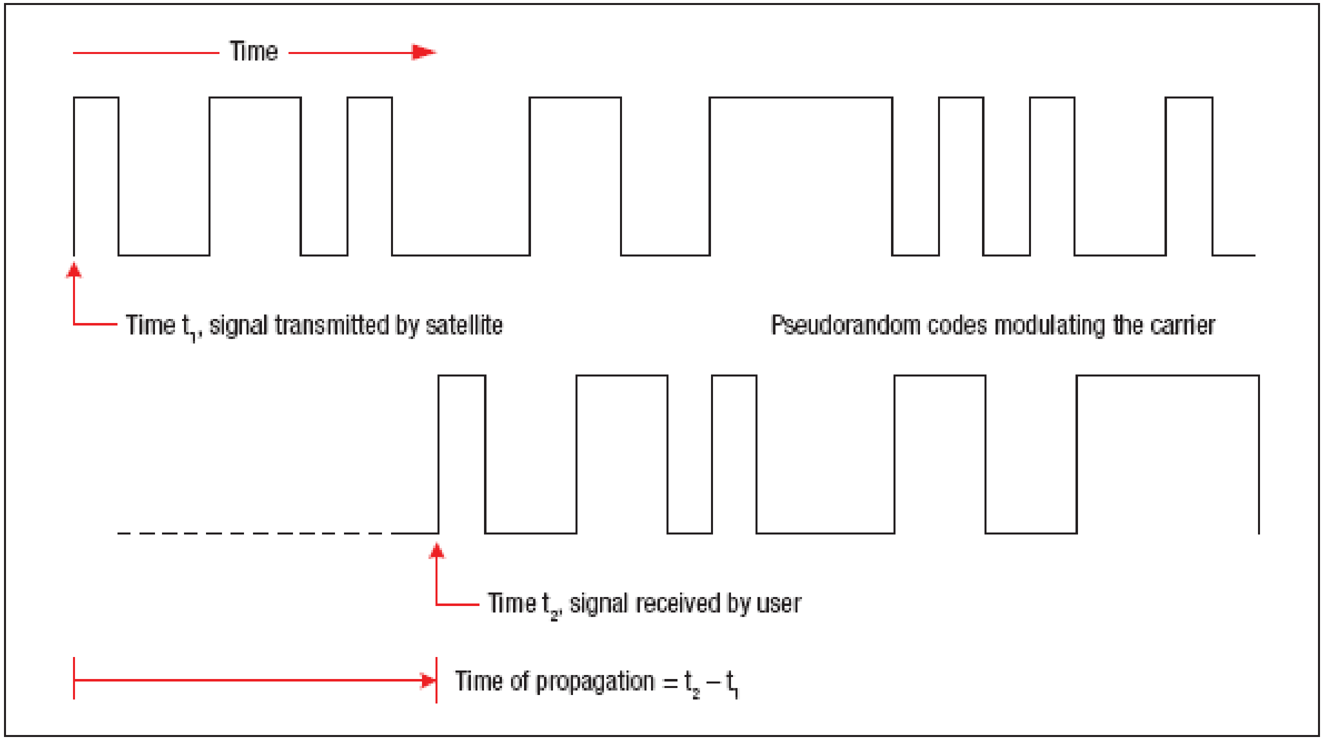
Nome	f (MHz)	λ (m)	Periodo
C/A	$0.1f_0$ = 1.023	293.0	1 msec
P(Y)	f_0 =10.230	29.3	37 settimane



- Finally, the navigation message D is given (Satellite name, signal start time, ephemeris equation (pos. As a function of time))

Code measurements

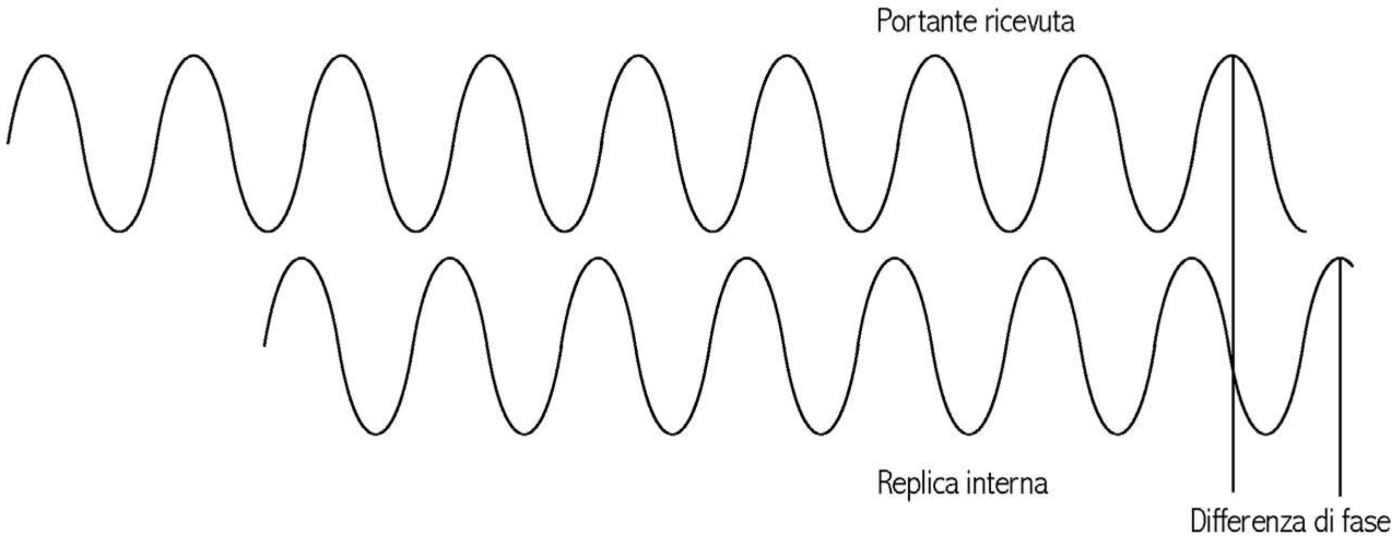
- The receiver, after identifying the satellite, makes a correlation between the code generated by the internal oscillator (equal to that generated by the satellite) and the code received from the satellite



- The observation noise is of the order of 1% of the signal wavelength
- 3-5 m for observations on the P (Y) code;
- up to 10 m (depending on the quality of the receiver) for observations on the C / A code.

Phase measurement

- They are carried out on high frequency sinusoids (the carriers)
- Compared to code measures (or pseudorange) are more complex to acquire (more expensive receivers) and to be processed (specialized software);
- Since the observed signal has a small wavelength, they are much more accurate, instrumental errors even lower than one millimeter.
- The receiver can make a phase difference observation in cycles between the carrier received from the satellite and a sinusoid of the same frequency generated by an oscillator inside the receiver.



- N represents the whole number of cycles between the satellite and the receiver;
- N can not be measured or deduced from indirect estimates; it represents an unknown quantity of which only the whole nature is known.

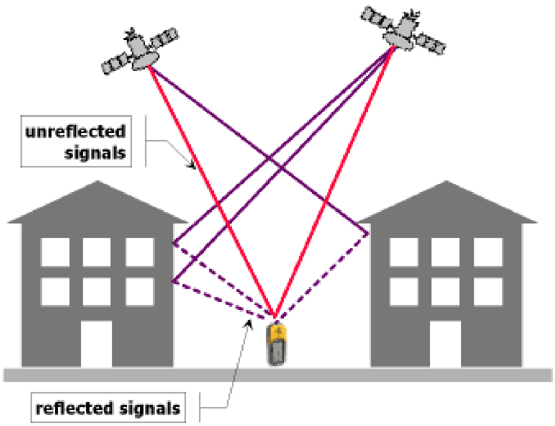
Phase measurement

- 3 satellites for the unknowns of position and 1 for the time one
- With 5 or more redundant system satellites
- Every era a measure - Increasing the time I use the repetition
- Epochs from 1 / sec up to one every 10 seconds (60 per minute or 6 per minute). You also receive receptions of hours
- Each era changes the constellation

GPS – Accuracy

- clocks synchronization defects) (10-100m)
- errori di orbita dei satelliti
  (riducibili usando effemeridi precise) (5-10m)
- propagation errors in the atmosphere
- reception errors
  - multipath

the signal partially reaches the receiver after reflections (eg on metal surfaces)



GPS – Accuracy

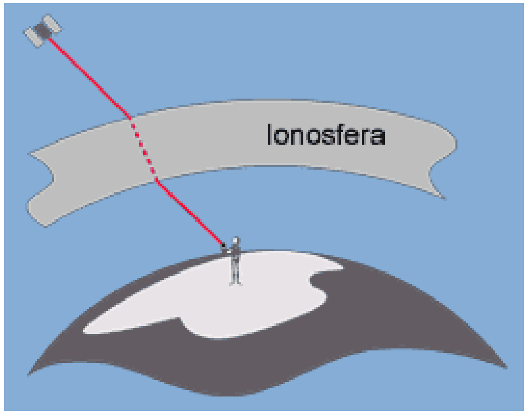
- propagation errors in the atmosphere
  - Ionosphere (above 40-50Km)

    interaction with charged particles

    - variable over time
      eg, with solar activity

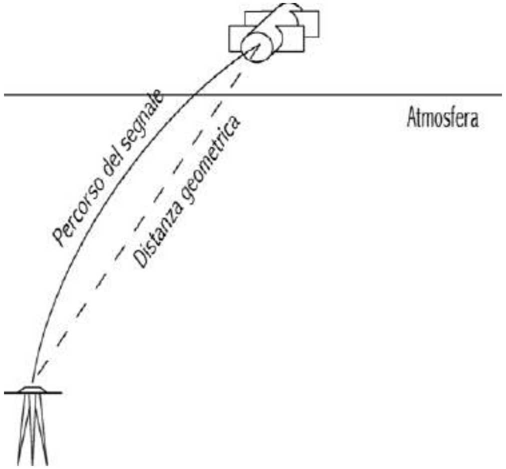
    depends on the frequency

    ⇒ it can be modeled using both signal frequencies



(20-50m)

  - Troposphere (under 20Km)
    - depends on the amount of water vapor
    - difficult to model (you should know the amount of water vapor along the entire signal path)

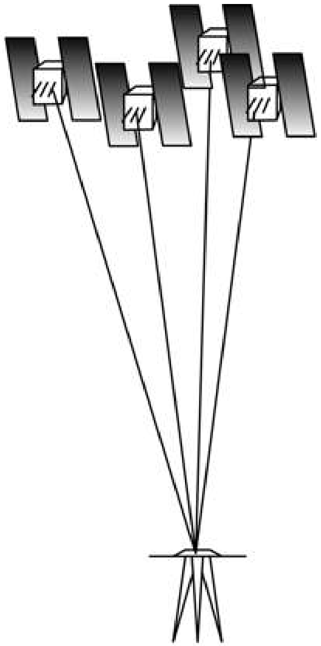


(2-10m)

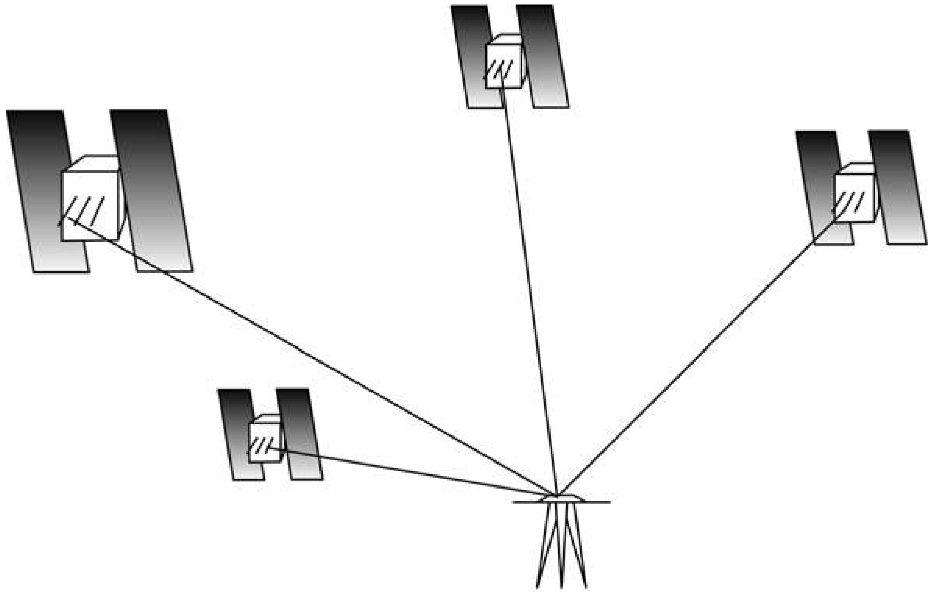
GPS – Accuracy

- The accuracy in estimating the absolute position of a receiver depends on the errors on the single signals (already seen) but also on the geometry of the satellites with respect to the receiver.

- PDOP: geometric index of accuracy in estimating the 3 coordinates by absolute positioning.



Bad satellite geometry: PDOP high

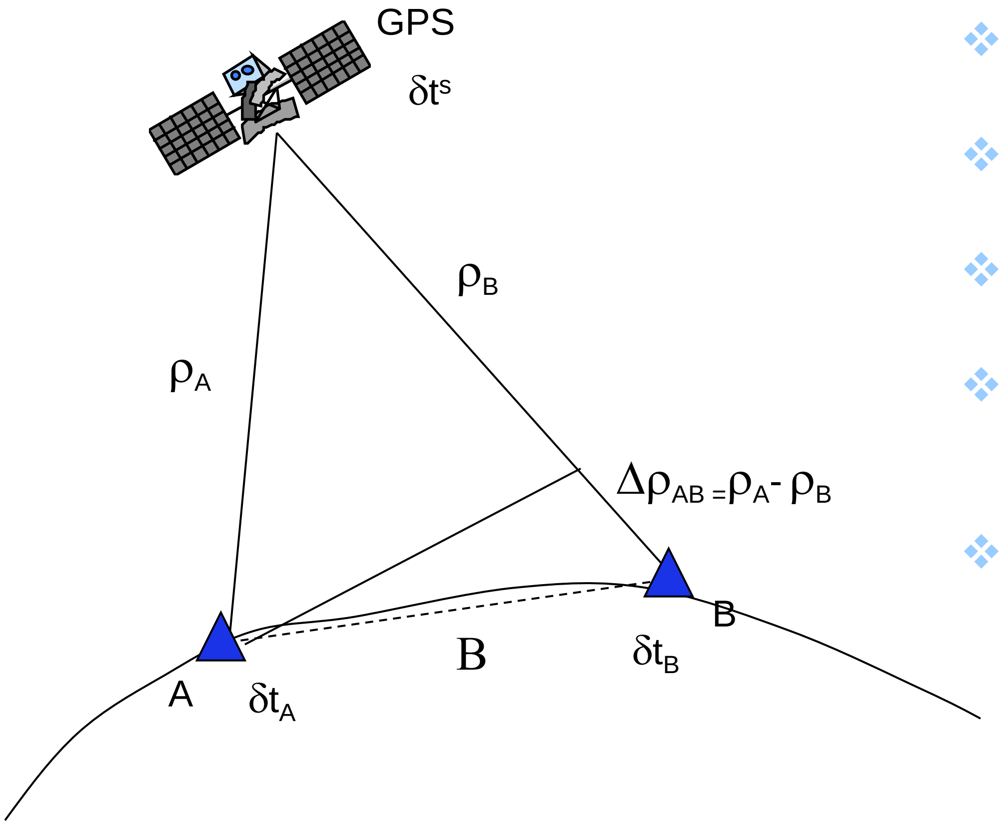


Good satellite geometry: PDOP low

GPS – Differential positioning

- Most of the modeling errors are similar for observations made by neighboring receivers: differentiation eliminates the common part, leaving only the differences of error (residual error)

- On the other hand, the use of differentiated observations makes it possible to estimate the vector between the receivers (base) and not the position of the individual receivers: only relative positioning is achieved.



- If the two receivers are close, the effects of the errors will be equivalent
- The relative position (baseline) is influenced marginally
- Distances of km (even 500 km) with satellites to 20,000 km!
- The more distant the receivers are, the less the conditions will be verified. I have to increase the reception time
- They can be used only to estimate the components of the three-dimensional vector joining the receivers, provided that the coordinates of one of the two (called back point of the base) are known a priori

Baseline

- The baseline dS is a space-oriented distance consisting of geocentric dX, dY and dZ

$$dS = \sqrt{dX^2 + dY^2 + dZ^2}$$

- If I know X, Y and Z of either end of the baseline I can calculate X, Y and Z of the second extreme

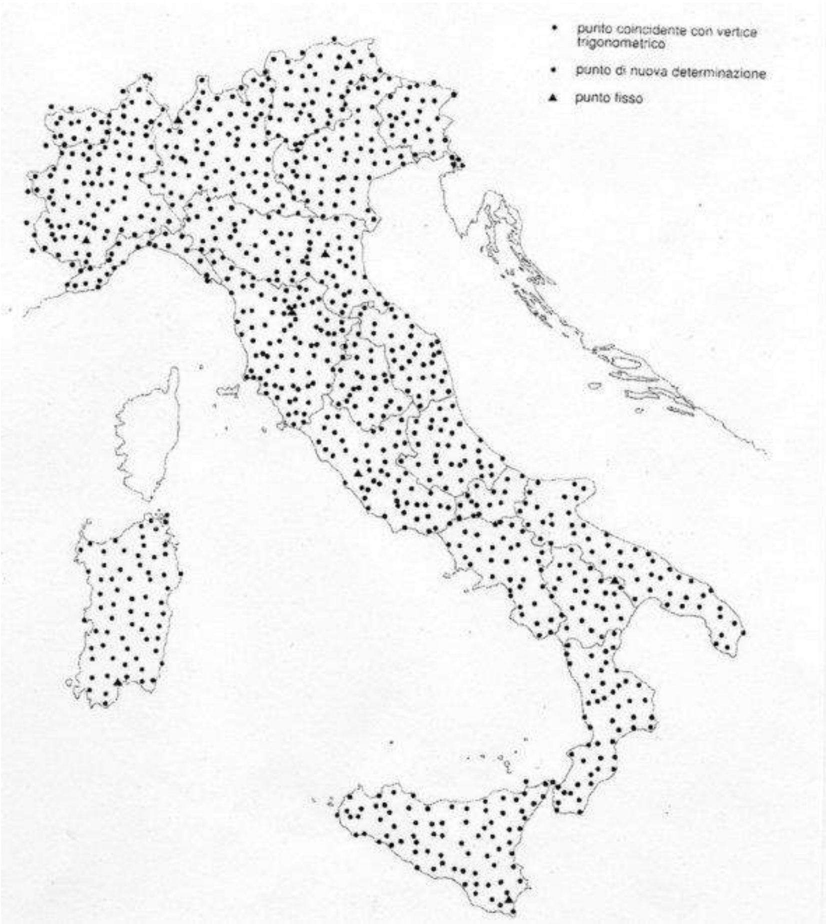
DGPS static

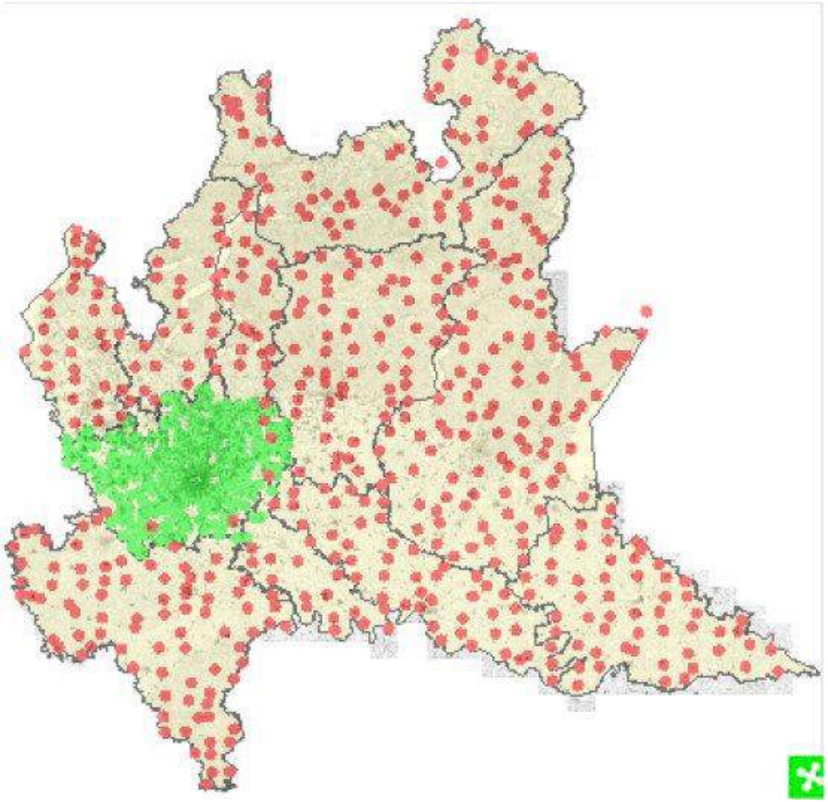
- I simultaneously turn on 2 receivers placed at the ends of the baseline, one of them on a point of known coordinates
- Register for the desired time the signal for a certain number of epochs in function of ΔS
- Download the recordings to a PC and start post processing
- I get very high precision for the dX, dY and dZ. I get the coordinates of the unknown point
- I lose the real time (I have to post process)
- If I consider the movements I can measure a few points a day

Permanent Stations

- Entities of various types position GPS in stable places, with known coordinates; they are in continuous reception
- Internet downloading the reception period required by the nearest permanent station
- I process my reception in static (just an antenna) with that of the permanent station
- I'm still without real time (post processing required)

Known positions





Rete di raffittimento regionale

Un punto ogni 7 km circa

Rete nazionale IGM95

Un punto ogni circa 40 km

RETE GEODETICA IGM95

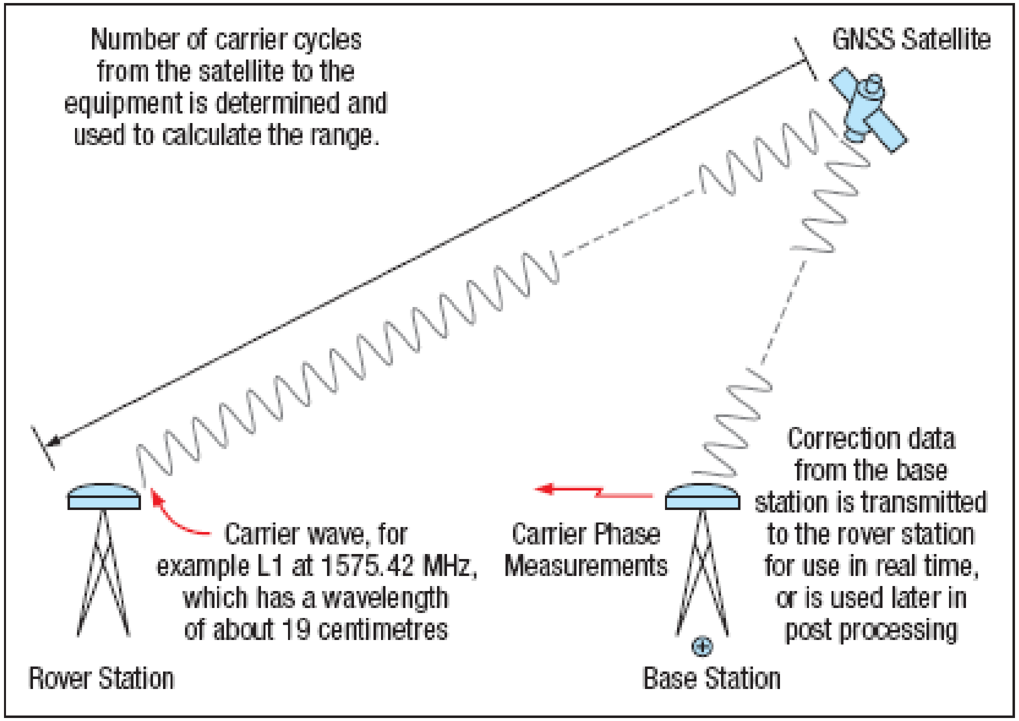
At the end of the last century, the Geodetic Direction completed the establishment and determination of a new fundamental geodetic network - IGM95.

The new network was entirely determined using GPS differential techniques and is part of the conventional ETRS89 system, in particular in the ETRF2000 implementation at the time 2008.0, through the National Dynamic Network; it is also connected to the "classic" triangulation and leveling networks.

The IGM95 network consists today of over 2000 points characterized by high precision, with an average inter-distance of about 20 km. An increase is underway, carried out in collaboration with the Regions, which will lead to an average density of one point every 7 km.

DGPS kinematic (RTK)

- I place the master receiver on the point of known coordinates
- On it determine the error in X, Y and Z as the difference between the known coordinates and those evaluated in pseudorange
- I transmit the corrections via gms to the rover receiver that I place on the incognito point
- I repeat the operation for some epochs
- I recovered the real time
- I need to have a telephone connection between the master and the rover



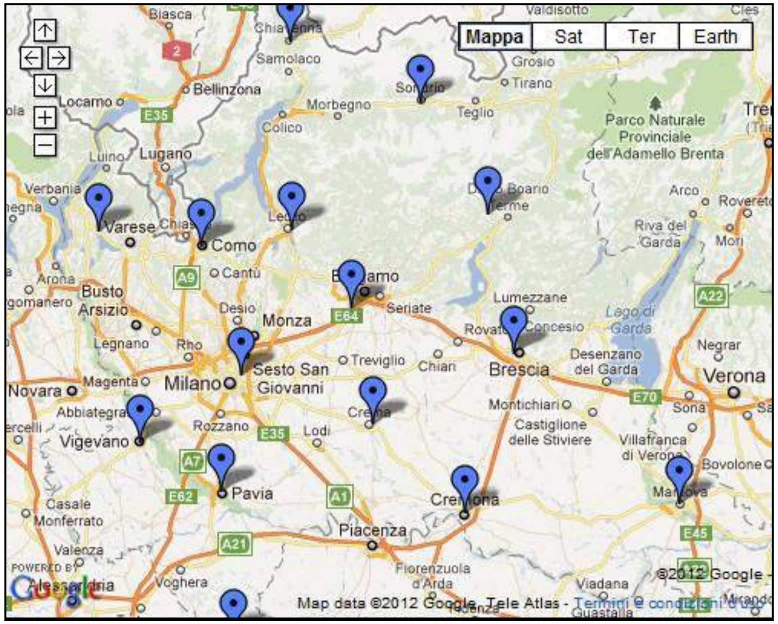
Permanent stations Regione Lombardia

Positioning service: permanent station system

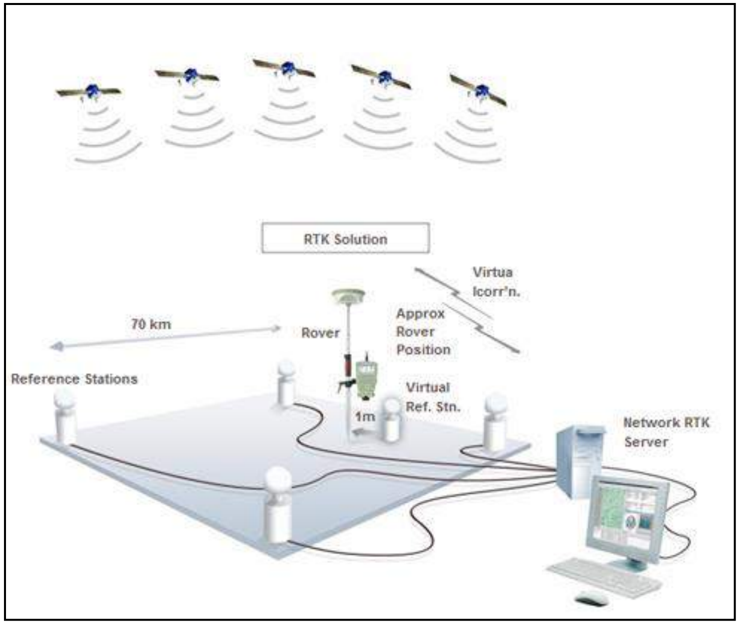
- The permanent stations are coordinated with each other
- The rover connects with the permanent station system
- Virtual master station that estimates errors
- Application of errors to the rover
- Recovery of real time and DGPS
- Some problems of gsm connection to the Service

Positioning services

RETE GPS LOMBARDIA



VIRTUAL REFERENCE STATION (VRS)



GPS coordinate systems

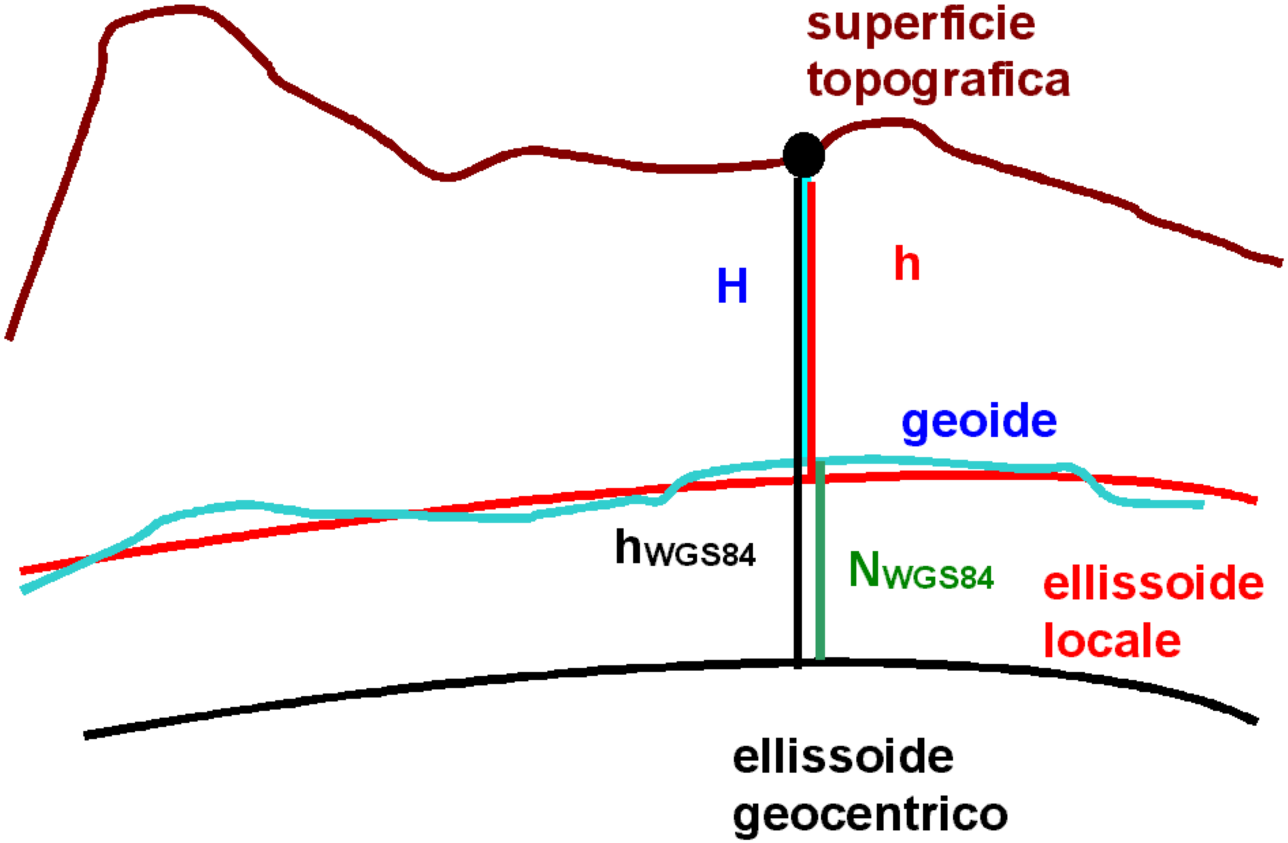
The GPS uses the WGS84 ellipsoid as the reference surface

The quota provided by the GPS system is the ellipsoidal one and not the orthometric one

In general, the GPS coordinates are geographic (latitude, longitude, ellipsoidal altitude) or Cartesian (X, Y, Z)

The transition from cartesian to cartographic coordinates takes place by means of some mathematical passages, the transition between geographical coordinates and cartographic coordinates is performed by means of a regular mesh model (IGM grids)

The passage from ellipsoidal to orthometric occurs by knowing the undulation of the geoid

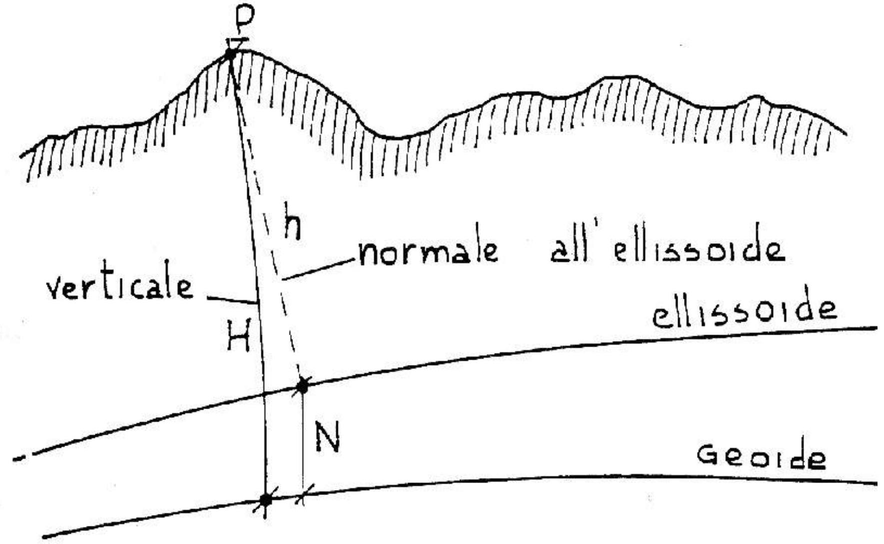


A point has two different dimensions:

-Ellipsoidal elevation (h): normal length to the ellipsoid

or height of a point above the ellipsoid

- Orthometric dimension (H): length of the line of the force field of gravity or height of a point above the mean sea level or geoid



$$\underline{H = h + N}$$

N: geoid ripple

Knowing N

- In our areas N is worth about 30 - 40 m (attention, not cm !!!)

- In order to pass from H to h and vice versa, it is necessary to know the model of N (model of geoid) with accuracy of the order of 5-10 cm

- Where this is not the case, GPS can not be used to define the altimetry in the engineering design field

GPS coordinate systems

The rigorous passage from ellipsoidal to orthometric (or vice versa) can be done by sw Verto