Current Trend in GNSS Based Heighting: Conditions and Limitations on Its Applications in Nigeria

O.A. Isioye and F. A. Fajemirokun

***Abstract*— One of the goals of modern geodesy is the global unification of vertical datums so that height data from them can be properly integrated. Well established vertical geodetic framework, apart from being the backbone of any national surveying and mapping system, also enhances the reliability of elevation data used in spatial information systems for preserving the environment and enhancing sustainable development. The GNSS technology is a three dimensional positioning tool and GNSS heighting can be viewed as a viable alternative to other more conventional forms of height measurement. Nowadays the time of GNSS static baseline determination is almost out-of-date for everyday applications. The current trends are to continuously observe and measure using GNSS, install permanent GNSS base stations or networks and provide real time accurate positioning. These three trends together offer an advanced component of geodetic infrastructure known as a GNSS CORS network. These networks need to have a geodetic datum, meaning that they have to be linked to the available terrestrial reference frames. In some countries/regions, GNSS CORS networks are so well developed and dynamic that they have a more prominent role than the existing classical passive geodetic infrastructure, in reference frame determination, monitoring and positioning. This paper focuses discussion on the trend in GNSS based heighting and their associated accuracies and limitations. The procedures for realizing the link between the GNSS CORS and the available reference frames and effort made by countries and agencies around the world in keeping with trends in GNSS based heighting are discussed. In addition, this paper outlines the limitations and possibilities of real time accurate GNSS height determination in Nigeria.**

***Keywords*— GNSS CORS, Height, RTK, ITRF.**

I. Introduction And Background

Global Navigation Satellite Systems (GNSS) consist of satellites, ground stations and user equipment and are utilized worldwide across many areas of society. Global Navigation Satellite Systems, operating in different constellations, are the United States' Global Positioning System (GPS). The Russian Federation's Global Navigation Satellite System (GLONASS), Europe's European Satellite Navigation Systems (GALILEO), and China's Compass/BeiDou are also a part of the Global Positioning System. Meanwhile, India's GPS Aided Geo Augmented Navigation (GAGAN) and Japan's Quasi-Zenith Satellite System (QZSS) are part of the Regional Navigation Satellite Systems (RNSS) which provides signal coverage over a number of nations or region.

The most known GNSS is the Global Positioning System (GPS). International Committee on Global Navigation Satellite Systems (ICG) ensures compatibility and interoperability of GNSS systems through international cooperation and making positioning, navigation, and timing available globally for societal benefits, including monitoring all aspects of environment and security [1].

For all GNSS measurements of geodetic accuracy, at least two simultaneously measuring receivers are required. In general, the one on a site with known co-ordinates is called the 'reference' station. The one located on the site with unknown co-ordinates is called the 'rover'. The development of GNSS, especially of GPS, has lead to the operation of Continuous Operating Reference Stations (CORS) that acquire GPS signals without interruption. In addition, these CORS have the task to store the data and in some circumstances process the data and then transmit this data to rover receivers. These CORS help the users by economizing one GPS receiver as the operation of the reference station is performed by the service provider of the CORS network. In general, a service provider owns or operates a network of CORS that is capable of estimating or resolving the 'ambiguities' of all CORS as one homogeneous model in real time. This is often referred to as a 'network solution' within a GNSS CORS network [2], [3] and [4].

Global Navigation Satellite Systems (GNSS), notably the Global Positioning System (GPS), yield ellipsoidal (geodetic) heights relative to the surface of a geodetic reference ellipsoid,

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which are transformed from the Cartesian coordinates used in the GNSS data processing. Typically, WGS84 is the geodetic reference ellipsoid used since this is embedded in GPS and is generally the default in GPS processing software, but which is geometrically and practically identical to the GRS80 geodetic reference ellipsoid (to less than 0.1mm) [2] and [5]. The ellipsoidal height (h) is measured positively above the ellipsoid (away from the Earth) and negatively below, and along the ellipsoidal surface normal. Ellipsoidal heights, determined from Global Navigation Satellite Systems (GNSS) are inherently the least accurate coordinate component, due mainly to satellite geometry and errors due to atmospheric refraction. For most practical purposes, however, these GNSS-derived ellipsoidal heights have to be transformed to heights that relate to the Earth's gravity field, which generally adds further uncertainty. The reduction in accuracy of the transformed height is due to errors in gravimetric quasi/geoid models, but this is compounded yet further in Nigeria and elsewhere because of the imperfect realisation of local vertical datums[5], [6], [7], and [8].

From a spatial information perspective, it is common for spatial datasets and geographical information data to extend over national or regional boundaries. In this situation it is needed to have a common reference frame for the collection, storage, visualisation and exchanging of the information. The International Terrestrial Reference Frame (ITRF) is the most accurate reference frame that exists internationally and consequently more countries are using national solution based on ITRF. Adopting an ITRF based geodetic datum allows for a single standard for collecting, storing and using geographic or survey related data [9]. This will ensure compatibility across various geographic, land and survey systems at the local, regional, national and global level. This is the main reason that the ITRF based CORS networks should form the basis for Spatial Data Infrastructure (SDI) which is the enabling infrastructure to manage a country's key spatial data sets. An ITRF based geocentric datum or CORS network will provide direct compatibility with GNSS measurements and mapping or geographic information system (GIS) which are also normally based on an ITRF based geodetic datum; minimise the need for casual users to understand datum transformations; allow more efficient use of an organisations' spatial data resources by reducing the need for duplication and unnecessary translations; help promote wider use of spatial data through one user friendly data environment; reduce the risk of confusion as GNSS, GIS and navigation systems become more widely used and integrated into business and recreational activities.

Furthermore, height determination within a consistent reference system is at the basis of a large number of economic activities. These activities range from mapping, engineering, and dredging to environmental studies and natural hazards; from precision agriculture and forestry, to transportation, commerce and navigation; and from mineral exploration and management of natural resources to emergency and disaster preparedness. All of these depend on the compatibility of height information enabled by a common coordinate reference system through which all types of geo-referenced information can be interrelated and exploited reliably. While the height reference system supports numerous technical applications, it is also referred to in many legal documents related to land and water management and safety such as easement, flood control, and boundary demarcation.

GNSS-based height (ellipsoidal height) is inherently less accurate than horizontal position. This is caused by a combination of error sources which includes 1) errors inherent in the GPS-derived ellipsoidal heights and 2) the subsequent coordinate transformation(s) to get heights that are compatible with the Local Vertical Datum. Despite these inadequacies, GPS has established itself as a competitor to low-order spirit-levelling over long distances, and is generally superior to long-range trigonometric heighting, provided that a sufficiently accurate coordinate transformation can be achieved. For instance, to spirit-level 50 km takes around one working week on reasonably flat ground with good visibility, whereas it takes only a few hours with dual-frequency carrier-phase GPS. Therefore, GPS offers an attractive alternative height determination tool, provided that it is sufficiently accurate for the application at hand [5].

This paper focuses discussion on the different techniques of GNSS height determination (with emphasis on network based RTK technique) including the application of CORS with ITRF solutions and associated accuracies and limitations, efforts by organizations and countries around the world in accurate heights determination is appraised. Finally, the Nigerian scenario is discussed and solutions are proffered as to how to take care of the problems identified.

II. Overview Of GNSS Based Heighting Techniques

In practice, GNSS heighting typically involves measuring ellipsoidal heights with GPS or similar equipment, applying some form of geoid model and making any adjustment to fit the resulting orthometric heights to the existing vertical datum. Therefore, in examining the limitations of GPS heighting it is necessary to consider three broad areas viz: limitations of the GPS measurement, limitations due to the available geoid model, and limitations due to vertical datum issues [10]. Error sources that degrade GNSS (GPS) measurement includes; *orbit and clock errors, ionospheric delay, tropospheric delay, multipath, antenna phase centre variation, electromagnetic, dilution of precision and satellite availability, GPS baseline length, optimistic internal precision estimates, incorrect integer ambiguity resolution and user related errors(i.e., GPS surveying by radiation, vertical coordinate transformation, and bad survey practice)*. A general description of these error sources and possible remedies are contained in [6], [10], [11], [12], and [13]. Some or all of these issues vary in importance depending on the overall extent of the GPS survey in question. GPS surveys over national and continental scale are typically associated with datum level geodetic operations and need to consider many more issues than day to day surveys which extend over a few kilometres or less.

Obviously, the first limitation in GPS heighting is the quality of the GPS solutions used to obtain a height. Three broad categories of GPS observation types are possible, namely: Point Positioning which is the stand alone navigation mode for which GPS was designed; Differential GPS (DGPS) which uses a differential correction approach but which is primarily based on pseudo range measurements; and GPS Surveying using a differential approach but primarily based on measurement of the phase of the GPS signals.

While DGPS and even Point Positioning may be useful for producing heights in certain applications, the term GPS heighting is typically taken to refer to the use of phase measurement techniques that can be grouped under the broad heading of GPS Surveying. This paper concentrates on heighting using these higher precision GPS Surveying techniques.

Within GPS Surveying, an overall consideration is whether the phase ambiguities have been resolved to integer values. Ambiguity resolution affects all three dimensions, not only height. For the measurement techniques known as *Rapid Static* and *Real Time Kinematic (RTK)*, which are used for shorter baselines, ambiguity resolution is a prerequisite and should be achieved for most day to day GPS surveying applications. It is important to realise that RTK uses the smallest possible amount of data and even the best algorithms sometimes resolve the ambiguities incorrectly. To avoid such errors, which can reach the metre level, it is important to build redundancy into a survey by, for example, occupying stations more than once. The current state-of-the-art implementation for high precision GPS positioning is the so-called Real-Time Kinematic (RTK) hardware/software system that can deliver centimetre-level positioning accuracies of a moving (i.e. kinematic) user receiver, if the integer carrier phase ambiguities are correctly resolved. However, the impact of baseline length dependent GPS errors, such as orbit uncertainty, and atmospheric effects, constrains the applicable baseline length between reference and mobile user receiver to perhaps 10-15km. These constraints have led to the development of several network-based RTK techniques, including the Virtual Reference Station (VRS) approach, and the Area Correction Parameter techniques [14].

The key concept in using multiple reference stations (i.e., a network) to support GPS carrier phase-based positioning is: (a) to generate so-called "correction terms" representing the distance-dependent errors; and (b) to interpolate and apply them to mobile user receiver measurements, so as to significantly diminish the residual error terms, thus making it possible to perform medium or long-range (tens to hundred kilometre receiver separations) positioning. The correction message data are generated based on the pre-determined coordinates of the reference stations. Integer ambiguities among the reference stations must be correctly resolved and station dependent errors, such as multipath, measurement noise, and antenna phase centre variation, should be mitigated in the correction terms. In addition, the generated correction message data with respect to each reference stations have to be interpolated or modelled for the user's location. Over the past decade, a number of interpolation methods have been proposed. These include *Linear Combination Model*, *Distance-Based Linear Interpolation Method*, *Linear Interpolation Method*, *Lower-Order Surface Model* and *Least-Square Collocation* [15]. However, [16] demonstrated that the performances of all of these methods are similar. In order to obtain optimal estimates from the least-square solution, both a *mathematical model*, also called a functional model, and a *stochastic model* should be correctly defined. The functional model describes the relationship between measurements and unknown estimates. On the other hand, the stochastic model represents the statistical characteristics of the measurement that is mainly provided by the covariance matrix for the measurements. Whilst the mathematical models for the network-based GPS RTK positioning are sufficiently investigated and well documented (e.g., [14]), stochastic modelling is still an issue under investigation. In the case of network-based GPS RTK, the positioning performance is largely affected by the residual biases due to imperfect network mathematical models. The residual biases contribute to the noise terms and make it difficult to define a functional model that can deal with them. Hence, they should be taken into account within the stochastic model.

III. The Current Ground Infrastructure For Positioning

It is generally recognised today that a reference network comprised of permanent, continuously operating reference stations (CORS) equipped with GNSS (i.e., GPS+GLONASS) receivers provides the fundamental infrastructure required to meet the needs not only of geodesy and the geosciences, but also of many professional GPS surveying, mapping and navigation users. Furthermore, the widespread use of the GNSS-RTK technique means that such reference station receivers may also have to support ever expanding non-geodetic, *real-time* applications of high accuracy positioning for engineering, machine guidance, precision agriculture, etc. This requires additional investment in communication links – between reference receivers for monitoring performance and computing network parameters, as well as with real-time users via wireless telecommunications.

A contemporary CORS network can provide a variety of positioning services for ultra high accuracy measurements for positioning to general navigation applications. Examples of services could be: Downloading of code or phase data (such as RINEX files) through WWW/FTP for post-processing;

Provision of an Automated Processing Service via the internet; Network RTK Service (phase observations); Network DGNSS Service (code observations); Transmitting raw data streams to users or other service providers using NTRIP3.

The type and level of positioning services that a CORS network could implement or adopt will largely depend on the interest, possibility, resources available to the operators as well as the demand of the market. Some operators may also enter into such services so as to offset costs associated with maintaining this type of geodetic infrastructure that is used to perform their core geo-science business. Examples of CORS networks around the world and web links that describe their services can be found in [4] and [17].

In situations whereby there are no existing ITRF based networks, and processing software is unavailable or not suitable, then there are also internet based, on-line processing services, which derive ITRF co-ordinates or positions if sufficient RINEX data has been submitted for processing. These systems will provide a position solution based on an ITRF co-ordinate system by calculating baselines from nearby GNSS reference stations of known ITRF position. These reference stations could be in another country and / or part of IGS sites. These options are not quite suitable for a local engineer who requires physical height in almost near real time. Requirement and delivery of the different online facilities vary from each other. Refer to the following web locations to find out more about such on line GNSS processing services and their requirements: *Auto Gipsy (JPL)*-service provided by JPL. (Website: http://milhouse.jpl.nasa.gov/ag/); *AUSPOS* (Geoscience Australia)-service provided by Geoscience Australia (website: http://www.ga.gov.au/geodesy/sqc/wwwgps/) ; *OPUS*-service provided by NGS, USA.(website: http://www.ngs.noaa.gov/OPUS/); *SCOUT* (*SOPAC)* - service provided by SOPAC, USA.(website: http://sopac.ucsd.edu/cgi-bin/SCOUT.cqi); *CSRS-PPP (NRCAN GSD)* - service provided by natural Resources of Canada. (Website: http://www.geod.nrcan.gc.ca/ppp_e.php).

It is important to recognise the significant contribution of the "super-network" of reference stations of the *International GNSS Service* (IGS – http://www.igs.org) to geodesy, and to the GNSS community in general. Several hundred globally distributed GPS receivers (many increasingly with GLONASS tracking capability) operate on a continuous basis, many for over ten years, contributing data to the IGS analysis centres and other users. The satellite (CPH and PR) tracking data collected have been used in progressive *realisations* of the *International Terrestrial Reference Frame* the most recent being ITRF2005. The IGS has recently launched a Real-Time Pilot Project (http://www.rtigs.net), with the following objectives [18]: Manage and maintain a global IGS real time (RT) GNSS tracking network; Enhance and improve selected IGS products; Generate new RT products; Investigate standards and formats for RT data collection, data dissemination and delivery of derived products; Monitor the integrity of IGS predicted orbits and GNSS status; Distribute observations and derived products to RT users; Encourage cooperation among RT activities, particularly in IGS densification areas. If successful, new RT IGS products will be generated on a continuous basis, to augment the current set of post-processed products. Table 1 presents accuracy and latency of IGS products.

TABLE 1
IGS PRECISE ORBIT AND CLOCK PRODUCT ACCURACY AND LATENCY

Ultra Rapid (Predicted)	Orbits	~10cm	Real time
	Clocks	~5ns	
Ultra Rapid (Estimated)	Orbits	<5cm	3hours
	Clocks	~0.2ns	
Rapid (Estimated)	Orbits	<5cm	17hours
	Clocks	0.1ns	
Final (Estimated)	Orbits	<5cm	~13days
	clocks	<0.1ns	

IV. THE NIGERIAN GNSS, CORS NETWORK AND INHERENT HEIGHT PROBLEM

GPS heighting is considered as an alternative to classical terrestrial height measuring methods in present time. From methodological point of view the determination of height using GPS is more complicated than by classical terrestrial methods. From well known reasons the GPS measures vertical component less accurately than the horizontal ones [9].

Whereas the developed countries have fully recognized and taken advantage of this technology, the developing countries like Nigeria are woefully underutilizing it to the detriment of her economic and social development. Despite the launch of a communication satellite (NigComSat-1) by the Nigerian government carrying two L-band payload for GNSS augmentation purposes, there are no good government policies towards the establishment of GNSS technology, human resource development, public and private sensitization and participation for the effective utilization of GNSS technology [19].

The importance of height determination within a global consistent reference frame is quite enormous and will be achieved on full realization of the regional reference frames known as African Geodetic Frame (AFREF), Geocentric Reference System for the Americas (SIRGAS), Reference Frame Sub-Commission for Europe (EUREF) and the European Position Determination System (EUPOS), and the Asia Pacific Regional Geodetic Project (APRGP).

In line with realization of the AFREF in Nigeria GNSS CORS are being installed in different part of the country, OSGoF (Office of the Surveyor General of the Federation), which is the National Mapping Agency of Nigeria, initiated a project to establish NIGNET (NIGerian GNSS Reference

Fig. 1. Location of Nigerian GNSS CORS Stations **[22]**

NETwork) in 2008. NIGNET will serve many different applications at national and continental levels. In fact, the first motivation to implement NIGNET was to contribute for the AFREF (African Reference Frame) project in line with the recommendation of the United Nation Economic commission of Africa (UNECA) through its Committee on Development, Information Science and Technology (CODIST). At national level, NIGNET will serve primarily as the fiducial network that will define and materialize a new reference frame based on space-geodetic techniques and linked to AFREF [20], [21], and [22]. Fig. 1 depicts the position and status of the GNSS CORS. The CORS station already installed in Zaria,Yola, Abuja, Port Harcourt, Nsukka, Lagos, Birnin Kebbi, Gembu and Toro are designed to collect continuous data which will be routed to the centre server in Abuja from where corrections for positioning and other application will be made available on request to users. The other CORS stations to be installed in Kainji, and Maiduguri are expected to be ready soon (under construction as the time of preparing this paper).

The network of the Nigerian CORS stations will enable a continuous GNSS surveying that will be computer processed at the control centre(at OSGOF, Abuja), and the obtained final results will be forwarded to the users in the field by wireless internet (GPRS/GSM). Compared to the present application of the GNSS surveying methods, the use of the Nigerian GNSS CORS will have the following advantages: - reduction of investments in the required equipment (for approx. 50%); reduction in time (at least 50%) and human resources (at least 50%) – during the surveying; while at the same time increasing the accuracy, reliability and homogeneity of the obtained surveying results; service available 24/7/365.

Height users in Nigeria who will require physically meaningful heights (orthometric heights) in the future from the Nigerian GNSS CORS network will be greatly limited by the absence of a national gravimetric geoid model and the associated uncertainties surrounding the definition of the Nigerian vertical datum [7], [23], [24], [25], and [26].

The reported a national gravimetric geoid solution for Nigeria with an accuracy of about 1m is contained in [27]. The gravimetric geoid model was generated utilizing data, from EGM96 potential coefficient model, terrestrial gravity anomaly data sourced from Bureau Gravimetrique International (BGI) and the satellite altimetry derived gravity anomalies obtained from Danish Space Centre, Denmark. Some state mapping agencies in Nigeria have developed their geoid models i.e., Lagos State. Similarly different organisations, institutions and authors have developed/proposed different forms of geoid model for different part of the country [7], [13], and [28].

V. A Conceptual Model For Physical Height Determination From GNSS-CORS In Nigeria

For the purpose of a national geoid solution we propose a refinement of the model reported by [27]; this can be accomplished by taking advantage of the recent EGM08 potential coefficient model, SRTM topographic data and finally existing GPS/levelling data in the country.

It is important that the necessary framework be put in place for future users of GNSS CORS network in Nigeria for the purpose of real time/near real time accurate orthometric height determination and other applications. In view of this fact, a model is put forward to bring together different GNSS CORS operators in Nigeria namely state mapping agencies and institution hosting GNSS CORS. It is known that about five institutions in Nigeria are hosting geodetic grade GNSS receiver for space weather study.

Fig. 2 depicts the model for CORS network management in Nigeria. The model encourages a high standard of GNSS position correction services and CORS network infrastructure sustainability. The model also supports a unification of state sponsored CORS networks and establishes the fundamental relationships between CORS network operators, data custodians, researchers, developers, data providers and data users. The model is based on cooperation, which is appropriate for a nation as geographically large as Nigeria, with 36 states, 774 local government areas and with a relatively high population of about 150 million. Combined, these statistics make CORS network establishment and service provision challenging. The model combines the coordination and standards setting capabilities of the public sector with the technical innovation, marketing and distribution capabilities of the private sector to achieve an optimum outcome for Nigerian CORS network users.

The model supports a unified CORS network; each typically coordinated, managed and operated by a government agency. Federal government CORS networks (i.e., those controlled by OSGOF) would provide a framework that would be 'in-filled' at state and Local Government Level. While it would be expected that individual networks would have features particular to a jurisdiction, multilateral agreement between jurisdictions would ensure consistency in relation to core institutional, operational, commercial and legal management requirements and arrangements.

CORS network operators would be located in spatially focussed, government agencies contributing to the national spatial agenda. Support for the Nigerian Spatial Data Infrastructure (NSDI) by strict compliance with agreed technical standards (which do exist in the country) would be a core requirement for CORS network operators. Government agencies responsible for both CORS networks and overarching spatial policy (i.e., OSGOF, NARSDA) would ensure the needs of the widest possible CORS network user base would be addressed. CORS network operators would agree to nationally consistent operational arrangements and make available standardised CORS network data for distribution. CORS network operators would also be responsible for maintaining agreed legal arrangements including privacy standards in relation to user registration data, CORS network user position and legal traceability of GPS/GNSS measurements of position.

CORS network data custodians would be located in the same government agencies as network operators and make publicly accessible, documents that set out CORS network product descriptions in a nationally consistent manner. Data custodians would be responsible for over viewing data specifications and ensuring that data quality meet the reasonable needs of users. As a key element of institutional arrangements, CORS network data custodians would provide an administrative feedback route for users in relation to data quality and supply standards. CORS data service providers (DSPs) would typically be private sector organisations taking advantage of unified CORS network coverage, providing GNSS satellite correction services to the widest possible user base. Data would be provided by CORS network operators at wholesale rates established using neutrally competitive pricing policies. Data would be gathered seamlessly across jurisdiction networks providing homogenous positioning and across Nigeria. DSPs would also be able to use their marketing and promotional capabilities in combination with published product descriptions, to reach a greater number of user segments than could be expected, if for example, state government agencies attempted to do this alone. DSPs would be licensed to distribute data and pay royalties to jurisdictions

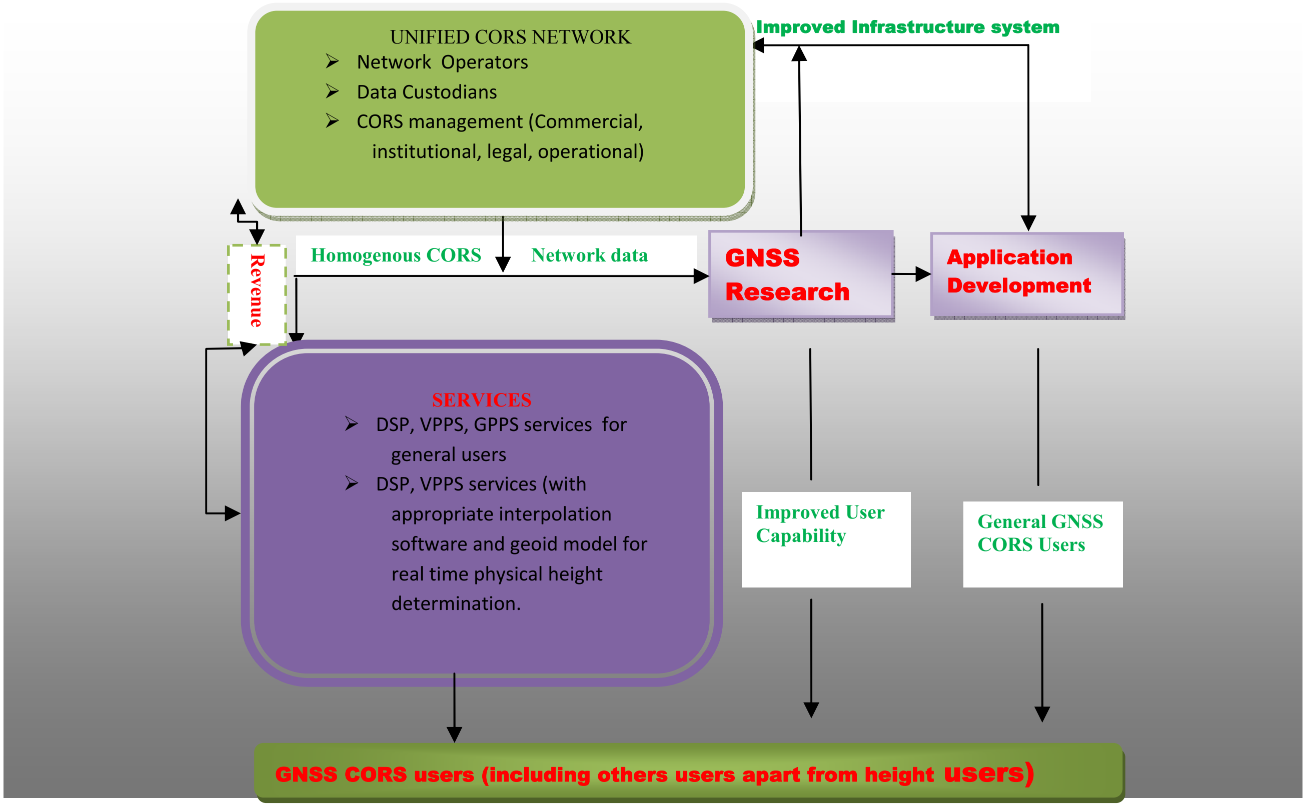

Fig. 2. GNSS CORS Network service Model

on an equitable basis that would support sustainable CORS network expansion, maintenance, and renewal. Value added resellers (VARs) would also be able to integrate CORS data with complementary services adding further value for user applications.

Commercial CORS data users would pay for services provided by DSPs and VARs according to market forces. Research organisations however could obtain CORS networkdata direct from CORS network operators without charge if applied to non-commercial research and help improve CORS network and end user systems and processes. CORS data would also be available for multimodal application development enabling new application areas to develop, and on occasion, contribute to GNSS / CORS system improvement.

The above model supports unified CORS networks, delivering high quality and nationally consistent satellite correction data to users. If used with appropriate equipment and techniques, user position measurements would be supported for legal traceability and meet position outcomes compliant with specifications detailed in product descriptions made available by CORS network data custodians. The model also supports infrastructure and service growth as users would be attracted by accessible, high quality data, offered seamlessly over significant areas of the nation. Examples exist of unified, government sponsored, CORS networks that span member jurisdictions that are technically consistent, and adopt an agreed mode of management. For example the unified German national network of 250 CORS generates the SAPOS (www.sapos.de/pdf/Flyer/2004Heft_e.pdf) suite of GPS correction services including NRTK with 1 to 2 cm horizontal accuracy known as the High Precision Real Time Positioning Service. SAPOS is the required method of conducting official cadastral surveys in all German jurisdictions. SAPOS demonstrates how federated states can combine CORS networks to achieve a national outcome. Another example of broad scale, multi-jurisdictional CORS infrastructure are the National and Cooperative CORS networks located in the United States of America, coordinated by the National Geodetic Survey (NGS). The NGS CORS (www.ngs.noaa.gov/CORS/corsdata.html) is managed in accordance with published criteria.

VI. CONCLUSION

This paper has discussed the current trends in GNSS based height determination and provided a frame work for GNSS height determination for engineering and topographic applications in Nigeria. A recommendation was also made to refine the Nigerian gravimetric geoid model using available state- of –the-art earth global data (i.e., EGM08 potential model, SRTM topography) as well as local GNSS and levelling data. Since it is obvious that the Nigerian Height Datum (NHD) will not be revised in the foreseeable future, it will be necessary to warp the proposed refined gravimetric geoid solution to fit the Nigerian Height Datum, this will produce a geoid type model that allows for the direct transformation of GNSS heights to NHD, provided that good quality GNSS-NHD data have been used in its construction. Discussions on the shortcomings of the NHD were deliberately omitted in this paper; these issues should dominate future symposia on modernizing the NHD.

A major area of interest in the future of GNSS height determination in Nigeria will be in production of documents recommending specifications and guidelines for GNSS operation in the country and encouraging researches aimed at modelling associated errors based on the configuration of the future referential network of the country and accuracy of adopted geoid model(s). Also, issues of GNSS augmentation systems (ground based transmission systems such as geosynchronous satellite), comprehensive integrated GNSS CORS network and data distribution technologies should dominate discussions on the future general GNSS CORS applications in Nigeria.

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