Review of Techniques to enhance the Accuracy of GNSS Receiver

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Abstract: Multipath is one of the major error sources in satellite based navigation systems. Most of the satellite based navigation system works on the DS-CDMA techniques in L-band spectrum. The position of user is estimated based on the principle of Triangulation. Various position error occur in this techniques such as Dilution of Precision (DOP), Satellite and Clock error, Ephemeris error, Ionospheric error, Tropospheric error and Multipath error. All these errors have been discussed briefly. There are two major errors: Ionospheric and Multipath errors. Normally Ionospheric errors can be mitigated using Dual frequency transmission or using a suitable algorithm. Multipath error can be mitigated using various techniques such as Multipath Estimating Delay Lock Loop (MEDLL), Modified RAKE Delay Lock Loop (MRDLL), Multipath Mitigation Technology (MMT), Narrow Correlator, Double Delta technique Vision Correlator (VC), TurboDLL and others. These techniques have been discussed in detail in this paper. The technique using the Rake receiver is generally used in Communication System. It is envesaged that this technique to mitigate the multipath error significantly.

Key words: *Global Navigation Satellite System (GNSS), GPS, Modified Rake Receiver, Noncoherent Delay Lock Loop, Multipath, Tracking error, Dilution of Precision, Ionospheric error, Tropospheric error, Multipath error.*

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I. INTRODUCTION

The speed of a radio signal is 2.99792458 x 10^8 meters per second. When a signal is transmitted, it Most of the Navigation systems uses CDMA Ranging techniques. Precision ranging using spread-spectrum techniques requires examination of ranging fundamentals takes a finite amount of time to travel from point x to point y. If the receiver knows the exact times the signal was transmitted and received, it can determine the amount of time the radio signal took to travel. Thus delta-time multiplied by the speed of the radio signal equals the range between the two points in meters. Notice the requirement that the receiver must accurately measure the exact times of transmission and reception with adequate temporal resolution.

For a receiver to know the time of transmission, it must either be told by an external means or have timing information embedded in the received signal. This latter method is ordinarily how a spread-spectrum system notifies the receiver of the time of transmission. A PN signal is transmitted with

timing information embedded in the message. The receiver now knows exactly when the PN signal was transmitted. One disadvantage is that this method requires both the transmitter and the receiver to have accurate synchronized clocks. Both the transmitter and the receiver knowing the exact time is a stiff requirement. Accuracy of both clocks is a must. For example, if the timing error is off by 10 nanoseconds, the range error would be three meters. Timing is a fundamental challenge in obtaining millimeter accuracies needed for position tracking in a multipath environment.

Navigation receiver operates in mobile environment. Due to multipath propagation fading of signal takes place. Hence performance of signal degrades. This can be improved by various technology such as Rake Receiver. Here, it is proposed to use Rake Receiver, for improving the performance of navigation signal in this multipath environment.

II. Principle of GNSS

The main principle behind a satellite navigation system is the creation of a trilateration from any point on the earth's surface to the satellites in view. The distance to the satellites is measured by the time the radio signal needs to reach the receiver. Because a radio signal travels with the speed of light, highly precise clocks are used. The satellites contain atomic clocks, and the receivers advanced quartz clocks. The distance to the satellite can be calculated by multiplying the travel time by the speed of light (approximately 300 000 km/s). The exact location of the satellite in space is a prerequisite for this procedure. This is possible because the orbits are very stable and predictable. The satellites are observed and controlled by ground stations, which put the spatial information into the signal. These are the so-called ‘‘ephemeris data’’ (orbit of one satellite) and ‘‘almanac data’’ (relation between all of the satellites). Additionally, information on the satellite clocks is transmitted.

In principle, three satellites must be available to determine a three-dimensional position. All points, which have the same distance to one satellite, form a spherical surface with the satellite in the centre. Three spherical surfaces intersect in two points. One point can be disregarded, because its position is located too far from the earth. A fourth signal is necessary to eliminate the time difference between the satellite’s atomic clocks and the receivers’ quartz clocks. This technique allows the use of inexpensive clocks in user equipment. After all, four satellites are necessary to determine a three-dimensional position. Another satellite is needed for integrity monitoring (quality control and identification of satellite malfunction). One more additional satellite is needed to identify the deficient satellite. The probability of receiving four or more GPS satellites with good geometry, quantified by a position dilution of precision (PDOP) of less than six and an elevation higher than 5° is about 99%. This is, however, a 24-h global average, and not a guarantee for the availability at a special place and time on Earth. The main influences on accuracy are:

- the geometric dilution of precision (GDOP);
- clock errors of the satellites;
- ephemeris errors;
- tropospheric and ionospheric conditions;
- multipath effects;
- inaccuracies of the receiver [1].

III. Types of errors in GNSS

- **The geometric dilution of precision (GDOP):**

It is an index that used to measures the accuracy of GPS (Global positioning system). It is a useful, authority and powerful method of measure the influence of the precision and accuracy of the data received from GPS satellites. All satellites in the field of coordinate structure can lead to a constellation's GDOP and the corresponding positioning error, the analysis of GDOP is an essential part in order to perform a better accuracy positioning system. To GPS, a low GDOP value usually obtain a better accuracy to positioning. The fast algorithm about GDOP can be obtained through analyzing the correlation of PDOP (Position Dilution of Precision), HDOP (Horizon Dilution of Precision) and VDOP (Vertical Dilution of Precision)[2].

- **Satellite Clock errors:**

All satellites contain atomic clocks that control all onboard timing operations, including broadcast signal generation. Although, these clocks are highly stable still they lack of perfect synchronization between the timing of the satellite broadcast signals and GPS system time. The satellite clock error is caused by the satellite oscillator not being synchronized to true time (GPS time). The deviation of a particular clock from GPS system time is modeled as a quadratic function of time. The satellite clock error is modelled using the second order polynomial. The correction parameters bias, drift and aging are available in navigation data. It is also known as User Range Error (URE) [3].

- **Ephemeris errors:**

They are differences in the identified and actual position data of the satellite. Ephemeris information is periodically broadcasted from the satellite.An "ephemeris error" is a difference between the expected and actual orbital position of a GPS satellite. Because GPS receivers use the satellite's location in position calculations, orbital error reduces GPS accuracy.It is also known as User Range Error (URE) [4].

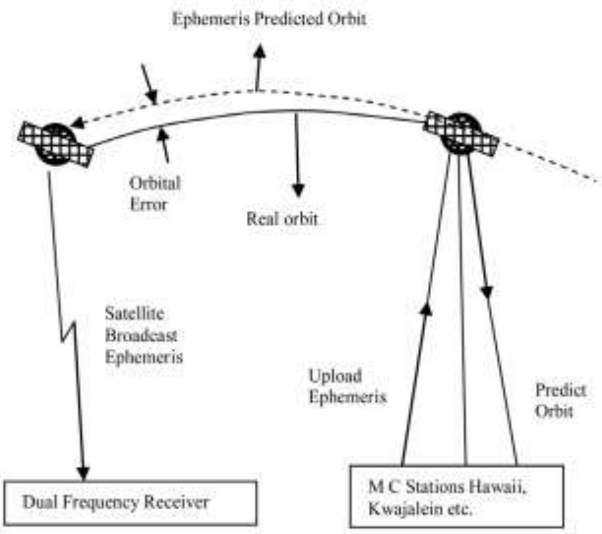

Fig: Satellite Ephemeris error

- **Ionospheric delay:**

The ionospheric layer has massive effects on GPS. These effects are known as the ionospheric delay error which is also indicative of the dispersive nature of the ionosphere. The main parameter of the ionosphere causing the delay in GPS signals is the Total Electron Content (TEC), which is defined as the total number of electrons per square meter along the path from satellite to receiver. The large numbers of TEC are often associated with ionospheric scintillation events that can cause amplitude and phase fluctuations of the GPS signal. In severe conditions, these fluctuations result in the GPS receiver to lose lock .

The ionospheric delay error of the GPS signal varies depending on several factors such as the time of the year, time of day, solar cycle, elevation angle and the user's location. Throughout high solar activity, this delay can cause a vertical ranging error between 5 to 15 m or exceeding 150 m in extreme cases , which greatly affects the performance of GPS navigation.

As such, forecasting and evaluations of transionospheric propagation errors hold important information for satellite and space navigation, radio astronomy applications and space geodesy. Thus, forecasting and assessment of transionospheric propagation errors are required to obtain accurate measurements leading to better results. A number of empirical models such as the Bent model, Klobuchar model , Global Ionospheric Maps (GIMs), and the International Reference Ionosphere (IRI), have been developed to forecast ionospheric variability at different locations worldwide during quiet periods, while producing reasonable forecasting results during geomagnetic storm periods. However, empirical models are not updated frequently. Recently, techniques such as neural network, Autoregressive Moving Average (ARMA), auto regression and self-consistent models have been developed as alternatives to traditional methods for ionospheric prediction purposes[5].

- **Troposheric delay:**

Troposphere is the lower part of atmosphere over the Earth's surface, which mainly consists of nitrogen, oxygen, and a small amount of water vapour. The troposphere has the concentration of about 75% of the atmosphere quality and more than 90% of water quality. The dielectric property of the troposphere changes with the time and space. Therefore, the propagation speed of the radio wave in troposphere is smaller than in vacuum, and the propagation path is bent. These changes coded the tropospheric refraction causes a delay that depends on the actual path of the radio wave and the refractive index of the gases along that path. There are usually two major delay effects of the troposphere which cause a delay about 2.5m totally. The first and larger effect is a dry atmosphere excess delay caused primarily by oxygen and nitrogen, which corresponds to approximately 2.3m accounting for 80%-90% in total genera. The second effect-the wet atmosphere is generally smaller, about 0.3m at zenith direction accounted for the total delay of 10%-20%. The troposphere has obvious large-scale changes superposed with the local atmospheric turbulence usually. Because of the right irregular changes, it is very difficult to accurately forecast the tropospheric delay besides the method of statistical research. Many domestic and foreign scholars have been extensively studied and put forward some methods of tropospheric delay error correction, such as ray tracing method, delay parameter estimation method and model correction method, and the model correction method is widely used [6].The effect of the troposphere on the GNSS signals appears as an extra delay in the measurement of the signal traveling from the satellite to receiver. This delay depends on the temperature, pressure, humidity as well as the transmitter and receiver antennas location.

- **Multipath error:**

Errors caused when a satellite signal reaches the receiver from two or more paths, one directly from the satellite and the others reflected from nearby buildings or other surfaces. Multipath is defined as the presence of multiple signal paths between a transmitter and a receiver due to reflection and diffraction. In GPS the desired signal is the direct path signal only. All other signals distort the desired signal and lead to ranging measurement errors [7].Multipath remains a dominant source of ranging errors in Global Navigation Satellite Systems (GNSS), such as the Global Positioning System (GPS) or the future European satellite navigation system Galileo. Multipath is generally considered undesirable in the context of GNSS, since the reception of multipath can make significant distortion to the shape of the correlation function used for time delay estimation. However, some wireless communications techniques exploit multipath in order to provide signal diversity though in GNSS, the major challenge is to effectively mitigate the multipath, since we are interested only in the satellite-receiver transit time offset of the Line-Of-Sight (LOS) signal for the receiver's position estimate. Therefore, the multipath problem has been approached from several directions in order to mitigate the impact of multipath on navigation receivers, including the development of novel signal processing techniques.

Several approaches have been used in order to reduce the multipath error. Among them, the use of special multipath-limiting antennas (i.e., choke ring or multibeam antennas), the postprocessing techniques to reduce carrier multipath, the carrier smoothing to reduce code multipath, and the code-tracking algorithms based on receiver internal correlation technique are the most prominent approaches [8].

Multipath is a significant error source in non-differential applications as well now that selective availability has

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been deactivated. The significance of multipath as as error source has led to the development of various multipath mitigation techniques. These ranges from antenna design and siting techniques to receiver architecture design and post-processing of observables [7].With the development and modernization of GNSS, receivers are approaching the theoretical accuracy limits when processing ideal signals. However, in reality there are no ideal GNSS signals due to the presence of different errors. Differential techniques can reduce or even remove most of the errors, except multipath error , since multipath signals of different receivers are not correlated . Traditional GNSS receiver uses a Delay Lock Loop (DLL) to track the spreading code and a Phase Lock Loop (PLL) to track the carrier. However, in a multipath environment, the multipath signal will distort the autocorrelation function of the GNSS signal, and introduce code error to the DLL that keeps the power values of Early and Late correlators equal. Meanwhile, the carrier phase of the received composite signal will be different from the direct-path signal, which will introduce a carrier error to the PLL.

There are many techniques researched to reduce multipath error in the receiver. Several of them are about the design of the antenna and its location , others are digital signal processing techniques. The digital signal processing techniques can be classified into two groups. The first group is to estimate the amplitude, time-delay and carrier phase of each multipath component. Then uses these estimated values to remove the multipath effect, thus restoring direct-path signal. Such techniques include Multipath Estimating Delay Lock Loop (MEDLL), Modified RAKE Delay Lock Loop (MRDLL), Multipath Mitigation Technology (MMT), Vision Correlator (VC), TurboDLL and others. These techniques have better performance, but they either consume too much hardware resources or need complex calculation. For example, MEDLL and MRDLL need many correlators to get correlation samples at different code phases. Then, the samples are calculated using maximum likelihood (ML) criteria to estimate the multipath signals' parameters. The Turbo architecture needs an extra amplitude lock loop (ALL) to estimate the amplitude of corresponding component, and uses complex monitor block methodology to adjust the states of the units. Another group of techniques does not involve estimation of multipath parameters. They reduce the multipath effect by improving the correlator's performance and the code loop discriminator. The representative techniques of this group are Narrow Correlator, Multipath Elimination Technology (MET), Strobe and Edge Correlator and so on. Such techniques are easy to implement, and they do not need many hardware resources or complex calculation, but the remaining multipath error can still be considerable [9].

IV. Various techniques to mitigate multipath based on Correlation

The classical correlation-based code tracking structure used in GNSS is based on a feedback delay estimator and is implemented via a feedback loop. The most known feedback-delay estimator is the Delay Lock Loop (DLL) or Early-Minus-Late (EML) loop.

- **Delay Lock Loop (DLL):**

In DLL, two correlators spaced at one chip from each other are used in the receiver in order to form a discriminator function, whose zero crossings determine the path delays of the received signal. The classical EML fails to cope with multipath propagation. Therefore, several enhanced EML-based techniques have been introduced in the literature for the last two decades in order to mitigate the impact of multipath, especially in closely spaced path scenarios [8].

- **Narrow Correlator:**

One class of these enhanced EML techniques is based on the idea of narrowing the spacing between the early and late correlators, that is, narrow EML (nEML) or narrow correlator. The choice of correlator spacing depends on the receiver's available front-end bandwidth along with the associated sampling frequency. Correlator spacings in the range of 0.05 to 0.2 chips are commercially available for nEML-based GPS receivers [8].

- **Double Delta technique:**

Ituses more than 3 correlators in the tracking loop (typically, 5 correlators: two early, one in prompt and two late). It offers better multipath rejection in medium-to-long delay multipath in good Carrier-to-Noise-density ratio (C/N_0). Couple of well-known particular cases of Double Delta technique are the High Resolution Correlator (HRC), the Strobe Correlator (SC), the Pulse Aperture Correlator (PAC), and the modified correlator reference waveform [8].

- **Multiple Gate Delay (MGD) correlator:**

Here, the number of early and late gates and the weighting factors used to combine them in the discriminator are the parameters of the model and can be optimized according to the multipath profile. While coping better with the ambiguities of BOC correlation function, the MGD provides slightly better performance than the nEML at the expense of higher complexity and is sensitive to the parameters chosen in the discriminator function (i.e., weights, number of correlators, and correlator spacing). Double Delta technique is a particular case of MGD implementation [8].

- **Early1/Early2 (E1/E2) tracker:**

It is closely related to Double Delta technique**.** In (E1/E2)tracker**,** the main purpose is to find a tracking point on the correlation function that is not distorted by multipath. The first step is to locate two correlators on the early slope of the correlation function. The correlation values of these two early correlators are then compared with the correlation values of an ideal reference correlation function. Finally, a delay-correction factor is computed based on the measured and reference correlation values of E1 and E2 correlators. It shows some performance improvement over Double Delta technique only for very short delay multipath for GPS L1 C/A signal (i.e., BPSK signal) [8].

- **Early-Late-Slope:**

Itis also known as Multipath Elimination Technique (MET). The ELS is based on two correlator pairs at both sides of the correlation function's central peak with parameterized spacing.
Once both slopes are known, they can be used to compute a pseudo range correction that can be applied to the pseudo range measurement [8].

- **A-Posteriori Multipath Estimation (APME):**

It isa new multipath-estimation technique which relies on a posteriori estimation of the multipath error tracking. Multipath error is estimated independently in a multipath-estimator module on the basis of the correlation values from the prompt and very late correlators.
The performance in multipath environment is comparable with that of the SC: slight improvement for very short delays (i.e., delays less than 20 meters), but rather significant deterioration for medium delays [8].

- **Slope-based Multipath Estimator (SBME):**

SBME first derives a multipath estimation equation by utilizing the correlation shape of the ideal normalized correlation function, which is then used to compensate for the multipath bias of an nEML tracking loop. SBME requires an additional correlator at the late side of the correlation function, and it is used in-conjunction with an nEML tracking loop. SBME has superior multipath mitigation performance than nEML in closely spaced two paths channel model [8].

- **Multipath Estimating Delay Lock Loop (MEDLL):**

One of the most promising advanced multipath mitigation techniques is the Multipath Estimating Delay Lock Loop (MEDLL) implemented by NovAtel for GPS receivers. The MEDLL uses many correlators in order to determine accurately the shape of the multipath corrupted correlation function. Then, a reference function is used in a software module in order to determine the best combination of LOS and Non-LOS (NLOS) components (i.e., amplitudes, delays, phases, and number of multipath). However, MEDLL provides superior long-delay multipath mitigation performance than nEML at the cost of expensive multi correlator-based tracking structure. MEDLL is considered as a significant evolutionary step in the receiver-based attempt to mitigate-multipath. Moreover, MEDLL has stimulated the design of different maximum likelihood-based implementations for multipath mitigation. Classical MEDLL is based on a maximum likelihood search, which is computationally extensive [8].

- **Correlator Reference Waveform:**

This technique, referred to as second derivative correlator, generates a signal correlation function which has a much narrower width than a standard correlation function and is, therefore, capable of mitigating multipath errors over a much wider range of secondary path delays. The narrowing of correlation function is accomplished by using a specially designed code reference waveform (i.e., the negative of the second-order derivative of correlation function) instead of the ideal code waveform used in almost all existing receivers. However, this new technique reduces the multipath errors at the expense of a moderate decrease in the effective Signal-to-Noise Ratio (SNR) due to the effect of narrowing the correlation function [8].

- **Vision Correlator (VC):**

A completely different approach to mitigate multipath error is used in NovAtel's recently developed vision correlator. The Vision Correlator (VC) is based on the concept of Multipath Mitigation Technique (MMT). It can provide a significant improvement in detecting and removing multipath signals as compared to other standard multipath-resistant code-tracking algorithms (e.g., PAC of NovAtel). However, VC has the shortcoming that it requires a reference function shape to be used to fit the incoming data with the direct path and the secondary path reference signals. The reference function generation has to be accomplished a priori, and it must incorporate the issues related to Radio Frequency (RF) distortions introduced by RF front end [8].

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- **Modified Rake Delay Locked Loop:**

It need many correlators to get correlation samples at different code phases. Then, the samples are calculated using maximum likelihood (ML) criteria to estimate the multipath signal's parameters [9].

- **Modified Rake (MRake):**

It is used to reduce multipath error in GNSS Receiver. It derives from the Rake Receiver in Communication System.It tracks direct path and multipath components of the received signal separately, and uses the time-delay of direct-path component to calculate the user's position. The architecture belongs to the first group of techniques that have better performance, but it is easy to implement, and do not need much hardware resources or complex calculation. According to the theoretical analysis, the MRake architecture needs M+1 Fingers if M multipath signals exist. It uses an Adaptive Finger Controller (AFC) to adaptively adjust the states of the Fingers, including turning on, detection, tracking and turning off. Each Finger first subtracts the components tracked by all the other Fingers from the received composite signal, and then tracks the remaining component. An Amplitude Estimation Unit (AEU) in each Finger estimates the amplitude of corresponding component according to the correlation value. And the noncoherent DLL in the Finger adaptively controls the time-delay of each component. In this way, the MRake architecture can estimate the multipath parameters easily. According to the simulation results study, it is advisable to choose 2-Finger MRake architecture for its cost-effective characteristic [9].

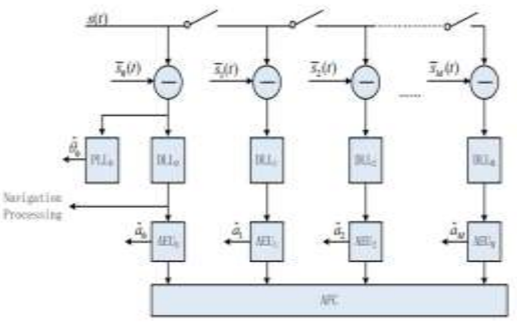

Fig: Block diagram of MRake architecture[9]

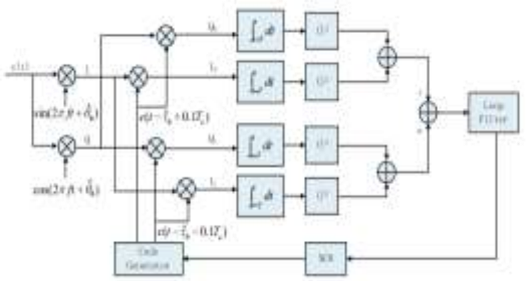

Fig: Block diagram of noncoherent DLL[9]

V. CONCLUSION

In the proposed paper GNSS principle based on DS-CDMA technique has been discussed. In estimating the User position various error occurs and have been discussed in detail. Most of the errors such as ionospheric error, satellite and clock error, ephemeris error are being improved using various models. The multipath error has also significant effect on GNSS position. Though various techniques are available for improving this error, however the Rake Receiver technique which is commonly used in Communication System will enhance the performance of GNSS System.

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