An example of GNSS - based measurement for high school students

Abstract

Global Navigation Satellite Systems allows measurements of position and time: in particular, distance measurements are obtained through the time of flight of a signal sent by a transmitter on the satellite.

Here a very simple simulation of GNSS functioning is proposed, based on the measurement of the range between simulated satellites and a local representative receiver.

This simulation has been proposed as a masterclass to the high school students of the Extreme Energy Events project, during the 10th Conference of Centro Fermi Projects, held in Turin from 6th to 8th March 2019.

The GNSS for position measurements

GNSS (Global Navigation Satellite System) is normally employed to determinate the coordinates of a dedicated receiver, with different levels of accuracy and precision, depending on the considered field of activity.

About 30 satellites flying in Medium Earth Orbits (MEO), covering all the Earth, compose GNSS system. Each satellite is equipped with atomic clocks, used to generate RF signals (for GPS typical frequencies are 1575.42 MHz, called L1, and 1227.60 MHz, called L2).

These signals are sent down to the Earth as pure carriers, but also modulated by different codes (for GPS, the original, and still used, C/A, P, and the new L2C, CM, CL ones, together with the D code, that is the Navigation Message).

At user level on Earth, depending on the receiver and field of application, these codes and carrier-phase are received and considered, in order to determine receiver's position.

This is done by measuring the time of flight of the signal - from its transmission from the satellite, to the reception on Earth– for each of at least four satellites, by using typically the codes (for mass market applications) and the carrier-phase (for precise and specialist applications).

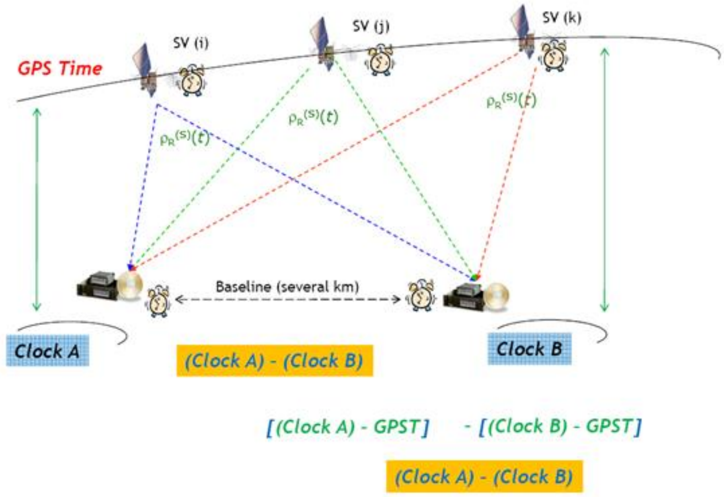
Taking into account for the speed of light, Ionosphere/Troposphere effects, satellites positions and onboard atomic clocks behaviour, as well as other error sources, a raw estimation (called pseudorange) of the distance between the satellite and receiver can be estimated.

Four satellites are needed, because the unknowns are four, namely the three X, Y, Z receiver coordinates, and the time difference between the onboard atomic clock and the clock installed at receiver level, that are not synchronized.

The GNSS for time comparisons

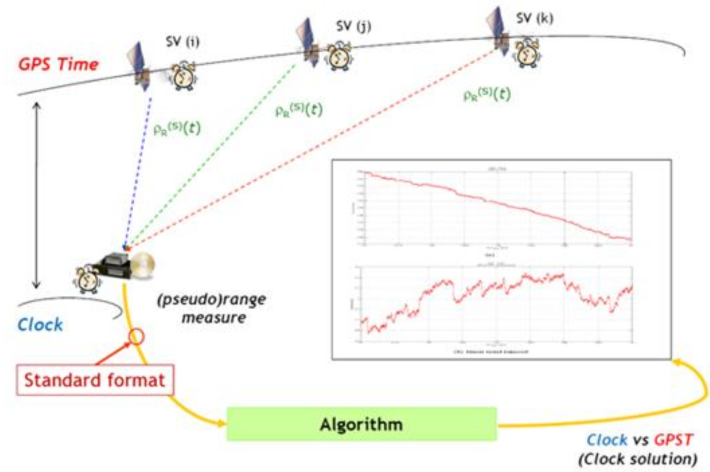
Since the end of 90s, GNSS systems are being used for the remote comparison of atomic clocks and time scales. In particular, they are regularly employed by the Time Laboratories (typically hosted at National Metrology Institutes or at Observatories) to contribute to the computation of the international atomic time scales TAI (International Atomic Time) and UTC (Universal Time Coordinated).

The atomic clocks time readings generated at mentioned Time Laboratories are transferred to the BIPM (Bureau International des Poids et Mesures) by using GNSS geodetic receivers for timing applications (i.e. able to perform satellites codes and carrier-phase measurements, and connected to an external atomic clock).

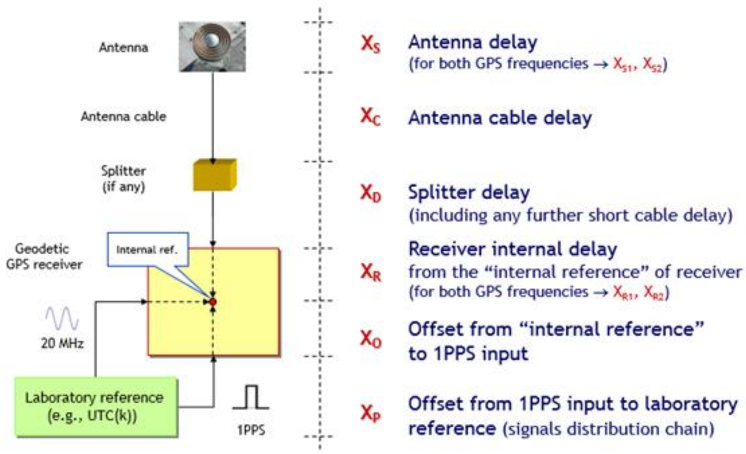


As indicated in the first figure, the basic idea of this approach is to use the code and carrier-phase measurements produced by a dedicated geodetic GPS receiver, physically connected to the ground atomic clock to be compared.

Ground clock phase is compared with respect to the satellites atomic clocks or with respect to an intermediate common time scale (the GNSS Time Scale or a time scale having reference to that).



In order to achieve this result, as depicted in the second figure, the measurements generated by the GNSS receivers have to be processed with dedicated algorithms, implementing proper geophysical models and solutions, allowing to get the required timing measurement with acceptable precision/stability (nanosecond level, down to some tenth of picosecond).



However, despite the good performances in term of precision/stability achievable, to provide accurate (i.e. nanosecond level) time transfer by means of a GNSS link, it is necessary to carry out calibrations, to be repeated periodically, to verify the long term stability of the equipment.

In particular, calibration exercises are aimed at estimating the delays introduced by the antenna, receivers, antenna cables, as well as the time delay from the clock to be compared, to the receiver itself, as shown in the third figure.

The Extreme Energy Events Project.

The Extreme Energy Events experiment is an outreach project by Centro Fermi (Museo Storico della Fisica e Centro Studi e Ricerche "Enrico Fermi", Rome) in collaboration with INFN, CERN and MIUR, designed to study cosmic rays and related phenomena via a sparse network of more than fifty muon telescopes, based on the Multigap Resistive Plate Chamber (MRPC) technology, installed in Italian High Schools.

Due to its wide coverage of the Italian territory (more than 10° in latitude and in longitude, covering more than 3×10^5 km^2), the EEE network is the largest MRPC-based system for cosmic rays detection.

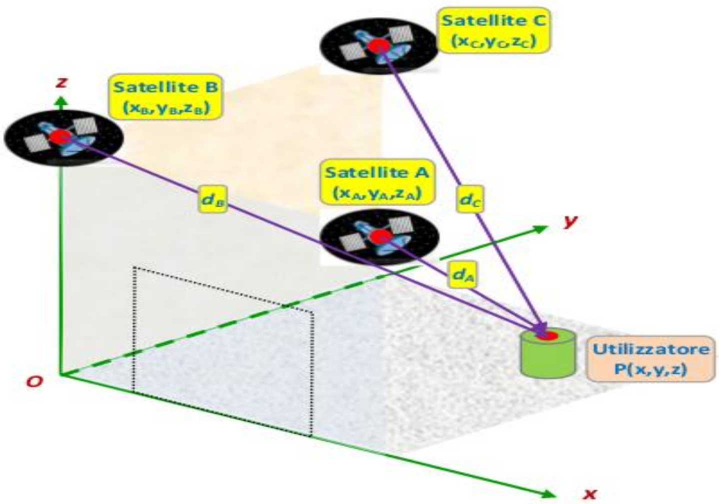
The high school students participating in the EEE activities participate to monthly organized Coordination Meetings with the Collaboration, set up by means of a vidyo connection. During these events, students can report to the Collaboration about their research activity in the experiment (telescope maintenance, data analysis, etc.) and can profit of General Lessons about cosmic ray physics, or hardware and software of the experiment, generally given by EEE researchers.

Furthermore, General Conferences are yearly organized, during which students not only show their scientific results, but also participate in groups to masterclasses organized by the researchers, , concerning measurements of physical quantities useful for analyze the EEE data. Usually, prizes are given to students performing masterclasses tasks with the best results.

The GNSS based masterclass for high school students.

Dr. M. Sellone and Dr. G.Cerretto, researchers at Istituto Nazionale di RIcerca Metrologica (INRIM), kindly developed, for the students of the EEE project, a masterclass based on the simulation of the GNSS functioning through the measurement of the range between local representative receiver and satellites.

In particular, to perform the masterclass students only need to know some basics about GNSS functioning: with 4 satellite in view, one needs to solve 4 nonlinear equations to get position and time, considering that distance measurements are obtained through the time of flight of a signal sent by a transmitter mounted on a satellite.



To perform the masterclass, a student has to put 3 simulated satellite in simple positions on a Cartesian reference, and to measure their positions (x_A, y_A, z_A), (x_B, y_B, z_B), (x_C, y_C, z_C) by means of a distance meter.

Then the student has to measure its own distances from the 3 satellites (d_A, d_B, d_C), and compute its position by inverting the equations of distances:

$$R_A = \sqrt{(x - x_A)^2 + (y - y_A)^2 + (z - z_A)^2}$$
$$R_B = \sqrt{(x - x_B)^2 + (y - y_B)^2 + (z - z_B)^2}$$
$$R_C = \sqrt{(x - x_C)^2 + (y - y_C)^2 + (z - z_C)^2}$$

It has to be highlighted that a laser meter uses the time of flight of a laser to compute distances, then the signal is transmitted and received by the same instrument.

So it is like the receiver and the satellite clocks are synchronized, than only 3 range measurements are needed.

The estimated position of the student, computed by inverting the equations of distances, can be checked with an actual measurement made by an instrument.

Resources

Students can develop their own code to invert the equation of distances, or they can use the Python code here attached, developed by Dr. Valerio Pettiti from INRIM.

- You can find the code at the link:
  - https://indico.cern.ch/event/855335/contributions/3627925/attachments/1953452/3244196/Simula_GPS_Pettiti_EEE.py

(*Please remember to cite the author of the code if you plan to use it!).*

Related Links:

- General Lessons about GNSS *(10th Conference of Centro Fermi Projects, Turin, March 2019)*
  - https://agenda.centrofermi.it/event/120/contributions/1041/
  - https://agenda.centrofermi.it/event/120/contributions/1042/

- Short description of the masterclass:
  - https://indico.cern.ch/event/855335/contributions/3627925/attachments/1953452/3244208/GNSS.pdf