GSJ: Volume 8, Issue 1, January 2020
ISSN 2320-9186



# Modelling of Multipath Errors from GNSS Observations in Urban Environment of South East, Nigeria

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## ABSTRACT

In the context of reliability, the general approach to satisfy some level of navigation integrity is to detect and exclude (or de-weight) distorted measurements when exclusion does not degrade measurement geometry significantly. In this way, Signal Quality Monitoring (SQM) techniques were developed to detect GNSS multipath distortions by incorporating monitoring correlators at the tracking level. References incorporated different early-late correlators to define symmetric and asymmetric delta and ratio metrics to detect multipath distortions in the tracking correlation peaks. References investigated an asymmetry test statistic called the Slope Asymmetry Metric (SAM) to evaluate signal quality in the presence of multipath. SAM compares the left and right slopes of the correlation curve and provides the receiver with timely alarms when one slope is steeper than the other as a result of multipath. References exploited the Carrier-to-Noise-density ratio ($C/N_0$) as a quality metric to weight GNSS measurements and improve positioning performance in multipath environments. Beside $C/N_0$, investigated a multipath detection approach using SAM and the DLL discriminator output to monitor the correlation peak quality. The correlator output samples are evaluated and integrity warning is set when the SQM metrics deviate from their nominal values. Based on a multi-correlator structure, a signal quality index was developed at the tracking level to evaluate the quality of GNSS signals and improve the performance of Receiver Autonomous Integrity Monitoring (RAIM) modules under multipath scenarios.

**Keywords**: Static position, Dynamic position, multipath, code-minus-carrier (phase).

## Introduction

Despite the common use of SQM metrics, their sensitivity and effectiveness in detecting multipath have not been fully characterized. It has been shown that multipath affects SQM metric statistics (e.g., mean and variance) by distorting the correlation peak but there is no analytical discussion about how sensitive different SQM metrics are under different multipath scenarios. It has also been discussed that SQM-based monitoring results can be exploited for reducing the effect of multipath through de-weighting or excluding affected measurements but there are few investigations on how effective SQM metrics can be for multipath mitigation with respect to different tracking and signaling strategies.

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This research based on a characterization and performance evaluation of SQM techniques under different multipath scenarios. After modeling the received GNSS signals in the output of tracking correlators, monitoring correlators are defined based on their relative code delays from the reference tracking correlators. Different SQM metrics were defined. Prior to setting an appropriate detection threshold, the statistical properties of the SQM metrics was investigated. The analytical discussion includes Binary Phase-shift keying (BPSK) and Binary Offset Carrier (BOC) modulations as the base schemes used for GPS and Galileo. For instance, BPSK(1) is the operational scheme used in GPS L1 C/A signaling. BOC is also considered as the base scheme for Galileo and modernized GPS signals. Different implementations of BOC signaling (e.g., multiplexed BOC or MBOC) are also considered as the common baseline for Galileo and modernized GPS. In this context, analysis of the basic BPSK and BOC signals is of interest. SQM metric variation profiles are proposed as a function of multipath relative delay and power. SQM metric effectiveness and sensitivity are then defined based on multipath range error envelopes and the proposed SQM profiles. These results are accompanied with an analytical discussion to evaluate SQM performance under different multipath scenarios. Two different correlator strategies, namely "Narrow Correlator" (NC) and "High Resolution Correlator" (HRC), are considered. These methods are commonly used in many receivers to mitigate multipath. Real data analysis is performed to validate the proposed SQM variation profiles and examine SQM detection performance for real static and kinematic multipath scenarios.

## THE STUDY AREA

South East of Nigeria was chosen area for the study which comprises five states but Awka is the major area of interest; Awka Capital Territory is located in Anambra State, South Eastern Nigeria (See Fig. 1 and 2). It is located between latitude $6^{o}$ 5' N and $6^{o}$ 15' N and longitudes $7^{o}$ 0' E and $7^{o}$ 5' E (see Fig 2). Awka capital territory covers a land mass of 400 square kilometres and comprises of six local government areas namely Anaocha, Awka North, Awka South, Dunukofia, Njikoka and Orumba North, in part or full (UNHABITAT, 2009).

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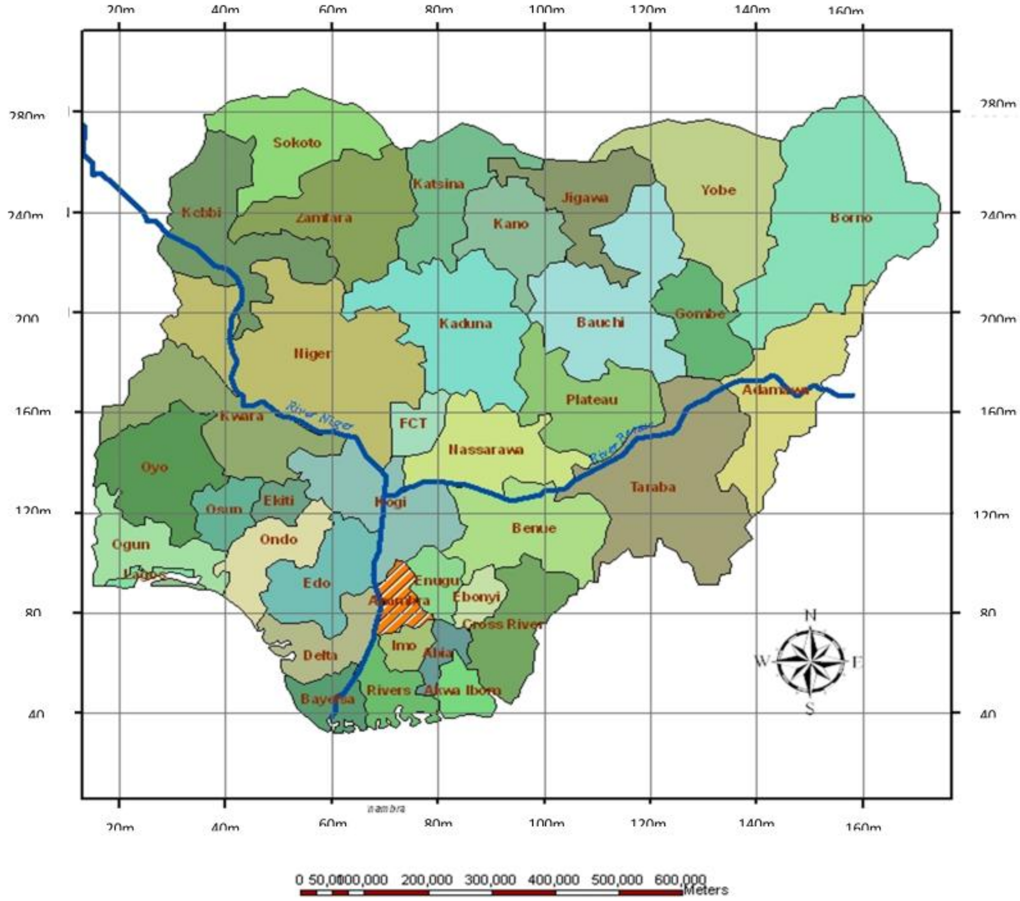


*Fig. 1: Map of Nigeria*

Source: Department of Surveying and Geoinformatics Unizik, Awka

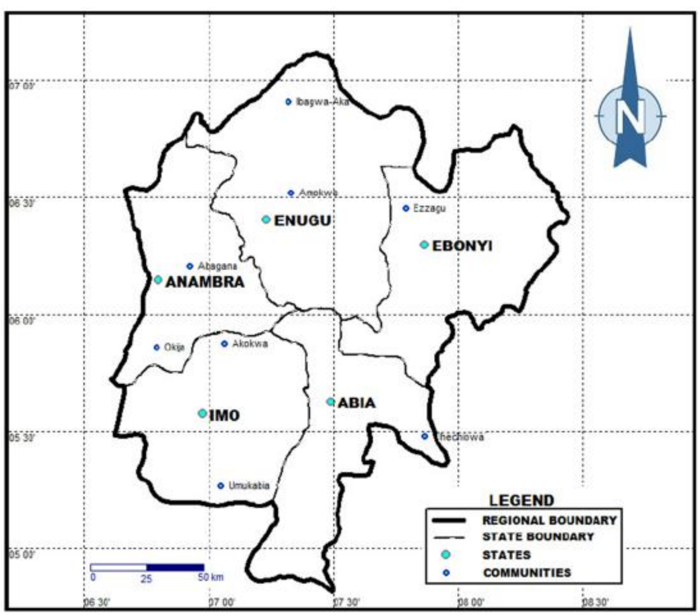


**Fig. 2***Map of South East of Nigeria*

Source: Ministry of Lands Awka

***Fig.3: picture of built-up area, Awka***

The study area is predominantly a low lying region on the western plain of the Mamu River with almost all parts at 333 meters above sea level. The major topographic feature in the region is two celestas (asymmetric ridges) with east facing escarpments each trending southward outside Awka urban to form part of Awka-Orlu upland. The higher one is the Abagana-Agulu cuesta. In a section of Agulu, the land rises above 333 meters or (1000ft) above mean sea level outside Awka urban but within the study area (UN-HABITAT, 2009).

Awka Territory has witnessed one of the fastest population growths in the state. The annual growth rates witnessed in the area for the past sixteen years vary from 2.20% per annum for Orumba North to 6.47% per annum for Njikoka. The average rate of growth per annum for the area is 2.62% per annum. Both Awka North with its figure of 5.34% and Njikoka recording6.47% are experiencing faster population growth rates when compared to the other LGAs in Anambra State (UN-HABITAT, 2009).

According to the 2006 census, the population of the six local Government Areas that make up the Awka Capital Territory is 1,002, 911, with an average annual growth of 3.17% per annum recorded during the past sixteen years (UN-HABITAT, 2009).



The study area has rainforest vegetation with two seasonal climatic conditions. They are the rainy season and the dry season. The dry season also has a period called harmattan. The dryness of the climate tends to be discomforting during the hot period of February to May (UNHABITAT, 2009), while the wet period between June and September is very cold. The harmattan which falls within December and February is a period of very cold weather when the atmosphere is generally dry with mist (UN-HABITAT, 2009). Awka Capital Territory is characterized by the annual double maxima of rainfall with a slight drop in either July or August known as dry spell or (August break). The annual total rainfall is above 1.450mm concentrated mainly in eight months of the year with few months of relative drought. Climatologically records since 1978, show that ACT has a mean annual rainfall of about 1,524mm (UNHABITAT, 2009). ACT has mean daily temperature of 270C, with daily minimum temperature of 180C. Annual minimum and maximum temperature ranges ace about 220C and 240C respectively. It has a relative humidity of 80% at dawn (UN-HABITAT, 2009).

The two geologic formations underlying Awka Capital Territory are the Imo Shale and Ameki Formation (UN-HABITAT, 2009). In the riverine and low-lying area particularly the plain west of Mamu River as far as to the land beyond the permanent site of Nnamdi Azikiwe University, the underlying impervious clay shales cause water logging of the soil during rainy season. The soil sustaining forest vegetation on the low plains farther away from the river maintains a good vegetation cover. The soil is rich and good for root tuber crops like yam, cassava and maize. The two main types of soil found in the area are ferruginous and hydromorphic soil. Ferruginous soil is rich in iron and is derived from marine complexes of sandstone, clay and shales. They therefore vary from the deep red and brown porous soil derived from sandstones and shales to deep porous brown soil derived from sandstone and clay (UN-HABITAT, 2009).

Awka Capital Territory falls under the low-land rainforest vegetation zone. It comprises tall trees with thick undergrowth and numerous climbers (UN-HABITAT, 2009). This has been reduced by human activities to a secondary plant cover so much so that large parts of the rain forest zone may be termed an oil palm bush' from accumulation of oil palms. The soil sustains forest vegetation but on the low plain further away from the rivers. The typical trees found in Awka Capital Territory are palm trees, raffia palm, iroko trees, oil bear trees and gravelina trees. Oil palm trees and raffia palm are the most common and they are not deciduous in nature, (UNHABITAT, 2009).

Awka Capital Territory covers 10 km radius, which is rapidly developing into a mass of urban areas growing to merge with each other. The areas not built upon have been due to certain natural barriers for development such as several water/flood courses, erosion sites, ravines, deep valleys, shrines, religious forests and traditional sites (UN-HABITAT, 2009).

Land uses and urban forms of especially in Awka urban are slightly different, exhibiting the dual character deriving from its two major components: The first is a new town grafted onto the old city and separated by the Enugu-Onitsha expressway. The older part reflects the urban elements peculiar to traditional Igbo settlement, with a palace and market square at the centre, providing ample open spaces for recreation, religious, economic and socio-cultural activities (UNHABITAT, 2009). The residential areas in Awka Capital Territory are made up of individual family residential compounds, which are walled and linked with pathways and un-tarred roads providing access to the people. Housing is very dominant, but uses here are very mixed as commercial activities, informal activities are carried out within the curtillages of buildings, with every inch of space around the homes, for air circulation and ventilation almost built up (UN-HABITAT, 2009).

Awka in Awka Capital Territory is the administrative headquarters of Anambra State. Civil servants both State and Federal thus live and work here (UN-HABITAT, 2009). The Nnamdi Azikiwe University, St. Paul's University and National Open University are three tertiary educational institutions located in Awka Capital Territory (UN-HABITAT, 2009). Education and administration are thus significant sources of employment in the territory (UN-HABITAT,2009). Contribution of industry and agriculture to the economy of the Territory is equally high. Self-employment is quite common and at 58% it is quite high. 50% of the self-employed belong to the informal sector (UN-HABITAT, 2009). The informal sector, mainly petty traders, blacksmiths, roadside mechanics and others are very dominant and visible in the landscape (UNHABITAT, 2009).

The quality of results obtained from many surveying and location based applications is dependent upon accurate position determination using GNSS receivers. A lack of available signals, particularly in urban canyons, means that position determination in certain locations is impossible during certain periods throughout each day (Taylor et al., 2005). When most available signals originating from the satellites are in the same vertical plane through sky, a poor DOP figure result, and it is the case in urban environment. Thus increment in satellite availability is unlikely to solve this problem. The signals received from propagation paths other than LOS, results in incorrect position determination that can be of the order of tens of meters (Yang et al., 2004) depending on the type of receiver. Therefore having the knowledge of the location and time where high/low quality satellite signals and its availability will be received, could be a strong input for decision making during GNSS surveys. Not only it will lead to short occupation time during survey but also gives user a choice of having better locations as user can plan the time of survey based upon signal quality and availability prediction.

Dynamic positioning also suffers the same problems as are with static positioning. For this purpose, mobile equipment with integrated GNSS receiver is used as in personal digital assistant (PDAs) with inbuilt navigation. Positioning in a mobile object, the magnitude of multipath error will be more as the range measurement will vary rapidly. Similarly, the satellite availability for dynamic positioning tends to change rapidly because of the relative motion between user and the surroundings. The applications using dynamic positioning operating in urban environment are generally used at ground level only where the interaction of satellite signals with the surroundings is highest. The use of inertial navigation system (INS) and map-matching resolves the difficulty of availability partially. Signal integrity is affected by frequent loss of lock in dynamic positioning. Therefore the essence of this research is to model multipath error and for improved GNSS surveying measurement results.

Multipath is the phenomena whereby a signal arrives at a receiver via multiple paths. Multipath propagation is almost inevitable in most GNSS applications, since all kinds of possible reflectors are normally present, such as the earth's surface, buildings and other objects. The influence of these reflections depends on their signal strength and delay compared with that of the line-of-sight signal, the attenuation by the receiver antenna, and the measuring technique of the receiver. The theoretical maximum effect of multipath on C/A code pseudorange measurements can reach 0.5 ms when the reflected/direct signal strength ratio is one. Carrier phase measurements are not free from multipath either. Though the effect is about two orders of magnitude smaller than in pseudoranges, it contributes to the phase measurement noise. For short baselines, it may even dominate the adjustment residuals in the solution. In a strong multipath environment, the observation time in the field may increase significantly in order to correctly resolve the satellite carrier phase ambiguities (Valencia et al 2011).

Multipath can be reduced by careful selection of observation site, and special design of receiver antenna and firmware (Larson et al 2013). In some special cases, multipath can be predicted (Wu et al 2009). In this thesis, instead of modeling multipath, an attempt is made to estimate the observation time required for solving the carrier phase ambiguities in a strong multipath environment.

It determines the code noise and the terms that are removed in this are tropospheric delay, clock errors (satellite and receiver) and geometric range. The phase noise and multipath are not taken assuming them to be negligible comparing with code phase and multipath (Bakker et al., 2009). It is done here by removing low-order polynomial fit from code minus phase data which removes constant ambiguities, hardware delays, low frequency ionospheric delay and low frequency multipath leaving the high frequency terms of ionospheric delay, code multipath and noise.

**METHODOLOGY AND ANALYSIS OF RESULT**

Multipath has been majorly analyzed either by using differencing models or by using some combinations of the observables. Different researchers have used different methods for quantification of the multipath. In this research, we have used code minus carrier, linear phase combinations and double differencing residuals. The observations were taken on 16/01/2018, sunny day, for more than 7 hours, with an observation interval of 10 seconds. The observations for code minus carrier and linear phase combinations were taken in standalone mode. A stochastic model generated could relate the SNR with code minus carrier residuals. A regression model was derived to analyze the DD residuals with respect to SNR values.

From the combinations discussed in section 2.2.18 the MP1 and MP2 are given by the following equations 2.27 and 2.28.

$$MP1 = P1 - 4.0915\phi 1 + 3.0915\phi 2 + K1 \qquad (1)$$

$$MP2 = \mathrm{P}2 - 5.0915\phi 1 + 4.0915\phi 2 + K2 \qquad (2)$$

The MP1 and MP2 represent majorly the pseudorange multipath on L1 and L2. K1 and K2 being the functions of noise, integer ambiguities and multipath on carrier phase. Carrier phase multipath is negligible compared with pseudorange. Provided there is no cycle, slip, K1 and K2 can be removed by averaging the data. As the P1 observable was unavailable the pseudorange multipath, C/A code on L1 (C1) was taken in place of the P1. Thus $MC_1$ and MP2 are plotted in Figure 4.11. There were 2438 observations for PRN 22. The plot shows the multipath variations on L1 and L2 carrier frequencies on C/A code and P code.

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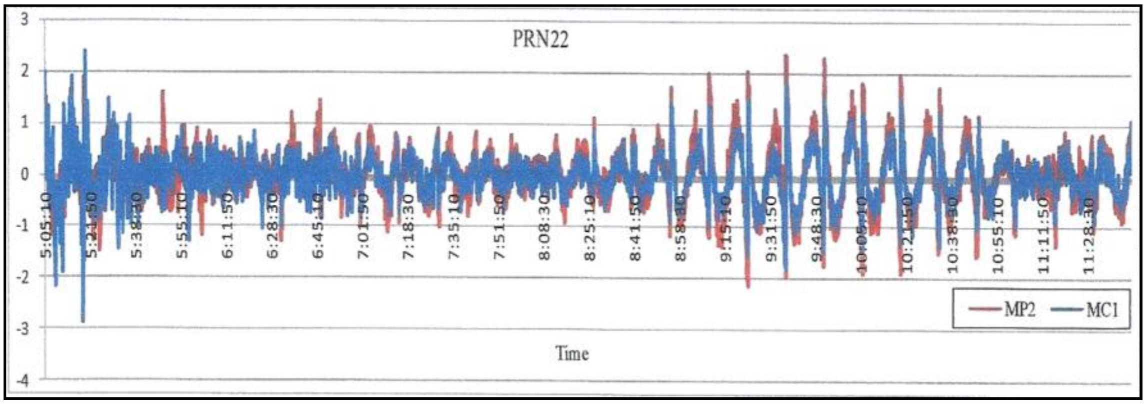
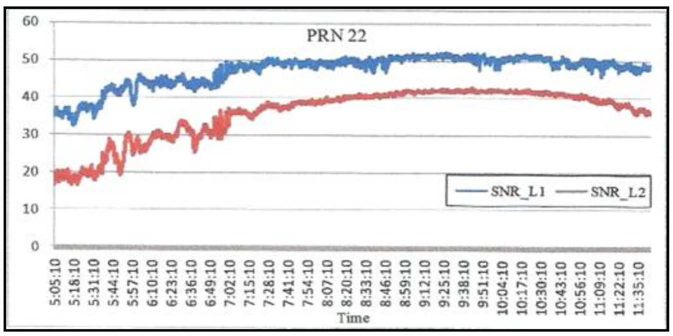



Pseudorange multipath C/A code on L1 and P code on L2 for GPS satellite PRN 22

The variations of MP2 are higher than MC1 as shown in Table 4.6. Comparing the corresponding SNR, L1 is much higher than L2 which relates SNR with multipath inversely




L1 and L2 SNR variation of PRN 22

## CONCLUSION

A stochastic model was derived to relate the multipath residuals (code minus carrier) and SNR, it was found that pseudorange multipath on L2 was higher than on CA code.

Double differencing residual were related with SNR having a Gaussian regression model while polynomial regression model related code minus carrier residuals with SNR.

A 3D building model was generated using GPS to analyse the effect of accuracy of 3D building model generated using Cartosat 1 DEM, on the multipath prediction model.

## RECOMMENDATIONS

Cartosat 1 DEM was used for 3D building shapefile as an input for the multipath prediction model but for attaining high accuracy in SNR prediction, high accuracy GNSS data can be used. To analyze the antenna gain pattern of GPS antennas, a comparative study taking different GPS antennas with different LHCP rejection ratio can be carried out.

The developed model to integrate the derived results, so that it can predict the positional accuracy along with SNR as literature provides strong relations between the two.

A study to estimate the optimum occupation time for a given urban scenario can also be carried out using this model.

Objects other than buildings in urban area like trees, electric poles can be incorporated in the model.

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