

Algerian Augmentation Positioning System (SAAP)

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ملخص : نتطرق في هذا المقال إلى المراحل الأساسية لمشروع ذو بعد كبير يخص انجاز شبكة لرفع دقة التموقع، تتركز على محطات دائمة الاستقبال من نوع "GNSS" المنظومة الساتلنتية الشاملة للملاحة (م س ش م).

محطات (م س ش م)، تشمل حاليا مجموعتين ساتلنتيتين عمليتين: GPS (الولايات المتحدة) و GLONASS (روسيا) وخلال السنوات القليلة القادمة يلتحق بهما GALILEO (أوروبا) و BEIDOU/COMPASS (الصين).

يغطي مشروع الشبكة كامل التراب الوطني بمحطات دائمة الاستقبال من نوع GNSS متعددة التردد، ذات الخواص التقنية و معايير الدقة المعمول بها عالميا في المنظومات الملاحية العملية.

يرتكز المبدأ على تعزيز المنظومات الساتلنتية GNSS بشبكة رفع أو تغطية، تبث أنيا تصحيحات تهدف إلى رفع دقة التموقع و تصخر معلومات لتأكد من مدى صحتها.

أصبحت منظومات رفع الدقة وسيلة ضرورية لكل التطبيقات ذات الدقة السنمترية. فهي تستعمل في الأشغال التي تتطلب دقة كبيرة في القياس لاسيما في حالة متابعة تشويه القشرة الأرضية، معاينة المنشآت الفنية، رسم الخرائط، الجيوديزيا، و استطلاع الغلاف الجوي من الأرض أو الجو.

عدة دراسات تستغل معطيات GNSS لمتابعة و تسيير أخطار الزلازل بما في ذلك البحوث الجيوفيزيائية التي يمكنها الاستفادة من دقة معطيات المحطات دائمة الاستقبال و قياسات محطات المد و الجزر "الماريغراف" لتحديد مركز الزلازل و شدتها.

الكلمات الأساسية : نظام الرفع، التموقع، النظام العالمي للتموقع الفضائي (GNSS)، الدقة-التمييز، الجزء الأرضي للنظام.

Résumé : Nous présentons dans cet article les phases principales d'un projet de grande envergure qui consiste à la réalisation par l'Institut National de Cartographie et de Télédétection, d'un réseau d'augmentation de positionnement à base de stations permanentes type GNSS (Global Navigation Satellite System). Les GNSS, englobent actuellement deux constellations satellitaires opérationnelles : GPS (USA) et le GLONASS (Russie) et dans quelques années, deux autres; GALILEO (Europe) et BEIDOU/COMPASS (Chine) sont prévus pour les rejoindre.

L'architecture du réseau projeté, couvrira tout le territoire national, par des stations de réception permanentes GNSS

multi-fréquences, répondant aux spécifications techniques et normes de précision adoptées par les systèmes déjà opérationnels à travers le monde.

Le principe consiste à compléter les constellations satellitaires formant le GNSS par des réseaux d'augmentation ou de recouvrement qui délivrent en temps réel des corrections destinées à accroître la précision du positionnement ainsi que la fourniture des informations permettant de garantir l'intégrité de ces corrections.

Ces systèmes d'augmentation, sont devenus aujourd'hui un outil indispensable pour toutes les applications de précision centimétriques. Ils sont de plus en plus utilisés dans le cadre des travaux nécessitant une grande précision dans les mesures, notamment pour le suivi des déformations de la croûte terrestre, l'auscultation des ouvrages d'art, la cartographie, la géodésie et le sondage de l'atmosphère depuis le sol ou l'espace.

Pour la surveillance des séismes, beaucoup d'études s'intéressent à l'exploitation des données issues des systèmes d'augmentation GNSS pour une meilleure gestion du risque sismique. La recherche en géophysique pourrait tirer profit des combinaisons de ces données précises à celles des stations sismiques et des stations marégraphiques pour déterminer la localisation des épicentres ainsi que les magnitudes.

Mots clés : Système d'augmentation, positionnement, GNSS, précision, segment-sol.

Abstract : We present in this article the main phases of a major project that involves the realization by the National Institute of Cartography and Remote Sensing, of a network increases positioning based on GNSS permanent stations (Global Navigation Satellite System). The GNSS consist of two currently operational satellite constellations: GPS (USA) and GLONASS (Russia) and in a few years, two other; Galileo (Europe) and BEIDOU/COMPASS (China) are expected to join them.

The architecture of the proposed network will cover the whole national territory, by receiving stations permanent GNSS multi-frequency meets the technical standards of accuracy adopted by the same systems already operational around the world.

The principle is to complete the constellations forming the GNSS, by ground segment increase or recovery, which delivers real-time corrections to increase the positioning

accuracy and the provision of information to ensure the integrity of these corrections.

These augmentation systems have now become an indispensable tool for all precision applications centimeter. They are increasingly used in the work requiring high precision in the measurements, in particular for monitoring deformations of the earth's crust, auscultation structures of art, cartography, geodesy and surveying of atmosphere from the ground or space.

For monitoring earthquakes, many studies focus on the exploitation of data from GNSS augmentation systems for better management of seismic risk. The geophysical research could benefit from the combination of these data with those of accurate seismic stations and tide gauges to determine the location of the epicenters and magnitudes.

Keywords : Augmentation system, positioning, GNSS, accuracy, ground segment.

1. Introduction

Although the installation of GNSS stations was preliminary designed as a continuous static network, mapping activities, intensive cadastral work, monitoring the tectonic and seismic activity requiring more accuracy, led to start setting up a network real-time kinematic (NRTK) that supposed to cover the whole country.

The NRTK positioning is nowadays a very common practice. It allows users metric or even centimeter accuracy in real time with an average distance of 25-35 km between reference stations.

In order to realize this goal, the National Institute of Cartography and Remote Sensing as the active mapping authority responsible for geodetic activities in Algeria, launched a major project on the implementation of a device covering the entire national territory, composed of permanent stations GNSS (Global Navigation Satellite System) such as GPS, GLONASS, and Galileo.

The preliminary aim of this network is to establish 14 reference stations throughout Algeria, attached to International GNSS Service (IGS) of the Mediterranean to form the first order. The ultimate goal is to install more than 350 stations.

2. Project objectives

What will the stations and/or network be used for? What is needed to day and what is needed in future?

The project comes as a continuation of the use of GPS spatial geodesy, for high-precision positioning. It is based on all systems GNSS. Its objectives are:

- Data contribution for the global network of permanent stations (e.g. the International GPS Service, IGS; the Mediterranean Network), enabling the realization of

reference systems in the International Terrestrial Reference Frame (ITRF) and at the same time participate in the rehabilitation and modernization of the Algerian reference system;

- ensure positioning with sub-centimeter accuracy by the use of more accurate models for processing data from a network of permanent GNSS stations distributed in Algeria and meet the highest international standards and requirements;

- set its reliable and of the highest quality in near real time and in real time, providing a wide range of scientific applications such as geodynamics, sea level monitoring, weather forecasting, applications mapping, monitoring of local and regional crustal deformation, enabling earthquake prediction and hazard assessment, and studies on the determination of the time;

- Controlling the height system and monitoring sea-level changes by tide-gauge fixing between the Algerian National Fundamental GPS Network and Algerian National Sea-level Monitoring System.

3. What type of stations and network are needed

GPS reference stations and networks are readily scalable. They can be easily enhanced and upgraded as requirements change and the number of users increases. Thus, initially, it will often be quite sufficient to establish only the stations and services that are really needed.

Afterwards, as the requirements increase, the number of users grows and additional funds are available, new stations and features can be added and the services that are provided can be improved and enlarged. The initial investment is never lost.

- What is required?
- What applications have to be supported?
- What will the stations and/or network be used for?
- What is needed today?
- What will be needed in future?
- The area to be covered
- Where to establish the stations?
- What can be the separation distance between stations?
- The need for suitable sites with an open view of the sky
- Power, communication, security
- The infrastructure that is readily available and can be used
- The new infrastructure that has to be added
- The type of users that have to be supported
- The number of users that have to be supported
- Is it sufficient simply to log data and provide RINEX files?
- Is it also required to transmit RTK/DGPS data?
- The most suitable methods of communication between the receivers and the server

- The most suitable methods for distributing RTK/DGPS data
- The most suitable communication for distributing RTK/DGPS data
- The cost of establishing the stations and/or network
- The cost of running the stations and/or network
- The running costs for RTK and GIS rovers
- Computing the baselines between stations to check the positions of the antennas
- The budget that is available today
- The budget that will be available in future
- Charging for services and data
- Who is effectively the owner ?
- Who from the organization will be effectively in charge of supervising the system?
- What is planned for promoting the services?
- What is the vision over the next 5 years?
- Does a business plan and a financial plan available?

4. Network size and configuration

GNSS measurement errors are spatially correlated, the quality of the error estimates degrades as a function of spacing between the reference stations of the network. So, what is the effective distance between reference

stations that enables the precision required for real-time positioning, using multi-frequency, multi-constellation receivers?

Given the vastness of our country, the deployment study of this project provides three networks with different inter-station distances:

The first network as reflected in Figure 1 and identified in the following discussion the “blue” or “large” network, has inter-station distances of about 400 kilometers. We use it as a first order or reference network and it is intended to consolidate networks of densification.

The second (the “green” or “medium” network) is characterized by distances of about 150 kilometers, which is the average spacing of a national-scale geodetic network.

The last one “red network” or “small network” with distances of about 70 kilometers, is comparable with existing GNSS European networks designed for RTK purposes. Although these last two networks are designed for post-processing applications (i.e., to materialize a national or international reference system), the possibility of using these for real-time positioning could be very interesting in the future.

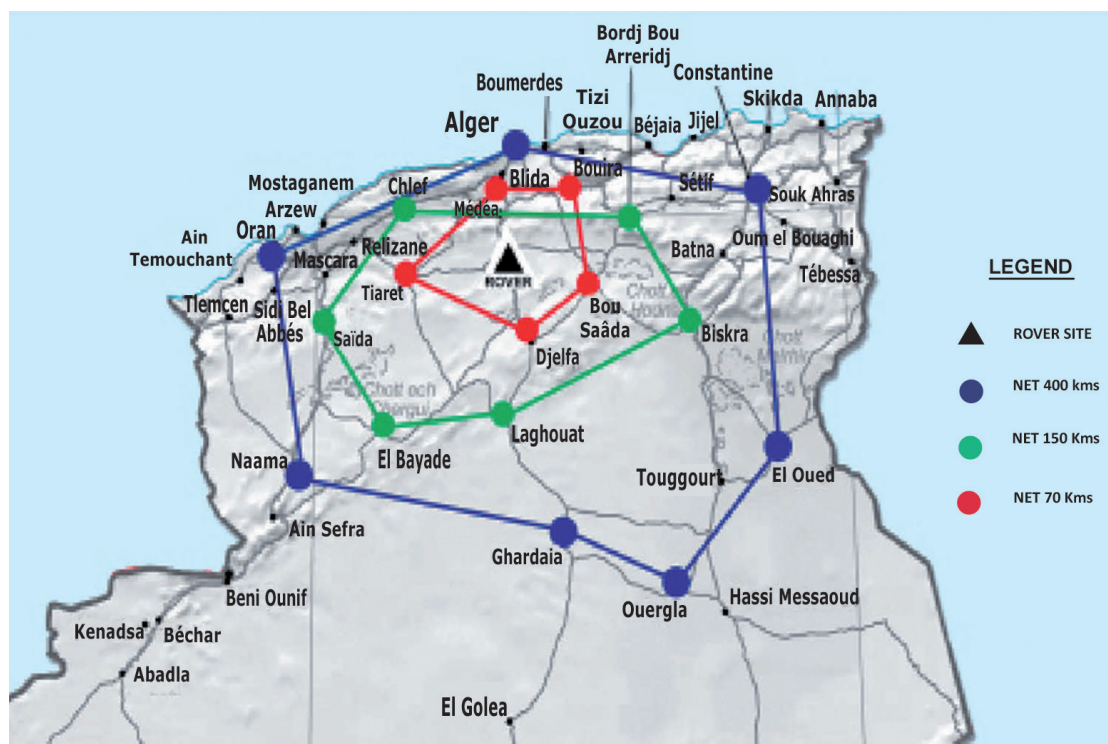


Fig. 1 Example of the three different GNSS networks distribution around the rover/SAAP project [10]

Based on experiments conducted around the world (including study GNSS solutions by Dr. Mark Petovello, University of Calgary), the influence of the distance of rover site and reference stations is clearly shown by figure 2 below.

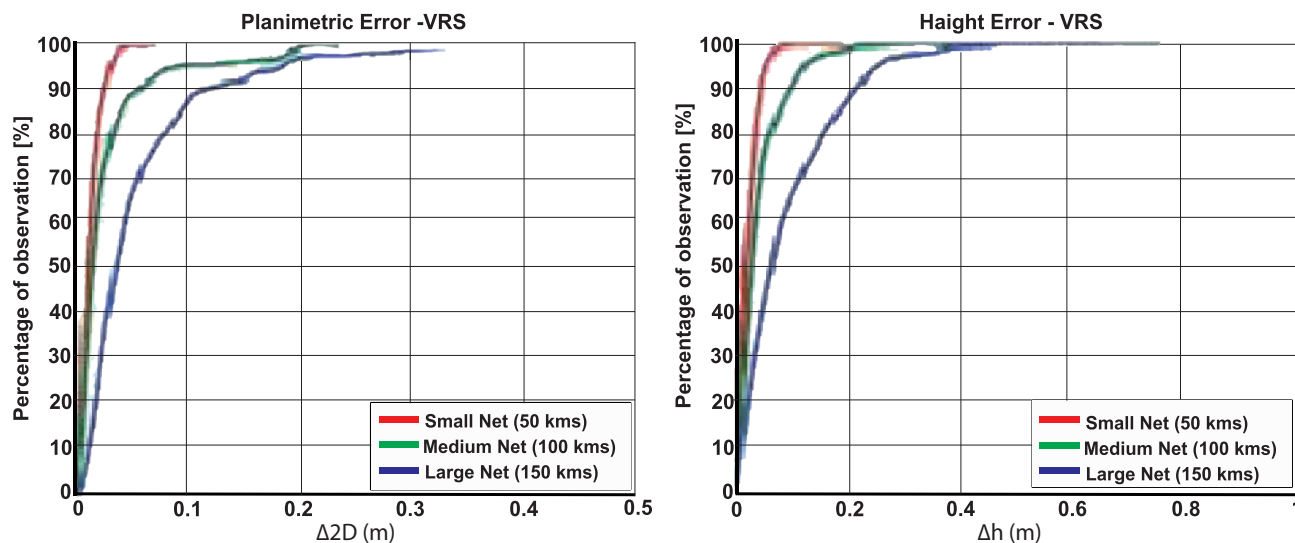


Fig. 2 NRTK positioning quality of planimetric/horizontal error (left) and the height error (right) [10]

The figure shows the average behavior of a multi-frequency, multi-constellation GNSS receiver in the case of a VRS (Virtual Reference Station) correction broadcast by networks of various sizes. The CDF (Cumulative Distribution Functions) analysis brings out an effective increase of the errors (both planimetric/horizontal and height) when the size of the GNSS network increases.

The planimetric error, for example, changes from values below 5 centimeters (95% probability) considering the “red” network up to 10 and 15 centimeters with the “green” and the “blue” ones, respectively. A similar behavior can be observed for the elevation error, with values from ranging from 6 centimeters (“red” network) to 10 centimeters (“green” network) and about 25 centimeters (“blue” network).

4. SAAP implementation and functionality

4.1 Ground segment

The SAAP ground segment is a terrestrial platform planned for horizontal and vertical accuracy enhancement of GNSS systems. It consists of a permanent GNSS stations network connected with a Control Center (CC) via specific lines. GNSS stations form an active geodetic network called ALgerian Continuously Operating Reference Stations (AL-CORS).

Data provided from AL-CORS will be used to provide useful services to increase the accuracy of GNSS systems in batch mode and in real time.

Indeed, the SAAP project will provides:

- A precise real-time positioning service, providing decimeter accuracy;

- A real-time positioning service with high accuracy, ensuring centimeter level ;

- A geodetic positioning service in offline and online modes, ensuring millimeter accuracy.

4.1.1 The AL-CORS Networks

AL-CORS is composed of 372 permanent GNSS stations well distributed all over the national territory and subdivided into two networks, the Special Order Network-A (ROSA-A) and the Special Order Network-B (ROSA-B).

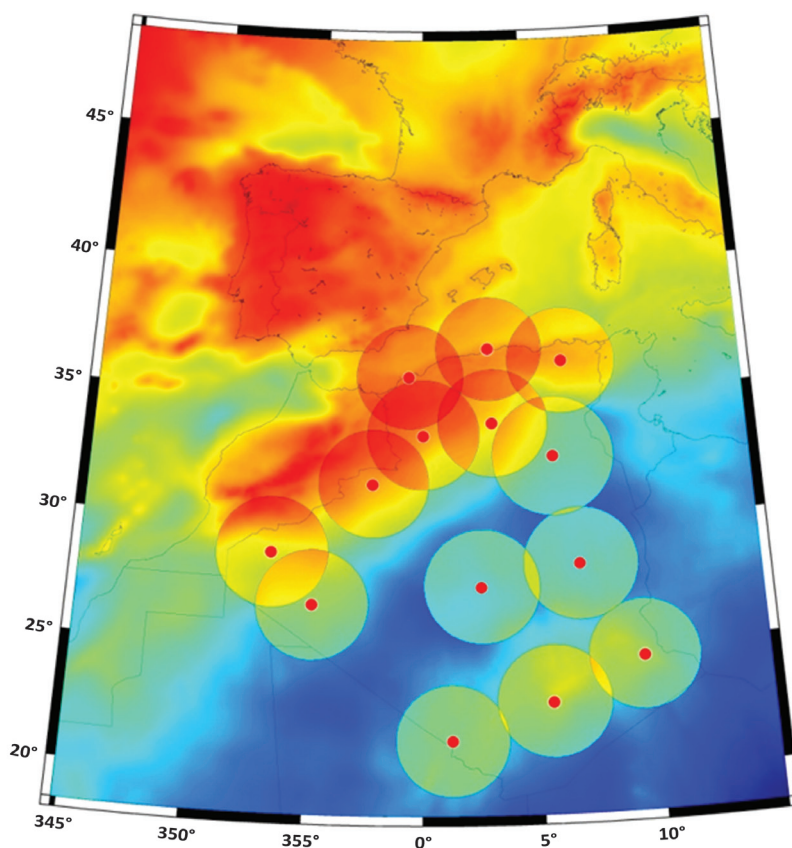
AL-CORS has a twin role:

- Provides a permanent, stable and precise framework to the national geodetic infrastructure. Thus, it will constitute the Reference Network for a new Algerian Reference Frame;
- Supplies the necessary data for GNSS users working with DGNSS or DGNSS/NRTK modes for practical tasks.

The first AL-CORS network is constituted by fourteen (14) permanent GNSS stations. These sites are located in the following cities : Algiers, Oran, Constantine, Ouargla, Laghouat, Nâama, Hamaguir, Oum el Assel, In Salah, Tamanrasset, Borj Badji Mokhtar, Djanet, Bordj Omar Dris, Chenachen; their geographical distribution is shown in figure 3.

They observe continuously at a rate of 30 seconds and broadcast the measurements to the Control Center for processing and dissemination.

The distances between neighboring GNSS stations are from 400 km to 450 km, with homogeneous geographical distribution over the national territory and aligned to surround IGS COR-Stations.



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Fig. 3 GNSS Permanent Sites configuration: Special Order Network-A

4.1.2 Control Center and SAAP network applications

Regarding the delayed mode DGNSS post-processing, the Control Center will publish on the Internet the GNSS observation files in RINEX and Hatanaka formats. These files are downloadable by users after authentication via FTP. On the real-time mode DGNSS/NRTK, the CC will process the corrections to be broadcasted, from the operating ALCORS stations raw data.

CC software uses this data to process the network RTK corrections and diffuses them into the RTCM standard format to user mobile subscribers.

4.1.2.1 Real time applications

The NRTK (Network Real Time Kinematic) could be the most important SAAP ground-based augmentation feature; it is an evolution of the RTK positioning appeared with the development of GNSS permanent networks. Instead of using the measured observations in a single base station, a GNSS network known coordinates for positioning in real time, is used. This is called NRTK with the advantage that the corrections are transmitted more frequently by mobile telephony (GPRS/EDGE/3G). The most important difference from the single RTK is the length of baselines that in the case of NRTK are generally longer (density of permanent GNSS network).

This accuracy parameter is compensated by the inclusion of a plurality of fixed stations instead of one only [8].

Three types of technical solutions NRTK could be used, as described in the flowchart in figure 4, providing more or less equivalent information. The only differences between these solutions act on the distribution of tasks performed by the computers of the Control Centers (which retrieves permanent stations observations and transmits correction information) and the unknown station [2].

1. The MAC (Master Auxiliary Concept) solution: this is the solution where the majority of operations are performed at the receiver side. The receiver sends its approximate position to a server which infers subnet stations near the unknown station. A master station is selected from that subnet, the others are considered as auxiliary stations. The master station observations are sent to the unknown station and differential corrections to the auxiliary ones processed in the server.

2. The FKP (Flaschen Korrektur Parameter) solution: this is an intermediate solution for the distribution of operations between server and receiver. The server calculates a surface model of corrections from GNSS network. This model of corrections is then sent to the receiver in order to process a new position.

3. The VRS (Virtual Reference Station) solution: this is a solution where the majority of operations are performed on the server side. The receiver sends its approximate position to the server of processing. From the observations acquired on the permanent stations, the server simulates

observations for a virtual station in the approximate position sent by the receiver and transmits this information. The receiver then uses these simulated observations to perform differential process.

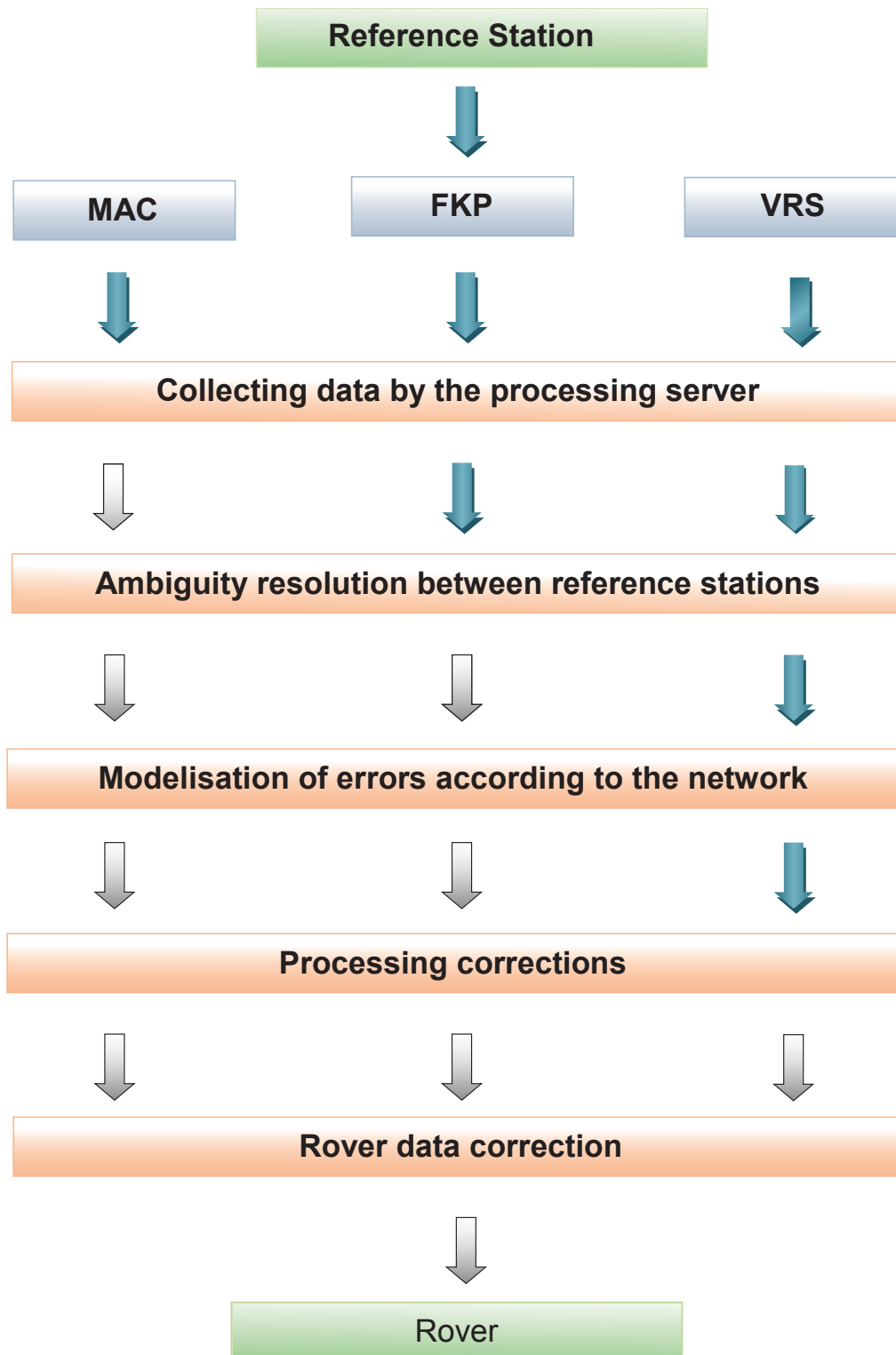


Fig. 4 The different methods of NRTK. Steps following the empty arrows are achieved in the servers and steps following full arrows in the mobile receiver

4.1.2.2 IGS products and SAAP data processing

The International GNSS Service (IGS) is a worldwide association that gathers resources and permanent GNSS stations data to make available precise GNSS products. The IGS is dedicated for providing products as the standard for GNSS according to Earth science research, multidisciplinary applications, and education [9].

In addition, the IGS is supporting applications requiring real-time access to IGS products through its Real-Time Service (RTS) which is a GNSS orbit and clock correction service that enables precise point positioning

(PPP) and related applications, such as time synchronization and disaster monitoring, at worldwide scales. In order to remain at this level of performance and to achieve this degree of accuracy, the Algerian permanent GNSS stations are constrained to surrounded IGS COR-Stations through a treatment in post-processing using sophisticated GNSS softwares and IGS products, providing combined weekly solutions.

The figure 5 below shows the first six operational GNSS permanent stations of INCT with their geographical distribution.

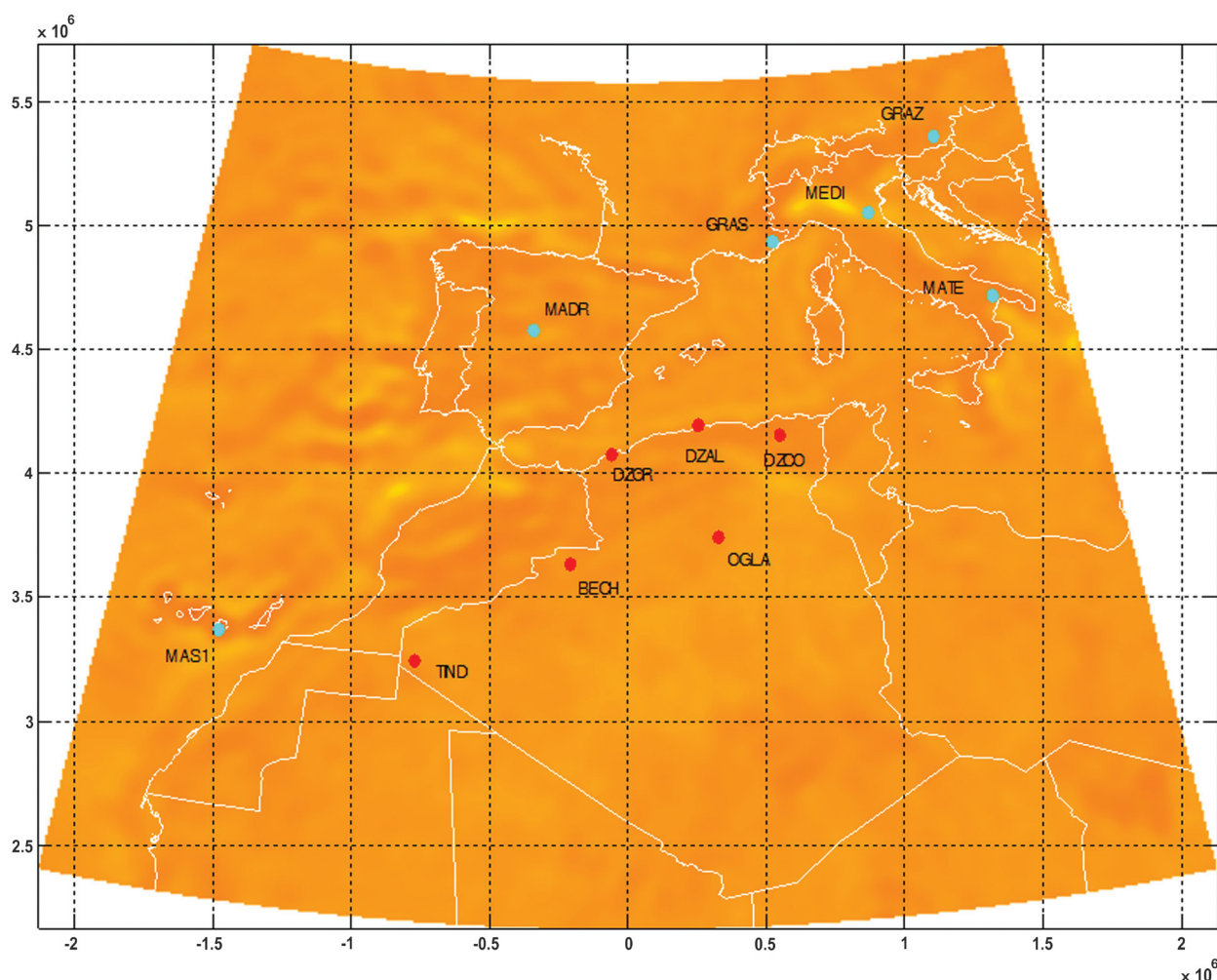


Fig. 5 Operating Algerian Permanent GNSS Stations in red and the IGS COR-Sites in blue

5. Expected errors

The error which can be expected between two adjacent stations in the different networks, can be computed from the formula (see Standards and Guidelines of Federal Geodetic Control Committee FGCC):

$$\sigma = (e^2 + ((0.1)(p)(d))^2)^{1/2}$$

Where :

σ = maximum allowable error in cm at 95% confidence level;

e = base error in cm;

d = distance in km between adjacent stations;

p = the minimum geometric relative position accuracy standard in parts per million at 95% confidence level.

Order A: National Geodetic Reference System, primary networks

Order AA: Global-regional geodynamics deformation measurements, (using IGS data and orbital adjustment techniques).

Order B: National Geodetic Reference System, secondary networks and engineering surveys.

Thus,

$\sigma_{70 \text{ km}} = 7 \text{ cm}$, (Order B : e=0,8cm, p=1ppm)

$\sigma_{150 \text{ km}} = 1,6 \text{ cm}$, (Order A : e=0,5cm, p=0,1ppm)

$\sigma_{400 \text{ km}} = 5 \text{ mm}$ (order AA : e=0,3cm, p=0.01ppm)

6. Perspectives

The SAAP project was initiated in April 2013 with many ambitious tasks intended for promoting various academic studies and development in order to support the ongoing realizations mentioned above.

The main stages and practical responsibilities to carry-out in the mean and long terms in the setting of this project are enumerated as follows:

- 1 - Complete the installation of the Special Order Network-A (ROSA-A) and the Special Order Network-B (ROSA-B) and their connection to the nearest IGS COR-Sites;
- 2 - Processing and analysis of SAAP GNSS data in post-processing;
- 3 - Realization of a Control Data and Analysis Center;
- 5 - Validation of data and broadcast corrections through real application tests;
- 6 - Implementation of automated on-line processing utilities for user subscribers.

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