The use of the Carrier to Noise Ratios (C/N_0) to alleviate the problematic GNSS phase multipath

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***Abstract* – The Global Navigation Satellite System (GNSS) multipath caused by the large time delays of the reflected signal causes errors to the output of the GNSS receiver, the Position, Velocity and Time (PVT). These errors are mitigated by the technology and architecture of the GNSS receiver. Numerous research has been conducted to reveal the correlation between the Signals to Noise Ratio (SNR). Various multipath-mitigating techniques uses the concept of SNR measurements during the data processing in the GNSS receiver to ease the impact of the signal multipath if the signal is imitated. In this paper, we define and analyse the concept of the multipath mitigation techniques that are dependent to the SNR measurements. Hence, all signal components that are found in GNSS signal such as phase, code, time and SNR will be utilized to estimate impact of the GNSS phase multipath. The technique of the C/N_0 is incorporating the density power ration to the SNR measurements and this is used to calculate reliability of the GNSS signal tracking.**

***Index Terms*— GNSS, PVT, SNR, C/N_0 , Receiver**

I. INTRODUCTION

The current systems of the GNSS network includes Global Positioning Systems (GPS), Galileo, Beidou and Glonass. There are numerous studies and developments along the space and ground segment all trying to mitigate the errors and multipath signal[1]. The first programme to deal with the phenomenon of the signal multipath was introduced long time ago, that implies the assessment of diverse signal parameters in the reflecting surface to improve the concept of GNSS reflectometry. The importance of the GNSS applications implies the characterization of the C/N_0 attempting to mitigate the multipath errors. In most applications relating to communication networks and systems, the SNR measurements are important to define the quality of the systems and predict the possible signal disturbances[2]. The lower SNR or C/N_0 means, there signal quality is decreasing that will results to the weak processing and acquisition. Improving the processing and acquisition of the weak signal is a major problem, the GNSS receivers are often using the real, and imaginary component evaluate the processing of the weak signal due to distortion, interference, multipath etc. The GNSS network in areas with degraded communication systems cannot fulfil the requirements of GNSS applications, especially in areas with long buildings. In these scenarios, the possible solution is to adopt the use of multi-constellation satellite communication systems that will incorporate the Global Positioning Systems (GPS), Galileo, Glonass and Beidou. The multi-constellation satellite approach improves the performance of the signal acquisition and processing for both traditional and hybrid GNSS receiver. Most of the networks for now are equipped with the traditional GNSS receivers and their performance is improved through the adoption of the multi-constellation network[3]. The GNSS receivers are capable of recording the SNR data, carrier code observables and carrier phase for all signal wave that is coming through. The SNR values are used to measure the efficiency of the GNSS receiver and the signal strength for satellites in view. For the GNSS receiver to compute the accurate PVT and precise the receiver clock offset, its needs at least more than three satellite to be visible and this is called trilateration. In case the SNR measurements are computed from the accrual of the GNSS receiver tracking Loop, those computed SNR values are correlated to the carrier phase error and indicates the presence of multipath[4]. The GNSS multipath error of the carrier data and code measurements are of serious concern in the sphere of GNSS applications. Hence, the estimation and prediction of the presence

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of the multipath errors required a thoroughly analysis of the SNR or C/N_0. There is a strong link between the SNR oscillations and the carrier phase multipath errors[5]. This paper describe the concept of the multipath mitigation using the signal to noise ratio. The parameters of the SNR is then used to estimate the phase multipath for each phase measurements. Therefore, the estimated multipath error is re-applied to the system in order to correct the phase measurements before the final processing.

II. The Architecture Of The GNSS Network And Signal Acquisation

As stated above, the GNSS positioning system is adhering to the principle of trilateration and this concept uses the scientific geometry to locate the position using the determined reference point on earth. The GNSS receiver under this concept is equipped to determine spatial coordinate including the receiver clock offset that needs to be corrected for incoming signals by measuring the distance from the satellite that are orbiting around earth[6]. Satellite orbit are classified into four different types, the Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geosynchronous Orbit (IGSO) and the Geostationary Earth Orbit (GEO). The data of the duration for the satellite signal to reach the GNSS receiver is used to predict the distance from the receiver to the satellite, where the propagation time of the satellite is t_{sp}, and the speed of the signal in the vacuum space is C_s, therefore the approximation of the distance is:

$$D_{S\rightarrow R} = C_s * t_{sp} \quad (1)$$

Equation (1) indicate the approximation distance from satellite to the GNSS receiver assuming the perfect signal wave propagation. Fig. 1 shows the architecture of GNSS network and receiver. For all visible satellites, the GNSS receiver will require the specific data to compute the distance from receiver to each satellite[7].

The architecture of the GNSS network consist of three segments. The space segment (satellite) in the earth orbit, user segment (GNSS receivers) on the ground and the control segment to ensure the perfect integration between the satellite and receiver. The space satellite transmit the unique code along the signal wave to the receiver, the code is Pseudo Random Noise (PRN) that is utilized to determine the sending satellite[9]. The satellite PRN codes allow the use of the Code Division Multiple Access (CDMA) through the functions of autocorrelation and cross-correlation. The received PRN code for the signal is aligned with the replica signal to measure the propagation delay of the chip resolution. The architecture of the GNSS receiver in Fig. 1 shows the advanced stages of signal collection from the antenna to the receiver output[10]. The Right Hand Circularly Polarized (RHCP) antenna is the first element of the GNSS receiver, which collect the Radio Frequency (RF) signal from the space and pass through the processing stages. The RF signal goes through Low Noise Amplifier (LNA) for signal amplification and filtration. The process of signal acquisition detect the useful signal and estimate two parameters, the Doppler frequency and code delay[11]. The estimation of the code delay and Doppler frequency are useful to ease the signal tracking to estimate the precise signal propagation period and the Doppler shift. The RHCP antenna of the GNSS receiver is equipped with the RF signal processing modules, the Analogue to Digital Converter (ADC) that is linked to the Automatic Gain Control (AGC) for further processing. The AGC ensures that, the amplitude of the incoming signal is regulated to keep the linear range up to the output of the receiver. The accurate time at which signal wave was transmitted or sent from the space satellite, the anticipated atmospheric delay, identify the exactly satellite that is sending signal to correlate the signal to the sending satellite and the data relating to the satellite time, atmospheric correction and ephemeris[8].

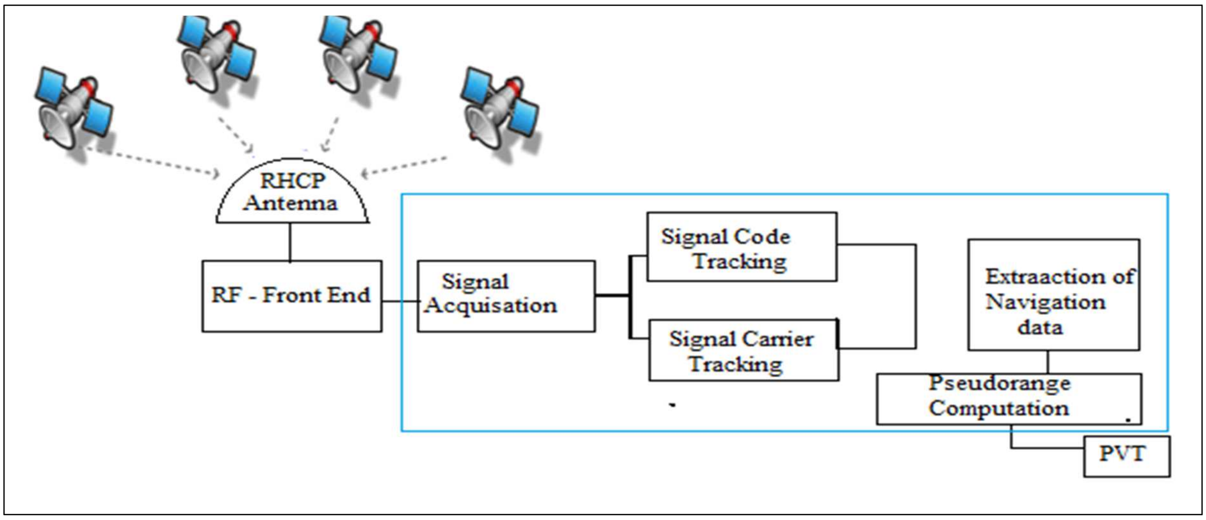

Fig. 1. The GNSS network and receiver

The incoming signal is amplified before going through LNA at the input stage of the receiver; this is because the GNSS signal is implanted into the thermal noise along the propagation channel. The LNA of the GNSS receiver have the specific gain limit that necessitate the use of additional amplifiers with low noise resistant and wide signal gain acceptance[9, 12]. Therefore, the GNSS receiver generate the referencing signal and compare to the satellite-incoming signal to identify the parameters of the signal. The referencing signal is also known as local oscillator used to generate the local signal carrier. The performance of the GNSS receiver is dependent to the local oscillator that is characterized by the sensitivity and the stability of the processing. The base band incoming signal model received by RHCP antenna is:

$$S_{Baseband}(t) = \sqrt{P_{BB}}\left(\sum_{a=-\infty}^{\infty} m_a h^{(a)}(t - aT_d)\right) + J\sqrt{1-\beta^2}\left(\sum_{a=-\infty}^{\infty} c_a Q^{(a)}(t - aT_d)\right) \quad (2)$$

Where the:

- P_{BB} is the power of the baseband signal
- T_d is the duration or period take for the baseband signal to reach the receiver
- m_a and c_a are the pseudorange values
- $h^{(a)}(t)$ and $Q^{(a)}(t)$ Are the signal spreading components for quadrant and in phase.

The baseband signal in (2) will then go through the acquisition and tracking.

A. Acquisition

The GNSS signal acquisition is the following stage just after the RF front end processing that include filtration in LNA. The GNSS signal acquisition start with the search of the visible satellites to identify the parameters of the visible satellites to the receiver and later determine two crucial properties of the GNSS signal, the code phase and frequency[13].

B. Tracking

Once the search of the visible satellite is completed, the signal tracking will commence for signal localization. The GNSS signal tracking needs a precise data similar to signal acquisition. The GNSS signal tracking is used to enhance the coarse values of the frequency and code phase that were identified at acquisition stage[14]. There is a relative motion between the GNSS satellite and receiver that causes code and frequency variations. There are dual processes of the signal tracking, the carrier frequency or phase tracking and code tracking[15]. The Delay Locked Loop is associated with the code tracking of the GNSS signal; in this case, three GNSS local codes are generated and further correlated with the duplicates of the PRN codes, Late (L), Prompt (P) and Early (E).

III. The Numerical Analysis Of The Gnss Receiver Losses And Snr Modelling

The signal reception inclusive of GNSS receiver and signal processing stages plays a crucial role in dealing with the SNR analysis to improve the reliability of the GNSS network[16]. The SNR values are the observables that are recorded by the GNSS receivers in the locations that are disposed to the signal multipath. In various GNSS receivers, the SNR is derived from the output of the carrier-tracking loop. Hence, the SNR is assumed in the through measurements of the carrier tracking loop accumulation. For the analysis and the estimation of the SNR measurements to the GNSS receivers, we recall (2). Equation (1) is the GNSS with dual parameters for autocorrelation function that is intervallic with T_d and *t.* This is wide enough to accommodate the Galileo and GPS signals. The periodic autocorrelation in the GNSS receiver is:

$$S_{AC}(T_d; \tau_c) = \sqrt{P_{BB}}\ s[(T_d + \tau_c)s^*(t)] \quad (3)$$

The S_{AC} is the signal in autocorrelation stage, τ_c, is the periodic signal chip s and s^* are quantities that denotes PRN codes. The time average of the GNSS signal along autocorrelation is:

$$S_{AC}(\tau_c) = \frac{1}{T_d}\int_0^{T_d} S_{AC}(T_d; \tau_c)dt \quad (4)$$

The issue of the noise and interference are the major problem in the GNSS signals and are commonly autonomous to the Gaussian noise. The signal from (1) contain the real and imaginary parts, the expansion of (10) for simulation and processing is:

$$S_{ma}(\tau_c) = \frac{1}{T_d}\int_0^{T_d} m_a(T_d + \tau_c)m_a(t)dt \quad (5)$$

$$S_{ca}(\tau_c) = \frac{1}{T_d}\int_0^{T_d} c_a(T_d + \tau_c)c_a(t)dt \quad (6)$$

Either the GNSS receiver is equipped with the filters low pass or high pass, it is dependent on the requirements of the GNSS receiver, hence the noise figure and transfer function of the data are expressed in (7) and (8):

$$N_{FR} = \frac{SNR_{Input}}{SNR_{Output}} \quad (7)$$

$$Y(f)_t = \begin{cases} 1, & |f| \quad < \frac{F}{2} \\ 0 & |f| \quad else \end{cases} \qquad (8)$$

Equation (8) define the transfer rate of the signal along the processing stages, in this case F is the dual sided bandwidth filter. For processing and simulation, (1) changes just after the signal filtration and the spectral density of the noise level is:

$$Y_{\overrightarrow{m_a}} = \begin{cases} h^{(a)}, & |f| \quad < \frac{F}{2} \\ 0 & |f| \quad else \end{cases} \qquad (9)$$

$$Y_{\overrightarrow{c_a}} = \begin{cases} Q^{(a)}, & |f| \quad < \frac{F}{2} \\ 0 & |f| \quad else \end{cases} \qquad (10)$$

To examine the autocorrelation we recall (3), the main goal here is to minimize the issues of the data acquisition processing and this is correlated in between the incoming signal in (2) and the replicas signal generated by the receiver for estimation of the parameters.

$$S_{AC}(\tau_c) = h^{(a)} F \frac{\sin(\pi F \tau_c)}{(\pi F \tau_c)} \qquad (11)$$

$$S_{AC}(\tau_c) = Q^{(a)} F \frac{\sin(\pi F \tau_c)}{(\pi F \tau_c)} \qquad (12)$$

The spectral power density of the received GNSS signal changes as the signal pass through the sampling that is considered to be a continuous density of noise and signal interference. Along the process, the signal go through the sampling at the specific sampling frequency[17]. The reliance on the SNR measurements are very important since the oscillation and time varying elements will be examined. In (11) and (12), the relationship between the data type are established in the cross – correlation stage. Along the process of calculating the correlation, we regularized the series of inputs so that, the autocorrelation values are identical for similar data bit types. There is a possibility of failure when analysing the SNR data and measurements, in that case, the relationship between the SNR and multipath will be poorly observed. Another problem that was detected along the processing was that, the GNSS sometimes losses the capabilities to read the phase PRN codes embedded in the sampled signal and the phase frequency due to the continuous movement of the satellites[13, 15]. Hence, the sequential GNSS data acquisition was adopted to correlate the parameters of the incoming signal in (1) and all potential code phases and frequencies. For a comprehensive analysis of the SNR measurements and oscillations, we monitor the changes in signal amplitude, by comparing the amplitude of the incoming signal and local generated signal. We further examine the change of the time delay and the Doppler shift. The signal interference sometimes is caused by the frequency of the different link, such as L-5 for GPS and E5a for Galileo respectively. The required PRN codes are obtained through the cross correlation between the signals. Equation (11) and (12) made it very clear that it is sometimes difficult to detect the solid GPS signals more especially, the GPS L-1 Coarse Acquisition (CA) code simple because it has the cross-correlation of about 15-20 dB apart from their auto correlation peak values. The issue of GNSS signal misdetection is the major problem in signals with low power levels and even in Galileo signals that why there is a continuous development of the GNSS systems. For this simulation, we have used the gLAB v5.5.1 software. The gLAB v5.5.1 simulating software accommodate the architecture of the GNSS receiver, having the input, process, modelling, filter and output as shown in Fig.2. For the GNSS receiver to determine the distance to the satellite, each satellite in view must generate the unique code through dual 10-bit shift registers. Furthermore, these codes are modulo-2 and are added to the bit shift so the C/A code is formed in GPS applications. This concept is common to all space satellite and is standardized to the data bit length of 1023. The GNSS receiver uses the codes generated by the satellites to calculate the offset value of the signal duplicate. The GNSS receiver generate, analyse and send the unique PRN code through the specific channel. The receiver will continuously do so until the similar code are matched, from the satellite and the receiver. This is called autocorrelation of the received signal. The correlation of the GPS L-1 C/A and Galileo E1 codes are sometimes similar depending on the additional features that are user specific, hence if the Doppler is present, the autocorrelation outputs are similar to the cross-correlation even though the actual processing might be different depending to the modulating scheme. The two popular modulating schemes are Binary Phase Shift Keying, (BPSK), and Binary Offset Carrier (BOC)

IV. Data And Results Analysis

In this section, we provide the data and simulation results analysis for the numerical modelling of the incoming signal in (1). The signal in (1) changed along the processing and the new algorithms were presented from (3) and (4) at the correlation stage. As the processing proceed, the latest algorithms for this simulation are presented in (8), (9), (10), (11) and (12). The trade-off does exist when selecting filtering parameters for the GNSS receiver. Since some filters uses values that are able to produce the smooth correlation for phase multipath by ignoring the constituent for the higher frequencies.

Fig. 2. The architecture of the GNSS gLAB software

In Fig.2. We presented the architecture of the software that is used in this paper for simulation, this is very innovative and it can accommodate both inputs for BPSK and BOC modulation.

The GNSS signal contain the parameters of interests more especially if evaluating the oscillation of the SNR measurements as illustrated in Fig.3. The parameters under observation in Fig. 3 are code phase (chips), Doppler and C/N_0.

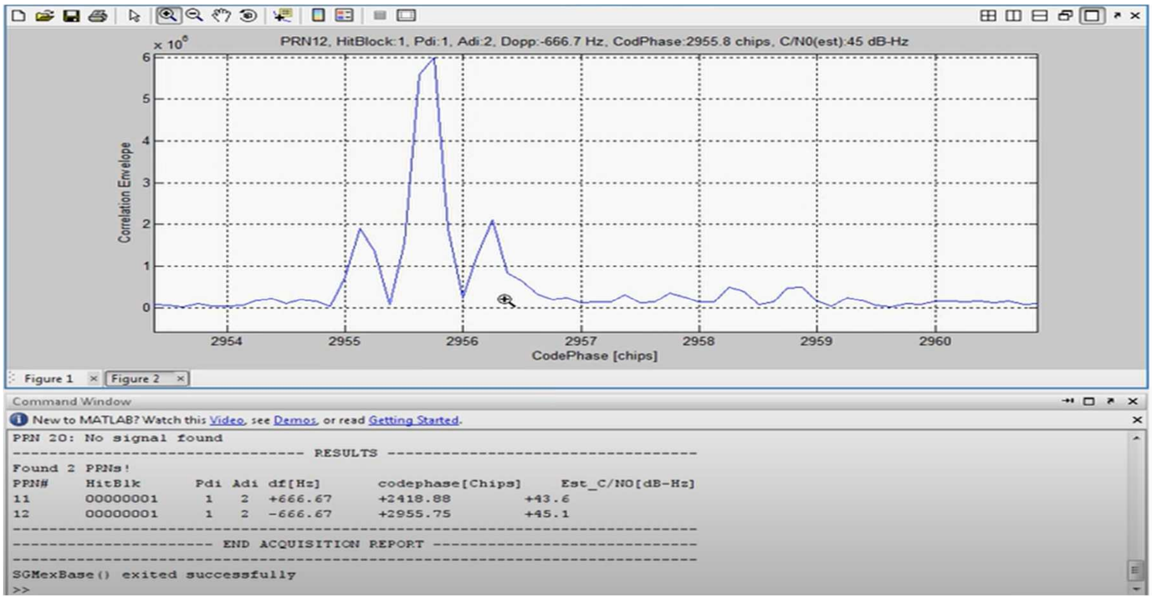

Fig. 3. The GPS signal tracking and acquisition

While the GNSS receiver shifts codes to find the matching ones, there is a probability of correlation spike in the process; however, that will not be a problem because the receiver is aware of all shifted number of chips for the replica codes. The following section present the analysis and discussion of the results and data.

These parameters are evaluated against correlation envelope for PRN 12. In this case, the input of the simulator is the GPS signals L-1 and L-5 respectively. The noticeable Doppler should be at -550.7 Hz or more and the signal to noise power density at 35 dB or more. In Fig. 3, both parameters are noticeable enough to be detected

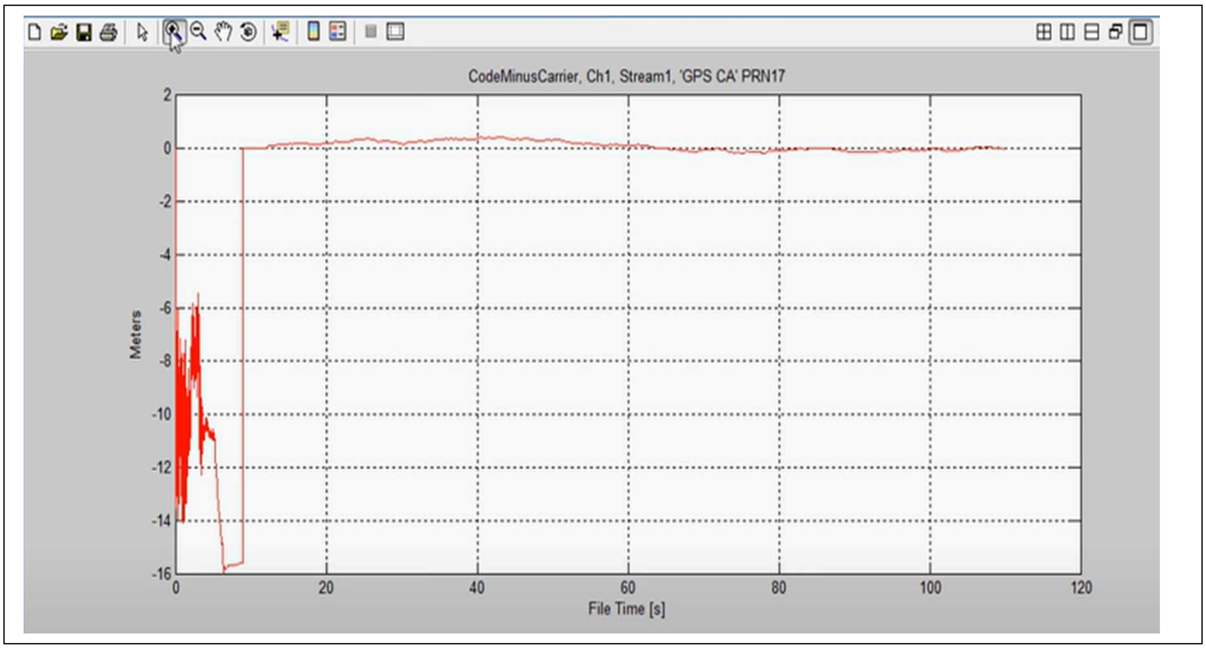

Fig. 4. The Code Minus Carrier analysis in GPS C/A signal

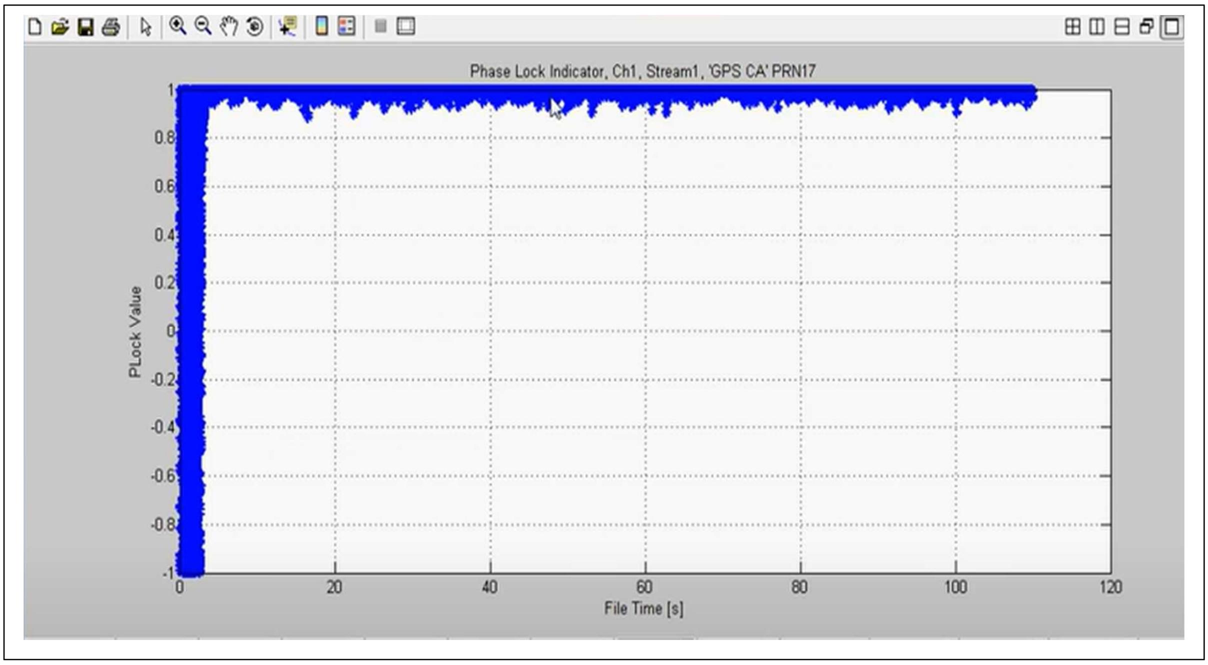

Fig. 5. The phase locker indicator for GPS C/A signal

This study was conducted considering the fact that, the integration time is longer enough to accommodate all data shifting along the channels. Fig. 4 and 5 represent the spectrum of GPS frequencies for phase lock indicator in channel one of PRN 17. The GPS codes are periodic in the duration of one millisecond. The GPS C/A code with the Doppler carrier have the spectrum density almost the same as Galileo E5a. In Fig. 4 the unique code shifting during the correlation and data bit acquisition is reported. Hence, the code period of this study is smaller than the time of coherent integration.

The phase lock indictor is evaluated for positive numbers against time to estimate the Code minus Carrier (CMC) of the GNSS signal. The CMC is considered to the differential method of handling the signal SNR and multipath. The CMC is used for carrier multipath that is smaller than the code multipath in GNSS signals. The Phase Lock Indicators in Fig.5 links the distributed clock bias to the clock of the incoming signal by varying the output frequency and phase until the perfect match is identified. The CMC in Fig. 4 measure the direct the range of the code multipath error following the estimation of the phase multipath error.

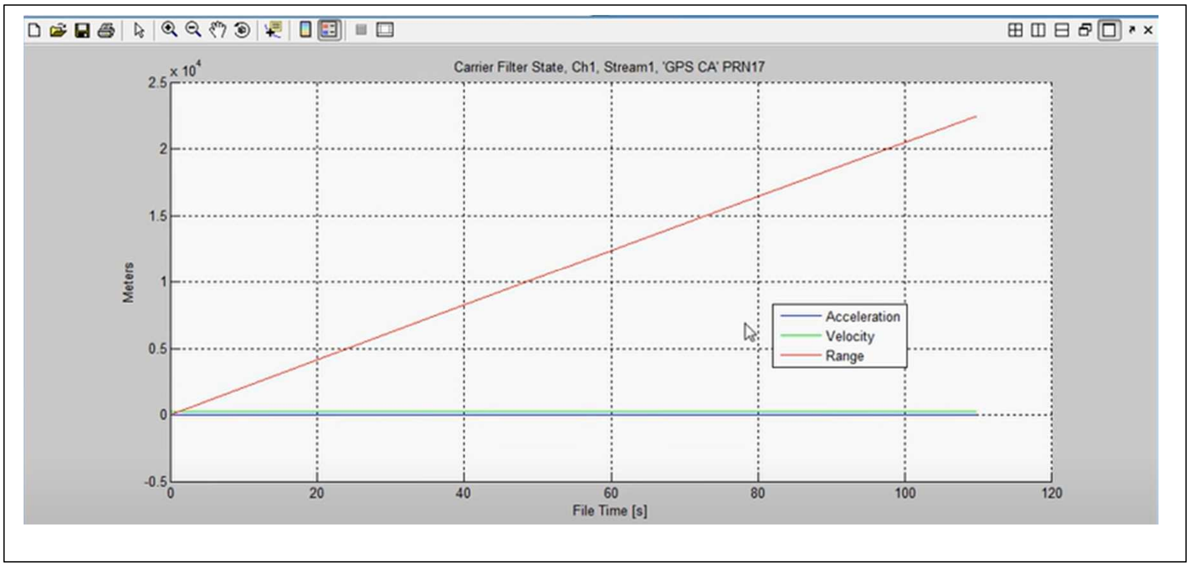

Fig. 6. The carrier filter in the GPS C/A signal for PRN17

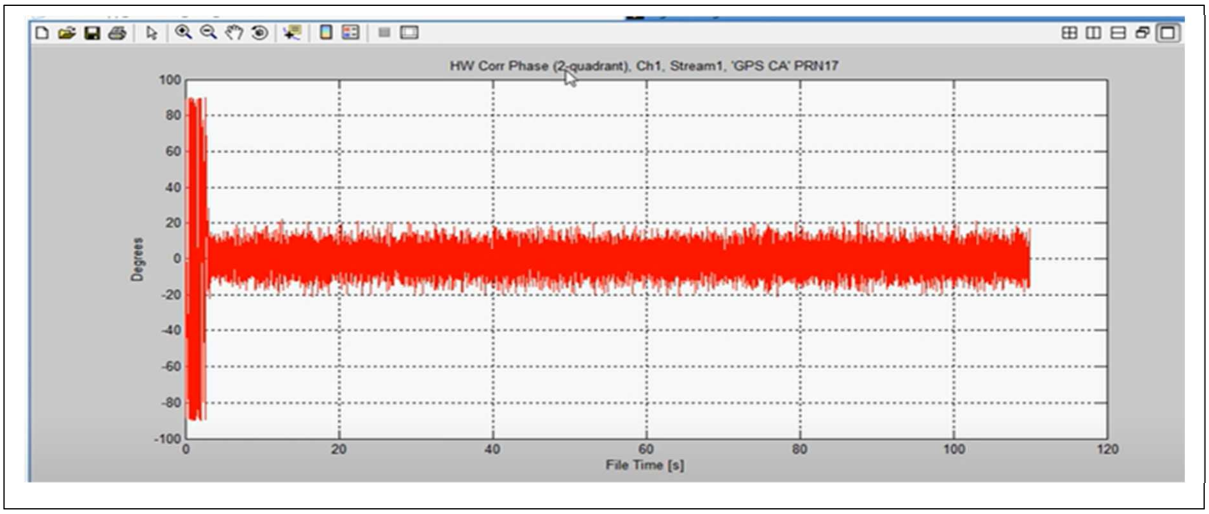

Fig. 7. The correlated phase GPS signal for PRN17 and SNR data

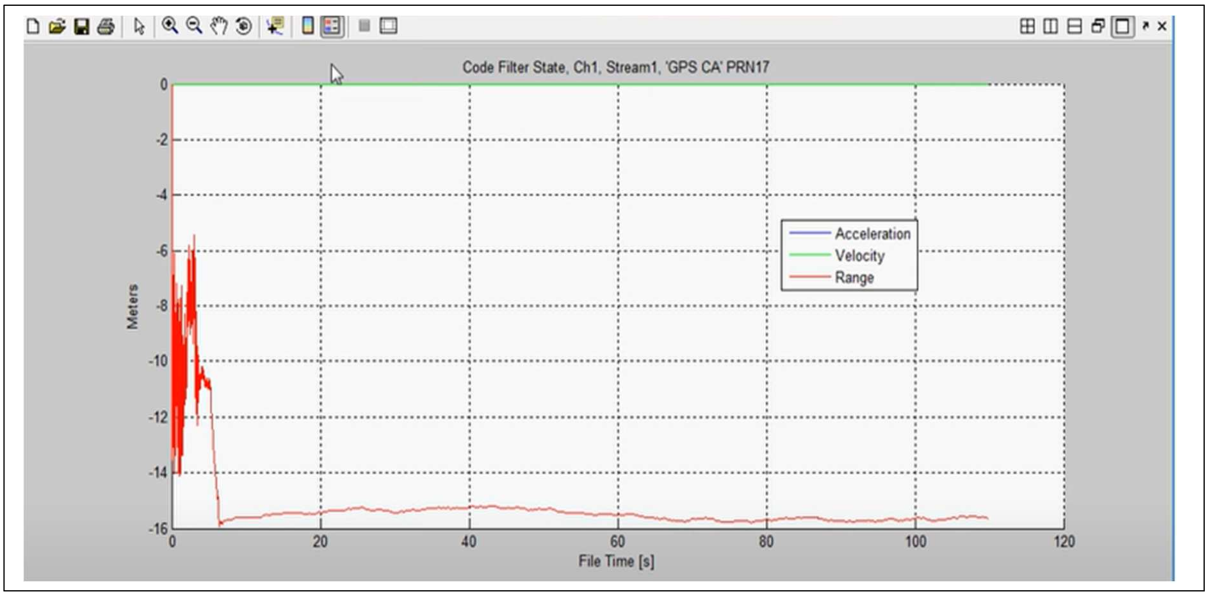

Fig. 8. The analysis of the code filter state and SNR for GPS network

Hence, the influence of the carrier multipath will be hidden in the CMC observations. In this case, the carrier multipath for GPS C/A codes is monitored as shown in Fig. 5 and 6. There is a possibility of linear testing by combining the observations of the correlation peak values for GPS and Galileo. In this case, we had the input of four satellites in view three for GPS and one for Galileo just to combine the signals of L-1 and E1. It must be noted that GPS and Galileo are using different systems that are interoperable that is why in some regions, where the GPS is used, the Galileo will be visible to the user of the GNSS receiver**.** In Fig. 6, 7 and 8 the code residuals for visible satellites is illustrated. By considering the concept of the trilateration, we took the consideration of more than three satellite, three GPS and one Galileo signals. The observed noise residuals and code multipath for E5 and L-5 signals are less than those of L-1 and L-2 signals. The average deviation of the E5 and L-5 is about 0.5 to 1 m. The modernized GPS signal have the stronger signal strength similar to the Galileo E5, hence these signals are combined to obtain the precise observation of carrier and code to ease the ionospheric error. The combination of L-5 and E5 provide the possibility to perform the wide code range and SNR measurements to ease mitigation of the multipath effects. In this case, the SNR data analysis is used for the purpose of the signal carrier multipath; the SNR data is corrected and used in combination with the analysis of the spectral density. The incoming signal from the space is transmitted and sent at the specific speed and range as illustrated in Fig. 7. The obtained values of code filter for channel one of PRN 17 in Fig. 7 and 8 are used to carry out the spectral analysis to determine the type and number of the multipath being present in the GNSS receiver. The observe data of the code and carrier filter for the specific period is used to model the SNR residual data in relation to the frequencies and amplitudes of the incoming signals from more than three satellites. Therefore, the adjustment that is present in the process, the attenuation factor and the phase multipath is estimated. The estimated values of the code and phase filter is essential to calculate the SNR observables, multipath errors and phase correction. The results shows that if more than three satellites are visible, the SNR values are at acceptable power levels while the phase data residuals changes with the margins of 3 cm. Hence, the combination of the GPS and Galileo is (GPS+GALI). This combination improves the PVT output. The numerical algorithms in (9), (10) (11) and (12) are used to calculate the SNR losses and quantize the sample of the incoming signal. These numerical algorithms further suggest that, the signal interferences and noise levels are wide stationary.

V. Summary And Conclusion

This paper presented and demonstrated the analytical model of the SNR data and measurements to calculate the likelihoods of the signal multipath error, the code and phase. The GNSS receiver is prone to the loses in form of the signal power that is caused by sampling and the signal quantization. The numerical modelling provided, are used to accurately predict the SNR data and measurements even though there are some loses along the process. We further demonstrated the multi-correlator and SNR oscillations remarks are used for multipath error mitigation. This is analysed in combination with the differential approach, which utilize the CMC techniques as shown in Fig.6. These results provide the potential options of obtaining the instant monitors of the signal threshold. The phase locker indicator and the tracking loop of the GNSS receiver made it easy to predict the code phase (chips), Doppler and C/N_0. Hence, these estimations and SNR data are strongly dependent to the communication links and the design of the GNSS receiver. The results shows that, the GNSS multipath errors are site specific and the Galileo E5 signal has much more advantage compared to the Glonass signal since they provide errors that are more multipath resilient codes.

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