Framework for the Establishment of a Nationwide Network of Global Navigation Satellite System (GNSS) – A Cost Effective Tool for Land Development in Ghana

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Key words: Geocentric, Reference station, Geoid, Ellipsoid

SUMMARY

Until now most surveyors in Ghana like in other developing countries have been underutilizing GNSS not only because of the perceived high cost and complexity of the GNSS equipment and its infrastructure but are also skeptical about the accuracies of their output. This perception continues to widen the gap between the developed and the developing countries as far as effective land utilization and management are concerned. To remove this perception, methods like differential corrections, area corrections and others should be employed. This requires the development of some basic GNSS infrastructure which can reduce the distance dependent errors. The establishment of a nationwide Network of GNSS Reference Stations has therefore been outlined where any user will be at most 100km from an active reference station and the establishment of passive stations as controls. This paper highlights the need to adopt the use of the geocentric ITRF reference system as a national reference system instead of the previous datum established through classical geodesy. The need to re-establish an IGS station in Ghana and the modelling of a national Geoid have been discussed and details explained. The equipment need, data handling and distribution and monument building has also been given.

Land use and natural resource management which plays an important role in Ghana development is based on effective surveying in mapping, and with the recent intense pressure on the land agencies like the Survey Department, Lands Commission, Land Title Registry and others, now is the time to pull all resources together to come out with a solution to the national land delivery process and this space technology is the answer. To be able to advance in the development of GNSS infrastructure and applications in the country, the authors highlight the need to form a GNSS Research Group.

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1. INTRODUCTION

Global Navigation Satellite System (GNSS) is one of the most useful gifts that science and technology has offered mankind due to its global coverage and free access. Whereas the developed world is advantageously utilizing it, most developing countries are woefully underutilizing it to the detriment of their economic and social developments.

With respect to GNSS, countries can be categorized into three groups, those countries that own the satellite vehicles that generate the signals in space which includes the United States of America, with their Global Positioning System, Russia with their GLONASS and the European Union with their yet to be commissioned Galileo. The second group is made up of countries that have developed various augmentation systems that improve the signals from the navigation satellites; these include Japan with the MSAS and QZSS, Australia with GRAS, India with GAGAN and a few others. The third group includes countries that are yet to develop any sophisticated augmentation system; at best signals are improved by local area augmentation systems. Countries in this group are characterized by lack of GNSS infrastructure, expertise, and motivation to adopt this technology. It is in this group that Ghana and most developing countries find themselves. The gap between the third group and the rest has been widening, and to bridge this gap there is the need for the institution of good governments policies towards the establishment of this GNSS technology, human resource development, public and private sensitization and participation for the effective utilization of this technology.

Most people including some professionals until recently were skeptical with the use of GNSS especially in the field of surveying due to the perceived inaccuracies, probably due to the then selective availability and other errors that were associated with the GPS. With the modernization of GPS satellite, the increased number of the satellite vehicles, tremendous improvement of the GNSS receiver technology, advances made in the software development as well as the accuracies in satellite orbit broadcast, there is a very reliable level of accuracy as far as the requirements for most applications in these countries are concerned. The next decade even promises a greatly improved performance with the arrival of the European Galileo, as well as the improvement of GLONASS which in the recent past is showing a recovery after a downward trend in some years past (Rizos C et al).

With the bright and promising future of GNSS, now is the time for Ghana as a nation to look into how this technology can be used to the benefit of its people in their quest for sustainable development. Establishing a network of GNSS reference station will be a great contribution to the use of this space technology for both Geodesy and Navigation, and more so as the nation is promoting land administration as a priority in its developmental goals.

2. GNSS APPLICATIONS IN GHANA

Currently the use of GPS in Ghana is limited to cadastral mapping which has just started and GIS data collection which is yet to be well organized nationwide. Applications in engineering have also started especially in the road engineering sector where there have been a few projects in which GPS survey was used to provide controls along the road corridors, for example the Accra-Kumasi Road Project and the Kumasi Outer Ring Road Survey Project. A few organizations like Center for Remote Sensing and Geographic Information Service (CERSGIS), Geotech Systems and Building and Road Research Insitute (BRRI) have set up passive base stations which are used as and when differential corrections are needed for particular projects. The Survey Department of Ghana also uses this technology for cadastral works but usually establish a base station within 20km from the area of survey (Ofori-Boadu, 2005). Other organizations in the road industry, forestry, health and others have been using the GPS, ranging from hand-held receivers to dual frequency geodetic receivers.

There is a great potential of the GNSS application in Ghana, among these are applications in land surveying which will basically include, geodetic control, and topographical, cadastral, hydrographical and mining surveys. Engineering Surveying will among others include, route survey, deformation studies. GIS and mapping applications will include utility distribution networks, environmental planning and assessment, urban inventory and municipal planning, forestry and others. Navigation applications will cover Pseudo-range Based DGPS Navigation like fleet management, Emergency services, mass transport and traffic guidance as well as Precise Navigation which may include machine control and others. Ghana being agro-based country may benefit from the application of GPS for precision farming, but this can be achieved only when mechanized farming is practiced.

Other applications that can be looked into are the use of GPS in meteorology, timing and exploration. With its passage through the atmosphere, GPS signals are able to provide information for meteorology. Integrating GPS to airborne gravimetric measurement will speed up the exploration activities in Ghana. With the synchronization of the time in GPS with the atomic clocks in the GPS satellites, very precise timing can be obtained for all timing applications in the country.

A very important application Ghana urgently needs is the application of GPS in Earthquake studies. Accra the capital is a heavily faulted metropolis, there are two main geological faults interspersed with other relatively minor faults around the metropolis. The 67 years silence of this fault has been very worrying to the experts, who predicted an occurrence before the arrival of the millennium (Amponsah, 2002; Andam, 2004). The most recent scare was the tremor of 3.7 on the Richter Scale that was experienced on the 12th January 2006. Although it did not cause any significant damage, it serves as a reminder to the need for commitment to the scientific investigations into earthquakes in Ghana. GPS provides a unique opportunity to measure ongoing earth processes in diverse ways and the Geological Survey Department can utilize it to give early warning signals of possible occurrence to arrest the fear of Ghana sitting on a time bomb.

The integrity requirement of the Ghanaian applications as at now is relatively low. Over 90% of the envisaged applications in Ghana will be satisfied by an integrity risk/hour of $1x10^{-4}$. With the introduction of more navigation applications like harbour docking, ambulance service, fleet management, machine guidance and control, the integrity requirements will have to increase. The accuracy requirements range from the order of sub-centimeter for crustal movement investigation, other scientific researches and control survey to over 10 meters for fleet management and other navigation applications.

3. GHANA'S GEODETIC REFERENCE SYSTEM

A local geodetic reference system is defined as a system for the determination of longitudes and latitudes based on an origin whose longitude and latitude are determined by astronomical observation and based on a chosen ellipsoid. These are prone to errors which may run into several hundreds of meters due to vertical deflection that affects the results of astronomical observation carried out at the origin (Matsumura S et al, 200).

Ghana's Geodetic Reference Survey started in June 1904 by the Governor of the then Gold Coast, G. Guggisberg, who made observation for latitude from a pillar in Accra with a zenith telescope, to fifteen pairs of stars giving the final probable error of 0,360″ (Mugnier C J, 2000). According to Mugnier, the longitude was also observed in November and December of the same year by exchanging telegraphic signals with Cape Town in South Africa. These formed the Accra Datum which has been adopted as the basic longitude and latitude for the country. The coordinates from both triangulation and traversing were computed using the Transverse Mercator projection system and heights were measured with aneroid barometer. The Accra Datum is based on the War Office 1924 ellipsoid with semi-major axis of 6378300.58m and flattening of 296. A second datum which is running alongside the Accra Datum is the Legon Datum, based on the Clark 1880 with semi-major axis of 6378249.145m and flattening of 293.465. The Legon Datum is also based on the Transverse Mercator projection and was in use after 1977 (Graham T et al, 2000)

The Ghana framework diagram of Geodetic Network, based on the Accra Datum, shows a network made of primary and secondary triangulation, primary, secondary and tertiary traverses and precise levels. The mountainous portion in the southern half is covered with triangulation points with baselines up to a maximum of about 55 miles and is controlled by three measured bases. These are supplemented with secondary traverses and primary levels. The northern part of Ghana which is relatively flat is controlled with primary secondary and tertiary traverses and primary and secondary levels. The vertical control is now referenced from two reference tidal gauges in Tema near Accra and Takoradi

Problems in the existing framework include large number of destroyed beacons and the sparse distribution of pillars especially in the northern half of the country.

4. SOME LIMITATION OF THE EXISTING REFERENCE DATUM

- Inaccuracies
- According to (Mugnier C J, 2000) the basic longitude and latitude for the country was found not to be very accurate and later works proved that the Accra measurement was influenced by local attraction. Work done by (Graham T et al, 2000), in Kumasi 200 km from Accra also shows an error of less than 1 meter in easting but more than 20 meters in northing.
- Support for precise scientific investigation
- The datum does not support precise scientific investigations which have a velocity component like tectonic activities.
- Difficulties in the determination of Transformation Parameters
  Ghana is yet to come out with workable transformation parameters for the whole country. The position and orientation relations of the Accra datum to the WGS84 Datum are not generally available (Graham T et al, 2000). This may be due to the concurrent use of the Legon Datum alongside the Accra Datum which makes transformation difficult when mixed up

5. GEOCENTRIC REFERENCE SYSTEM

Geocentric Reference System is a geodetic system for the determination of a geometric position. The origin is the center of mass of the earth, with its Z-axis along the assumed rotation of the earth, its X-axis along the prime meridian direction and the Y-axis adds up to form a right-hand Cartesian coordinate system which is a globally common standard for positioning. The classic geodetic reference systems like the War Office 1924 and Clarke 1880 which are being used by Ghana have started giving way to the newer versions which utilize technologies like Very Long Baseline Interferometry (VLBI), Lunar Laser Ranging (LLR), Satellite Laser Ranging (SLR) and Global Positioning System (GPS) for the achievement of very accurate centre of mass of the earth, rotation axis of the earth and other relevant parameters.

5.1. ITRF as a National Reference System

The International Terrestrial Reference Frame (ITRF) was formed from the contributions of space geodetic solutions for global set of coordinates and velocities combined. This frame specifies how its origin, orientation, scale and their time evolutions are materialized. It has the center of mass of the earth as its geo-center. Its defining parameters are implicitly defined by the combination of worldwide tracking sites of VLBI, SLR, DORIS and GPS involved in the IERS global solutions.

Although the coordinate frame of the WGS84 is accessible through broadcast and precise ephemeredes there is an advantage of using the ITRF due to the associated velocity at each station which indicates its time-dependent absolute displacement associated with movements in the earths crust. The ITRF has undergone improvements; with only 13 fiducial GPS stations collocated with SLR or VLBI used for the coordinates taken from ITRF92, ITRF93, and ITRF94 successively, the limited distribution and availability, and performance of the fiducial network was improved by 1997. With the introduction of ITRF96 in March 1998, the set of fixed fiducials was greatly expanded and improved to 47 sites, and later to 51with ITRF97 on 1 August 1999. The current ITRF2000 orientation time evolution is believed to satisfy the no-net-rotation (NNR) conditions at about 2 mm/yr level or better. (Ray, J et al, 2005).

The improvement in the ITRF has made it nowadays identical to the WGS-84 and in future, to the Galileo Terrestrial Reference Frame (GTRF). It is therefore advantageous to make it a national reference frame, to make the use of GNSS easier in Ghana. The adoption of this geocentric system will satisfy international requirements like ICAO, IHO, and AFREF etc. It will also help in scientific research as it is based on modern geodesy and astronomy. It will be easier to maintain this reference system using GNSS.

The adoption of a new geodetic system will require the need to transform the existing data into the new system. This then calls for the determination of transformation parameters between the systems. There should be a good number of well distributed control pillars that will be used as common points. The ellipsoid for these 'common points' should be known as there is the danger to mix up those of the War Office 1924 and Clarke 1880. The local geoid should be determined at these selected common points.

5.2. World Geodetic System 1984 (WGS84)

The WGS84 is conceptually similar to ITRF but differs in the realization. It was realized based on Doppler observations from TRANSIT satellites. With initial accuracy of 1-2 m it has undergone improvements to a level of a few centimeters over the years. This is the system used by the Global Positioning System and for most application this is identical with ITRF.

6. DRIVERS FOR A NETWORK OF REFERENCE STATIONS IN GHANA.

The need for a network of Active GNSS Reference Stations cannot be overemphasized in our quest as a nation for sustainable development. The benefit has always proved to outweigh the cost if systematically implemented. The listed factors are only part of the motivational drivers for the establishment of a national network.

- To remove the distortion in the current mapping system
- Encourage the use of GNSS throughout the country
- Provide differential corrections within reasonable base-lengths
- Speed up the land delivery process throughout the country
- Reduce the cost of Surveying and Mapping
- Facilitate the use of international systems
- Simplify the management of spatial data
- Enhance the scientific investigation in earthquake activities in Ghana
- Monitor the deformation of our civil structures
- Fulfill the requirements towards the realization of AFREF(Kanamia M, 2004)
- Form the basis for the development of RTK products

- Contribute to navigation system in Ghana
- Utilize the network for the acquisition of meteorological data

7. NETWORK OF REFERENCE STATIONS

The Network of reference stations should be made up of four categories, a Fundamental Station, the Regional Reference Station, the Hub Stations and the Passive Reference Stations.

7.1 Ghana Fundamental Point

The Ghana Fundamental Point is supposed to be an accurately positioned geocentric station geodetically tied to IGS and ITRF. This will be used to control the network in Ghana and shall be linked to the proposed AFREF. This should be in Kumasi which is farther away from the seismically active areas of the Ghana and is also centrally placed (see fig 3). With the presence of the Geomatics Engineering Department of the KNUST the Regional Survey Department and other research institutions this facility can be maintained. The Kumasi site can be developed into an IGS station and can be linked to other stations on the African Tectonic plate.

7.2. Network of Reference Stations

The Survey Department of Ghana which controls the survey and mapping activities has branches in all the ten regions in Ghana. With the human resources and physical infrastructure, an active base station can be set in all these regions. Assuming that every point in the country is to be less than or equal to 100 km from an active reference station then more than 70% of the country will be satisfied under this set up. Five regions including the Greater Accra, Eastern, Central, Upper East and Upper East Regions will fully covered. The selection of the 100 km radius coverage was chosen as a result of a field trial covering the Golden Triangle in which centimeter accuracies could be obtained over baselines of 200km. See fig1

To obtain 100% coverage of base-length of 100 km over the entire country there must be additional five hub stations established. These may be located in Wiawso in the Western Region, Kete Krachi in the Volta Region, Yendi and Bamboi in the Northern Region and Atebubu in the Brong Ahafo Region. See fig 2

The number of stations in the network of reference stations must be increased with Passive Reference Stations and this will act as control points for survey activities in the country. These have been selected in this framework to cover the whole country, and are well distributed to make it easy for users as reference pillars. These will also be used as ‘common points’ for transformation into other systems should the need arise. Their periodic occupation would check the stability of the system. These must be controlled from the Regional Data Centers and must be submitted to the National Data Center for nationwide spatial analysis.

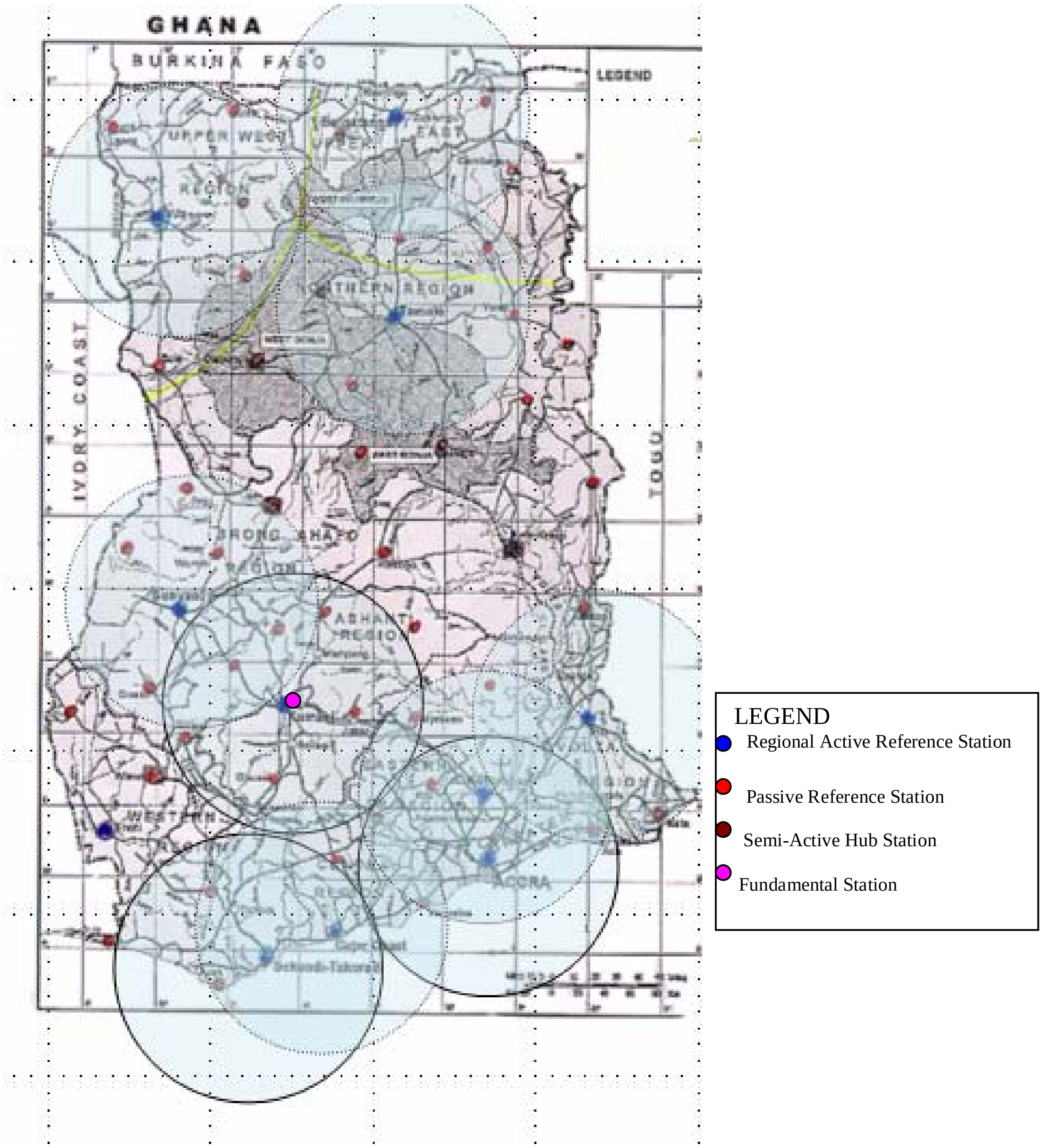

Fig 1 showing 100km coverage of active reference stations in the existing Regional offices of the Survey Department

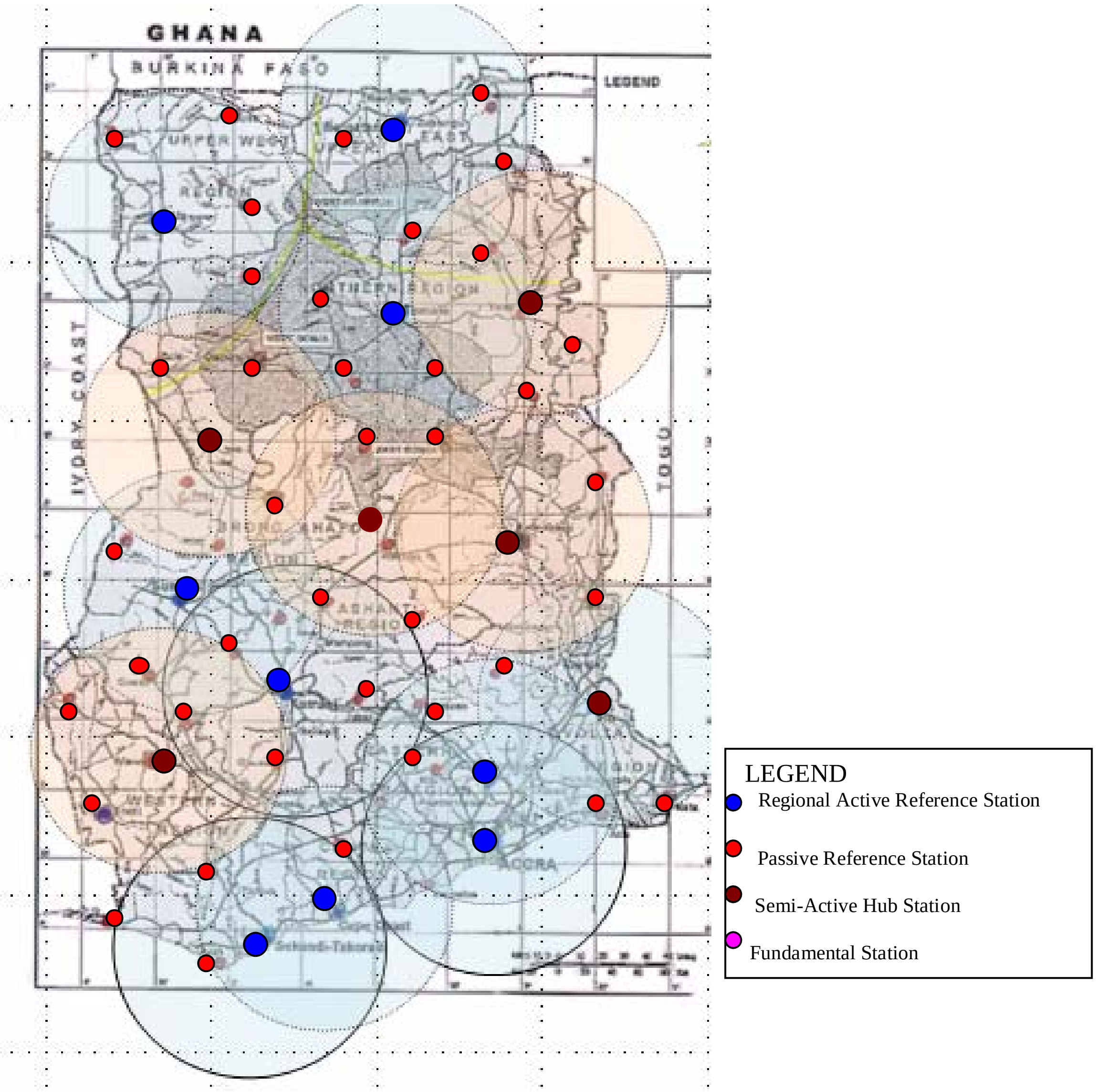

Fig 2 showing nationwide coverage of 100 km base-length with additional five hub stations to the existing ten Regional Active Reference Stations

7.3 Requirements for GPS Base Station

The establishment of a base station requires knowledge in GNSS software, hardware configuration, site configuration and data handling

The hardware includes the GNSS receiver, antenna, peripherals like UPS, communication equipment, and computer systems. The receiver should be at least a dual frequency type, capable of tracking and recording all components of the GNSS signal. The data recording rate should be 1 second or better and should be able to track a large number of satellites especially as Galileo will be operational soon. The receiver must use both internal battery and external power supply with uninterrupted power supply. This power problem is one of the main obstacles as far as Ghana is concerned and future research direction should be towards the use of solar power. The antenna should be a high precision one that can able to track L1 and L2 frequencies and must be designed to minimize multipath degradation e.g. choke-ring antennas.

The communication system for now should be through the internet as Ghana is now developing these ICT facilities. This system will require (ftp) for data transfer. On the other hand dedicated high speed telephone lines as well as modems can be used. For real-time data broadcast, GSM, FM and other radio bands could be used.

The required software will depend on the activity at the station, for example the fundamental station will require scientific software like GAMIT, Bernese and TEQC, while the other active Reference Stations may need a network and navigation software which should be capable of processing data from various brands of GNSS receivers.

7.4 Accommodation and Monuments

7.4.1 Accommodation

One of the important issues in the establishment of GNSS reference network is security of the equipment from vandalism and exposure to unwanted visitors. The Regional Survey Department offices could be used as the Data Centers where GNSS data could be processed and stored and distributed. Office accommodation should be made available a Research Center and a National Data Center preferably in Kumasi from where links could be made to other IGS stations. The semi-active stations which could be located at Yendi, Bamboi, Atebubu, Sefwi-Wiawso and Kete-Krachi, which are all district capitals, will also require office accommodation. These office accommodation should be sufficiently close to the monuments as the cable linking the antenna and the receiver should not be more than 30m. If this specification cannot be met then there should be an amplification of the signal in the cable.

7.4.2 Monuments

There are five sets of monuments for the network; these are at the fiducial point or the Stations, the Passive Reference Stations and the User Densification Stations.

The Fundamental station should comply with the requirements of IGS stations as it should have a high value to long-term geodetic service. It should have the following (JPL/Caltech, 2004; IGS Site Guidelines, IGS Central Bureau)

- Located on a regional crystal block, away from active faults or other sources of deformation, subsidence etc.
- Be on a firm, stable material
- Have a clear horizon with minimum obscuration

- Should not have excessive radio interference
- Should not be near RF reflective surfaces
- Should not be close to excessive vibrations
- A minimum of three footprint monuments to be located 10 to 15 km away (roughly in triangle pattern) to help in detecting ground movements in the neighborhood.

The monuments for the Regional Active Reference Stations and the Semi-Active Hub Stations should be like the fundamental station but not as strict, as they may not require any set of stations to check their integrity. At the hub stations the antenna should be permanently installed despite the fact that it may not be used continuously. The passive station will not require permanent installation of the antenna but will be set when reading is to be taken but like the others should have a stable monument. These stations will have to be occupied periodically to check its consistency with the geocentric datum which changes with time. The User Densification Station pillars must easily accessible by the user community and must be increased by the Regional Survey Department. These should be preferably on the ground unlike the usual rooftops for the others.

8 DATA HANDLING

Data generated by GNSS receivers is very huge especially the continuously operating ones, thus making the handling an important issue. With the modern high capacity computer systems large amounts of data can be stored. Despite this the system can be programmed such that data stored for a specified period can be deleted. It will therefore require that the data is copied and archived. Managers of the active stations must be responsible for the data formatting, distribution, archiving as well as quality control. All the data at the Regional Data Centers must be sent to a Central Data Center for analysis. This can be used to monitor the positional stability of the stations in the entire network. Daily data processing and plotting will also show the stability of the station.

In order to facilitate the processing of all brands of receivers, the receiver independent exchange format (RINEX) must be used. A system can be designed such that all users can access the data at a website or data can be stored on diskettes or compact discs for users. The centers should offer data processing services on request.

9 VERTICAL POSITIONING

Height measured from GPS is ellipsoidal height which, is defined as the distance between the measured point and the reference ellipsoid along the normal line on the ellipsoid. It is a geometric quantity while normal optometric height is a quantity based on gravity potential. The Geoids is defined as the equipotent surface of gravity that is coincident with the mean sea level. The difference between the ellipsoidal height and the corresponding genocidal height gives the optometric height. The accuracy that can be achieved at a point depends on the accuracy of the local geoids and the GPS ellipsoidal heights. The genocidal undulation is therefore a very important parameter that must be modeled for the maximum benefit of GNSS to be derived as far as leveling is concerned.

10. MANAGEMENT OF GNSS IN GHANA

A successful implementation of GNSS Reference Station Network in Ghana will require the involvement of various public and private institutions especially those that form the part of the user community. Institution like the Ghana Institution of Surveyors with their human resource capacity and the Geomatics Department of the KNUST with their experience gained from running an IGS station, in a collaborative research with the Bavaria Academy of Science will be beneficial. Research institutions like BRRI can share their experience in the use of GNSS in Traffic and Transportation, and CERSGIS which has been using GNSS in GIS application can play important roles. Private Companies like Geodic Systems can share their experience in the running of their passive base station and others. All these activities in the implementation will then be coordinated by the Survey Department of Ghana.

11. FORMATION OF A GNSS RESEARCH AND DEVELOPMENT GROUP

For GNSS to be sustained in Ghana there is the need to form a National GNSS Research Group that will research into problems pertaining especially to Ghana like the problem of the high ionosphere scintillation, solar effects, electromagnetic storm, and troposphere effects in low latitude regions. The research into the determination of a National Geoids, and other research and training activities in the country must be carried out by the GNSS Group. This group will be responsible for the general development of GNSS infrastructure and applications in Ghana.

12. CONCLUSION

The establishment of a modern mapping system is long overdue in Ghana and efforts are expected from all professionals in support of the Survey Department on Ghana, which is in charge of surveying and mapping in the country. The use of GNSS has been found to be appropriate to the development of Ghana but since cannot be used effectively with the current reference datum it is necessary to adopt the ITRF which has been found to be accurate and identical to WGS84 which is used by GPS and also GTRF which will in the near future compliment the services of GPS. This will put Ghana in the best frame to welcome the African Reference Frame which is in the process of providing a regional reference frame for the development the African continent. The establishment will not only encourage the use of this space technology which in the very near future will become indispensable in human life, but will help in solving the problem of land delivery in the country which is the backbone of our national development.

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BIOGRAPHICAL NOTES

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