GNSS Real Time Observations in Urban Environment for Computation of Discrepancies from Predicted Values

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ABSTRACT

Global Navigation Satellite System (GNSS) positioning in urban environment is difficult as the direct line of sight is obstructed. The signals coming from diffraction and reflection from building surrounding result to the problem. One of the major sources of error in GNSS surveying is multipath error, most especially in a crowding or congested environment like urban environment, which cannot be handled by differential mode of surveying. This research focuses on GNSS Real Time observations in order to compute ranges. Real-time observations were carried out to compute the ranges. A regression model was derived for finding the relationship between Signal Noise to Ratio (SNR) and elevation Angle. The satellite signal prediction was successfully validated against the observed values taken from different surrounding building. A model was developed for Signal Noise to Ratio (SNR) prediction in urban environment incorporating diffraction and reflection from the surroundings. The important of SNR being an important quality indicator was largely shown.

Keywords: Error sources SNR, Elevation Angle, Linear Phase Combination, Observables.

Introduction

The GNSS is an integral part of many systems ranging from communication to navigation. The functioning of these systems therefore is dependent on the positional accuracy given by the GNSS. GNSS is now being used in various urban and other information projects which require measurements to be very precise and accurate. Taking Ground Control Points GCPs for various small or large projects also requires having high positional GNSS accuracy. GNSS accuracy is mostly affected by the obstructions in many forms (buildings, trees and natural topography) which may lead to degradation of signal strength or complete signal blockage due to these obstructions. The position of any location cannot be computed if less than four satellites are visible or if satellite geometry at an instant is not well configured (Naveen et al, 2017), we cannot get desired geometric dilution of precision (GDOP), which is generally a case in an urban

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environment. Real-time satellite availability prediction is very useful for mobile applications such as in-car navigation systems, personal navigations systems and location based services (LBS) (Taylor etal., 2007). In all such areas which require desired GNSS accuracy and desired signal characteristics, preplanning for collection of GNSS points can actually increase the efficiency if these values can be known in advance. GNSS accuracy is a function of six major factors namely – geometry of satellites, ionospheric and tropospherisc delays, satellite ephemeris (orbit), satellite clock error, receiver noise, and multipath (Beesley, 2002). In an urban environment, all of these factors except geometry of satellites and multipath affect GNSS accuracy a constant amount (Muzi et al, 2017), so we need to deal with these two factors mainly. In this study, the focus is on the prediction of satellites with SNR in urban scenario, which finally would help the user for preplanning. The different urban scenarios will be discussed along with different building materials.

Many GNSS applications have strict reliability requirements as they involve Safety of Life (SoL) services and critical missions such as aviation, maritime and land transportation. In this context, the concept of reliability and service integrity will be defined based on the level of trust in navigation solutions, given the variety of error sources affecting the system. One of the major phenomena that degrades the integrity of navigation solutions is multipath. Generally, GNSS signals received by a receiver are a combination of line-of-sight (LOS) and a number of non-line-of-sight (NLOS) components reflected off nearby obstacles one or more times before reaching the receiver antenna. (Fan et al, 2006). They include spectral and diffuse reflections based on the characteristics of the reflector surface. Due to reflections, the received signals are different in power, delay, carrier phase and frequency, angle of arrival and polarization. The combination of these signals on the receiver antenna introduces multipath effects. Under multipath occurrence, a Delay-lock Loop (DLL) does not properly distinguish the actual peak of the correlation curve, as required for ideal code alignment. This results in a pseudorange error characterized by a significant multipath range error envelope. A detailed discussion of these multipath countermeasure methods and their relative comparison can be found in. As a general observation, some of these mitigating techniques attempt to minimize the effect of multipath by modifying the receiver tracking structure while others try to jointly estimate the multipath parameters and subsequently mitigate them. Polarization and spatial diversity is another solution

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to reduce multipath which relies on different polarization and arrival angles of the reflected signals. These methods, however, require special hardware (antenna) considerations and modifications. Other solutions include three-dimensional building models (2DBMs) in urban environments which also require additional geospatial information of nearby reflectors (John, 2015).

MAJOR ERROR SOURCES IN GNSS OBSERVATIONS

GNSS observations are affected by number of errors, both random and systematic. The major error sources include receiver noise, orbital and clock errors, and propagation errors (ionospheric effect, tropospheric effect, and multipath). They are briefly discussed in this section. The multipath effect will be discussed in more detail.

Orbital errors result from the situation where the satellite is not at the exact position dictated by the broadcast emphemerides. This discrepancy is the consequence of the inability to completely model the forces acting on a satellite, and the degradation due to Selective Availability (SA). If left uncorrected, such discrepancies will corrupt the range determination and hence the location of the user position. Differencing observations from one satellite between receivers can reduce the error.

This table summarizes the acceptable orbital error for a given relative accuracy in baseline determination (Zhang, 2010).

Relative Accuracy and Orbital Errors

Relative accuracy required	Acceptable orbital error
5ppm	125m
1ppm	25m
0.5ppm	12.5m
0.1ppm	2.5m

Another possibility to reduce the orbital error is to compute the *a posteriori* precise ephemerides, based on observations from globally distributed tracking stations. In addition to the U.S. military GPS satellite tracking networks, several civilian tracking networks are in the process of being established to determine the precise ephemerides (Zajicok, et al, 2010). A well-known one is the

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Cooperative International GPS Network (CIGNET) with about 20 tracking stations operating in 1992.

Clock errors occur in both the satellites and the receivers. Each satellite carries clocks which act as the time and frequency base for the realization of the GPS system time. Although the satellite docks are very accurate, they are not perfect. The behavior of satellite clocks is monitored by the GPS ground control segment and the clock correction model is reported to the users as part of the navigation message. The actual behavior of the clock, however, differs from this model because of unpredictable, correlated frequency errors. Receiver clock drift is generally of larger than the satellite clock drift due to the lower quality of the oscillator.

Differencing observations from one satellite between two receivers can eliminate the satellite dock error. Differencing observations between satellites can eliminate the receiver dock error. An alternative approach is to leave the receiver and satellite clock offsets as an unknown to be solved in parameter estimation (Small et al, 2010).

The DoD is intentionally degrading the accuracy of position information to unauthorized users. This mode of degraded operation is called Selective Availability (SA). SA involves the degradation of broadcast orbits and satellite dock dithering. Orbit degradation should not constitute a problem because high accuracy post-processing techniques routinely include orbit improvement calculations (Rost, 2009). Satellite clock dithering appears more problematic because it can result in unmodeled satellite clock errors. However, for the current level of SA, satellite clock dithering has a negligible effect on baselines determination if double difference processing techniques are employed and if the GPS receivers remain synchronized to better than 10 ms (Rao et al, 2012).

The atmospheric layer from about 60 km upwards is called the ionosphere and it includes free electrons. The ionosphere can retard GPS signals from their velocity in free space by more than 300 ns in the worst case, corresponding to range errors of 100 metres (Rizos et al 2013). The ionospheric delay depends on the Total Electron Content (TEC) along the signal path and on the

frequency used. TEC is a function of solar ionizing flux, magnetic activity, user location, and viewing direction. Dual frequency receivers make use of the fact that the LI and L2 signals experience different propagation delays in the ionosphere. However, the type of receivers used by the majority of civilian users will be of the less expensive, single frequency kind, which does not provide enough information to eliminate the delay. For precise positioning applications, some methods of reducing this error is highly desirable. In this thesis, one method of accomplishing this objective is proposed.

The troposphere is the lowest part of the atmosphere, extending up to between 9 and 16 kilometres in altitude although the neutral atmosphere can extend up to several tens of kilometers. The tropospheric delay depends on the temperature, humidity, and pressure. It varies with the height of the user, and can also vary with the type of terrain below the signal path. The total tropospheric delay can be separated into a dry and a wet component (Nievinski, et al 2014). The dry component, which reaches up to 90% of the total delay, is easier to determine than the wet component. This table gives some numerical values of the tropospheric delay for different satellite elevation angles in average situation.

Tropospheric Delay on Measured Ranges

Elevation	90'	20°	15°	10'	5'
Dry Component	2.3(m)	6.7	8.8	12.9	23.6
Wet Component	0.2	0.6	0.8	1.1	2.2
Total Delay	2.5	7.3	9.6	14.0	25.8

Various models have been developed to estimate the delay. The dry component can be precisely described by these models with an accuracy of $\pm1\%$, while the .wet component can be modeled by surface weather data to within 3-4 cm (Obstatel, 2012). Other approaches of determining the wet component include direct measurement with water vapor radiometers (Marais et al 2010) and the use of a station-dependent zenith scale factor for each satellite pass.

Multipath is the phenomena whereby a signal arrives at a receiver via multiple paths. Multipath propagation is almost inevitable in most GPS 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.

The receiver noise depends on the signal to noise ratio of the satellite signals. The dynamics acting on the antenna also have an effect. The greater the accelerations of the antenna, the wider the tracking loop bandwidths have to be in order to keep lock on an incoming signal, and the higher the noise level of the receiver will be. As a rule of thumb, the observation resolution for classical receivers is slightly better than 1% of the signal wavelength. The typical receiver noise level is summarized.

Receiver Noise for Different Observations

Type of Obs.	Wave length	Receiver Noise
C/A-code	300m	3 m
P-code	30m	30cm
Carrier Phase	20cm	2mm

Modern receiver technology tends to bring the internal phase noise below 1 mm, and to reduce the code noise to the ten centimetre level (Kumar et al 2013).

SNR determines the quality of the signal as the ratio of the power of the GPS carrier signal to the noise power. SNR is affected by factors external and internal to GPS receiver. External factors include space loss, transmitted power, multipath and atmospheric losses while internal ones are tracking loop design and antenna gain pattern. The SNR is stored in all the GNSS receivers, but there is no uniform method of calculating it. Therefore the values may differ from one manufacture to other. The noise level in a geodetic GPS receiver is almost constant, so the SNR is directly proportional to the GPS received signal strength. (Bilich et al., 2004), (Collins and Langley, 1999) have shown that variation pattern of SNR and elevation are same. Here also, we found a polynomial relation between the SNR and elevation angle as given in equation no 5.1.

We get the GPS observables from the RINEX. The pseudorange multipath can be analyzed using the linear phase combinations. It eliminates the clock and atmospheric errors. It is derived by the following equations by (Langley $et\ al.$, 1998), (Estey and Meertens, 1999), (Ge $et\ al.$, 2002):

$$MP_1 = P1 - 4.0915\emptyset_1 + 2.0915\emptyset_2 + [4.0915(\lambda_1 N_1 + MP_{\emptyset1}) - 2.0915(\lambda_2 N_2 + MP_{\emptyset2})] \quad (1)$$

$$MP_2 = P2 - 5.0915\emptyset_1 + 4.0915\emptyset_2 + [5.0915(\lambda_1 N_1 + MP_{\emptyset1}) - 4.0915(\lambda_2 N_2 + MP_{\emptyset2})] \quad (2)$$

Carrier phase multipath is negligible so $MP\phi_1, MP\phi_2$ are ignored. The biases in the remaining terms are almost constant provided there is no cycle slip, thus with averaging it can be removed and leaving the pseudorange multipath residuals along with receiver noise.

The GNSS signals after getting processed yield basically two observables namely code and phase solutions which are most important observables. Code observations: Also called pseudorange observation is not very precise measure of the receiver-satellite distance.

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THE STUDY AREA

This section discusses the study area of the study. The discussion is done under the following: location, topography, climate, geology, vegetation and landuse activities, patterns and trends. South East of Nigeria was the 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 60 5' N and 60 15' N and longitudes 70 0' E and 7o 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).
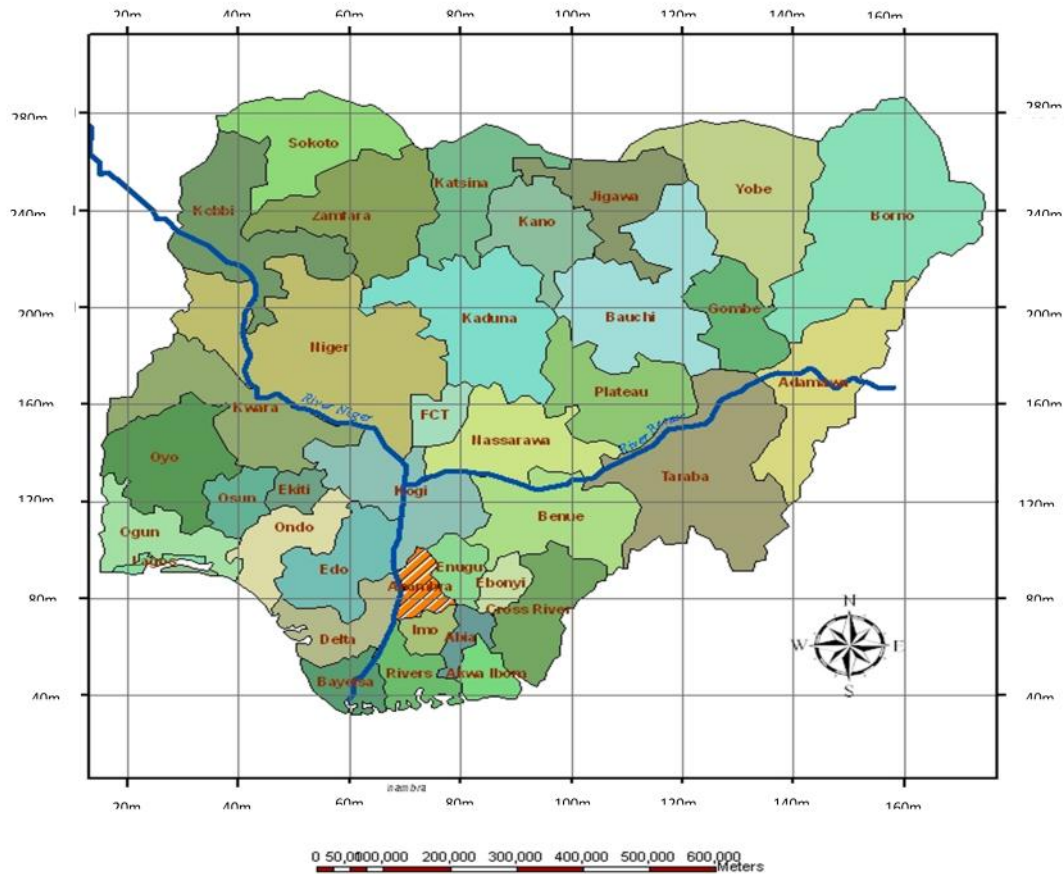
Fig. 1: Map of Nigeria

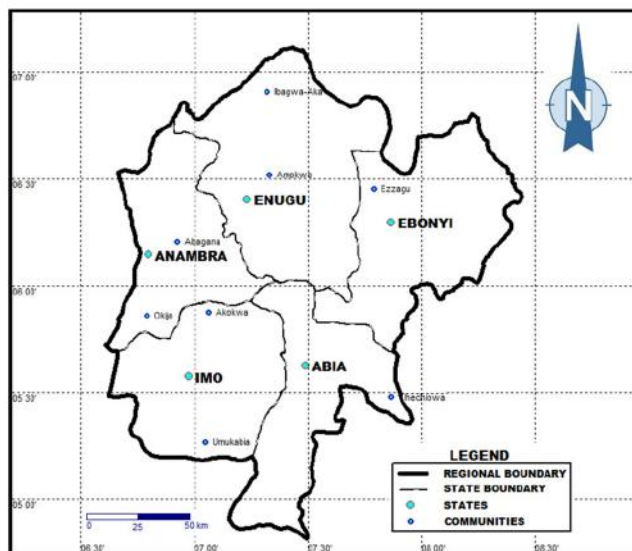Source: Department of Surveying and Geoinformatics Unizik, Awka

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. Ina 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 westof 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).

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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 belongto 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).

METHODOLOGY AND ANALYSIS OF RESULT

This follows the flow of the work, covering from prediction of SNR values to development of the software which further led to deriving the relations of the SNR with that of the Multipath residuals. Then the results predicted are validated against the results observed at different test sites.

The SNR is predicted using the equation given in $SNR = 3.199*10-05*\theta 3 - 0.0081*\theta 2 + 0.6613*\theta + 31.28$ (4.1) , with the R2 value to be 0.96. The developed program predicted satellite availability for base and rover. The 2D building footprints and location of base and rover was shown. The base was taken over the roof marked in green color) and the rover was kept in front of the buildings marked in red color.

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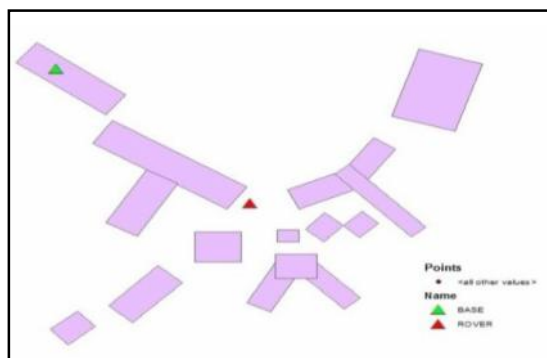
2D-building foot prints for DGPS

On 12/2/19, a sunny day, the values were recorded for more than three hours taking 1089 observations with 10 second interval in Anambra state. The values were predicted using viewshed analysis, blocking a signal completely if any building comes out in its line of sight. The 2D-model was generated using Cartosat1 DEM as discussed in previous section. The visible satellites (predicted and observed) at the base and the rover are shown in Table The base results show that the SNR values predicted are matching and the difference between observed and predicted SNR are less than 1dB. All the visible satellites could be predicted completely at the base; the difference came in SNR prediction and is more for low elevation satellites, which has less SNR, probably due to ground multipath which was not taken care at that stage. Observing the rover data, we found many satellites getting observed could not be predicted. The satellites with high SNR (>50dB) were getting predicted and the satellite with low SNR (<25dB) ones, completely getting rejected. The intermediate ones were computed.

Satellites predicted and observed at BASE with SNR

Time-6.20.00	SNR			Time-7.00.00	SNR		
PRN	Observed	Predicted	Difference	PRN	Observed	Predicted	Difference
GO2	43.5	42.41	1.09	GO2	45.7	44.15	1.55
GO4	48.5	47.24	1.16	GO4	50	49.44	0.56
GO8	41.8	42.89	-1.09	GO8	37.6	41.07	-3.47
GO9	45.8	43.39	2.41	GO9	47.7	45.64	2.06
G17	49.5	47.65	1.85	G10	38.2	41.28	-2.08
G20	29.4	41.29	-1.89	G17	48.8	46.49	2.31
G26	38	41.04	-3.04	G20	38.4	41.31	-2.91
G27	46.5	44.69	1.81	G27	45.9	45.54	0.36
G28	49.2	46.71	2.49	G28	47.8	45.78	2.02

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The results shown motivated to find out the cause of signal getting observed but could not be predicted. It is due to the positional error in the used 3D building model. It also concluded that even if a building is there obstructing the line of sight, the satellite may be visible probably due to the phenomenon of reflection and diffraction which is not taken and considered at this stage.

Satellites predicted and observed at ROVER with SNR

Time-6.20.00	SNR			Time-7.00.00	SNR		
PRN	Observed	Predicted	Difference	PRN	Observed	Predicted	Difference
GO2	44	-------	-------	GO2	47.5	------	-------
GO4	49.9	47.39	2.56	GO4	49.7	49.44	0.26
GO9	32.7	--------	------	GO9	30	------	-------
G17	49.9	47.65	2.25	G17	49.6	49.74	-0.14
G20	30	-------	------	G27	32.5	--------	-------
G28	47.7	46.71	0.99	G28	47.1	44.46	2.64

CONCLUSION

For the prediction of satellite availability along with SNR in urban environment, the reflection and diffraction from the buildings surfaces were incorporated in the multipath prediction model.

To analyse the signal quality in urban environment different urban geometries were incorporated with which a signal can reach to a receiver. Dry and wet surface were considered and results shown at low SNR the multipath error at wet surface. This leads to a conclusion if surface materials will affect the GPS positional accuracy significantly at low SNR.

A strong correlation was determined between SNR with elevation angle, and a polynomial regression model was derived, which was used in SNR prediction.

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