# Mitigation of Ionospheric Scintillation on Global Positioning System (GPS) Using Hamming and Convolutional Coding Techniques

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**Abstract**—The Global Positioning System (GPS) is a satellite-based system that can be used to locate positions anywhere on the earth surface. Any person with a GPS receiver can access the system, and it can be used for application that requires location coordinates. Currently, ionospheric scintillation is the largest error source in GPS. Scintillation causes some effects such as degradation of receiver tracking performance and in extreme cases, total loss of navigation capabilities. Ionospheric scintillation is a problem for satellite communication because it affects the amplitude and phase of radio signals. A decrease in the amplitude of a radio signal reduces its power level which directly affects the signal to noise ratio, thus affecting a base station's ability to detect and receive the signal. Error correction codes techniques are applied in almost all digital systems as they provide better performance for dealing with the unwanted signal (noise). This research work has investigated the performance of hamming and convolutional coding techniques in mitigating error in GPS signal modeled in MATLAB/Simulink by transmitting randomly generated data through a Rayleigh fading channel. The performance metric employed in evaluating the system is Bit Error Rate (BER). The simulation results showed a comparison of the BER performance of the uncoded and coded signals (using Hamming and Convolutional coding techniques).

**Keywords**—Global Positioning System, Ionosphere, Scintillation, Coding techniques

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## 1 INTRODUCTION

In the last thirty years, the world has experienced a dramatic change in the way communication is achieved. Wireless communication has evolved from being an expensive and rare technology for the few in the early 70's, to becoming a widespread and economical means for facilitating domestic, commercial, as well as public service communications. One of the major reasons for the continuous growth and development in the use of wireless communication is its increasing ability to provide efficient communication links to almost any location, at constantly reducing costs with increasing power efficiency (Jemibewon, 2000). GPS being an example of wireless communication, is a modern satellite based navigation system, created and designed by the US Department of Defense (DoD) and was originally run with 24 satellites which became fully operational in 1995 and the invention is credited to Bradford Parkinson, Roger L. Easton and Ivan A. Getting. GPS was developed in 1973; the system provides critical capabilities to military, civil and commercial users around the world.

The United States of America operates the GPS which is accessible to people with a GPS receiver. GPS can propagate signals that are 20.2 km from Medium-Earth Orbit (MEO) to the surface of the Earth and so, the received signals are extremely weak and of the order of 10-16watts. In addition, the navigation message signal which includes satellite orbital parameters, ionospheric error correction coefficients for single frequency receivers, satellite health and clock correction polynomials are affected by various errors and weakened by Radio Frequency Interference (RFI) and signal obstructions which are caused by a phenomena exhibited in ionosphere; which is a strata of the earth atmosphere, made up of volume of ions and divided into three layers. This phenomenon is known as ionospheric scintillation.

Ionospheric scintillation is the rapid change in either phase or amplitude or both of a radio signal as it passes through small scale plasma density irregularities in the ionosphere (Komjathy, 1997). Scintillation occurs when an RF signal in the form of a plane wave transverses a region of small scale irregularities in ions or electron density. The interaction between the ions brings about a concentration of ions forming cylindrical shapes that align along the magnetic line of force, (Radicella and Leitinger, 2001). These cylinders are typically 100 to 1000 feet in diameter and 10 to 100 miles long.

Ionospheric scintillation is greater in equatorial and high-latitude region but it also occurs at lower intensity at other latitudes. While ionospheric scintillation occurs all over the globe, scintillation associated with the equatorial region has received the most attention for a number of reasons. They are very pronounced in equatorial regions where they appear every day after sunset and may last a few hours. The irregularities bring about small scale fluctuation in refractive index and subsequent scattering of the plane wave producing phase variation and signal distortion (Forte et al, 2002). As the signal passes the region of irregularities of electron density, the noise floor of this signal is 400 times higher than the transmitted signal. Since the accuracy of navigation data is highly essential to obtain precise GPS receiver position fix, it is important that the orbital parameters gotten from the navigation message are accurate and are not affected by interference due to scintillation which is the reason for this research.

### 1.1 Review of Ionospheric Scintillation

The concentration of electrons in the ionosphere is affected primarily by the solar wind, solar flares, and electromagnetic radiation from the sun. Solar flares and the solar wind carry charged particles from the sun. When they reach the

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Earth, some of them are trapped in the Earth's magnetic field, thus adding to the total electron count. The intensity of solar flares and solar wind is closely related to the number of sunspots which fluctuates on the eleven year solar cycle. Thus, the effects of ionospheric scintillation are increased during the solar maximum and decreased during the solar minimum (El-Arini et al, 1994). As the radiation intensity increases, it penetrates further into the atmosphere and hence increases the concentration of electrons and charged particles. Therefore regions of the atmosphere closer to the sun typically have increased electron concentrations. As a result, there is a daily mid-day scintillation peak in regions nearest to the equator particularly within the tropics of Cancer and Capricorn. Similarly the total electron count also increases biannually during the spring and autumnal equinoxes when the earth is most exposed to the sun. It has also been observed that effects of scintillation are very prominent during the evening hours, sometimes even stronger than during the mid-day peak. This is explained by the Appleton anomaly, in which the F layer (also known as the Appleton layer) of the ionosphere has an increase in the number of electrons during the evening hours.

### 1.2 Effect of Ionospheric Scintillation on GPS Signal

Currently, the largest error source in GPS is due to the ionospheric scintillation. Scintillation causes degradation in receiver tracking performance and, in extreme cases, loss of navigation capabilities. It affects trans–ionospheric radio signals up to a few GHz in frequency and as such has detrimental impacts on satellite-based communication and navigation systems such as GPS and also on scientific instruments requiring observation of trans-ionospheric radio signals. The depth of fading caused by equatorial ionospheric scintillation is generally greater than for mid-latitudes or Polar Regions. Reduction in the amplitude of a radio signal reduces its power level which directly affects the signal to noise ratio, thus hindering a base station's ability to detect and receive the signal. Phase shifts can cause destructive interference in which the crests and troughs of a signal cancel each other resulting in spectral nulls and fading. Fading, the temporary loss of a signal due to attenuation or destructive interference, increases the bit error rate due to lost bits.

## 2 METHODOLOGY

GPS signals are particularly vulnerable to ionospheric scintillation primarily because they are low-power spread spectrum signals transmitted below the noise floor. GPS signal strength is typically measured by its carrier to noise density ratio, C/N0. The signal to noise ratio (SNR) is generally expressed in dB and is a ratio of the signal to noise power in a given bandwidth. C/N0 on the other hand is expressed in dB-Hz and is a ratio of the signal to noise power per unit bandwidth. The relation between SNR and C/N0 can be represented by equations (1) and (2).

$$\mathrm{SNR} = \frac{C/N_0}{\mathrm{BW}} \tag{1}$$

Or in decibel (dB)

$$\mathrm{SNR} = 10\log\frac{C}{(BW).N_0} \tag{2}$$

Where C is the carrier signal density, $N_o$ is the noise signal density and BW is the bandwidth.

### 2.1 Signal to Noise Ratio

Signal to noise ratio (SNR) is a performance metric used in science and engineering that compares the level of a desired signal to the level of background noise (unwanted signal). It is the ratio of signal power to the noise power. Signal to noise ratio is sometimes used informally to refer to the ratio of useful information to false or irrelevant data in a conversation or exchange. Thus, signal to noise ratio is given by equation (3)

$$SNR = \frac{P_{signal}}{P_{noise}} \tag{3}$$

where $P_{signal}$ is the average power of the desired signal, $P_{noise}$is the average power of the unwanted signal.

If the signal and the noise are measured across the same impedance, then the SNR can be obtained by calculating the square of the amplitude ratio as shown in equation (4):

$$\mathrm{SNR} = \left(\frac{A_{signal}}{A_{noise}}\right)^2 \tag{4}$$

Where$A_{signal}$and $A_{noise}$are the root mean square (RMS) amplitudes of the desired signal and unwanted signal respectively.

In decibels, the SNR is defined asshown in equation (5):

$$SNR_{dB} = 10\log\left(\frac{P_{signal}}{P_{noise}}\right) \tag{5}$$

This may be written in term of amplitude ratio as shown in equation (6):

$$SNR_{dB} = 20\log\left(\frac{A_{signal}}{A_{noise}}\right) \tag{6}$$

The noise in the signal transmitted comes in various forms as the case may be. It includes internal electronic noise and there can also be external occurrence that affects the accuracy of the signal such as wind, humidity, gravitation attraction of the moon, ionospheric scintillation, variations in temperature etc. Noise is known to change the content or characteristic of a particular signal which can be extracted fromthe channel.

### 2.2 Bit Error Rate

In digital communication, the number of bit errors is the number of received bits of a data stream over a communication channel that have been changed due to noise, interference, distortion etc. The bit error rate or bit error ratio (BER) is the number of bits errors divided by the total number of transferred bits during a particular period of time. The transmission BER is the number of detected bits that are incorrect before error correction, divided by the total number of transferred bits, (Ojo et al, 2012). BER performance and power dissipation are two important degree of performance used to characterize communication systems. The lower the Bit Error Rate (BER) performance of a system, the more efficient it is in correcting errors.

## 2.3 Coding Techniques

### 2.3.1 Hamming Code

In this research, Hamming Code is employed as one of the coding techniques. Hamming Codes send m information bits padded with a specific k parity-check bits. They have the ability to correct any single mistake. They manage this by having the k parity-check bits set at positions 1, 2, …, 2k-1 and checking every element whose binary representation has a "1" in position ki$^{-1}$. For example, bit 4 would check the sum of the parities in positions 100,101,110, 111, 1100, 1101, = 4, 5, 6, 7, 12, 13 … Encoding a message in this manner is computationally simple and understandable. Decoding it and determining where there is an error turns out to be just as simple (Valenti, 1999).

Hamming code is implemented by simulations in the Matlab R2013a version. A random integer is generated from the Bernoulli generator block sending 106 bits of signal. The Hamming encoder encrypts the signal and transmits it to the modulator passing through the Rayleigh fading channel which is the model of ionospheric scintillation. The hamming decoder dis-encrypts the signal to correct any error by performing a process called parity checking and finally the BER calculator to display the number of errors detected. Fig. 1 shows the Hamming encoded GPS signal during ionospheric scintillation using Simulink

### 2.3.2 Convolutional Codes

Convolutional codes are extensively used for real time error correction. Convolutional coding is done by combining the fixed number of input bits. The input bits are stored in fixed length shift register and they are combined with the help of modulo-2 adders. An input sequence and contents of shift registers perform modulo-2 addition after information sequence can be sent to shift registers, so that an output sequence is obtained, (Cheong, 2007). This operation is equivalent to binary convolution and hence it is called convolutional coding.

Bernoulli generator is used to generate polynomial for this research. An m-bit delayed source bit is added on the modulo-2 basis to obtain the nth encoded bit. The polynomial generator of the convolution code is selected based on the code's free distance properties. The coding rate (R) which is defined as the ratio of the input data bit n to the output data bit k is taken as shown in equation(7):

$$R = \frac{k}{n} < 1 \qquad (7)$$

The coding rate of the Convolutional code used is 1/2.

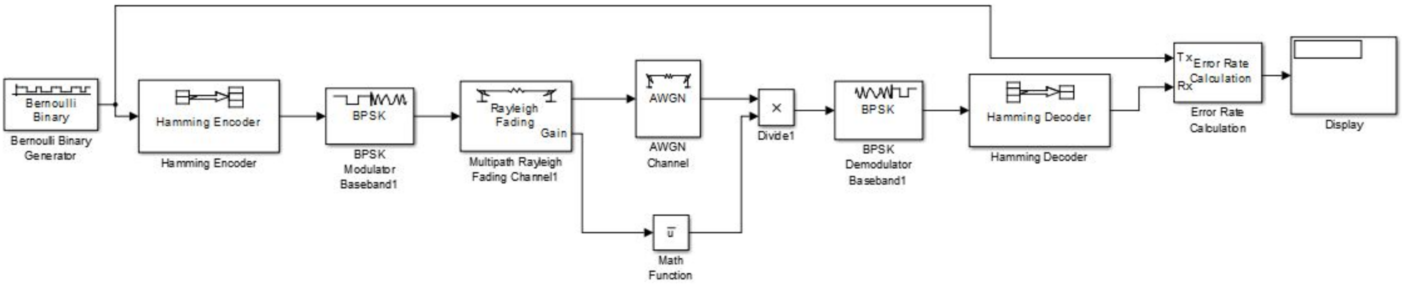

Fig. 1. Hamming encoded GPS signal during ionospheric scintillation using simulink

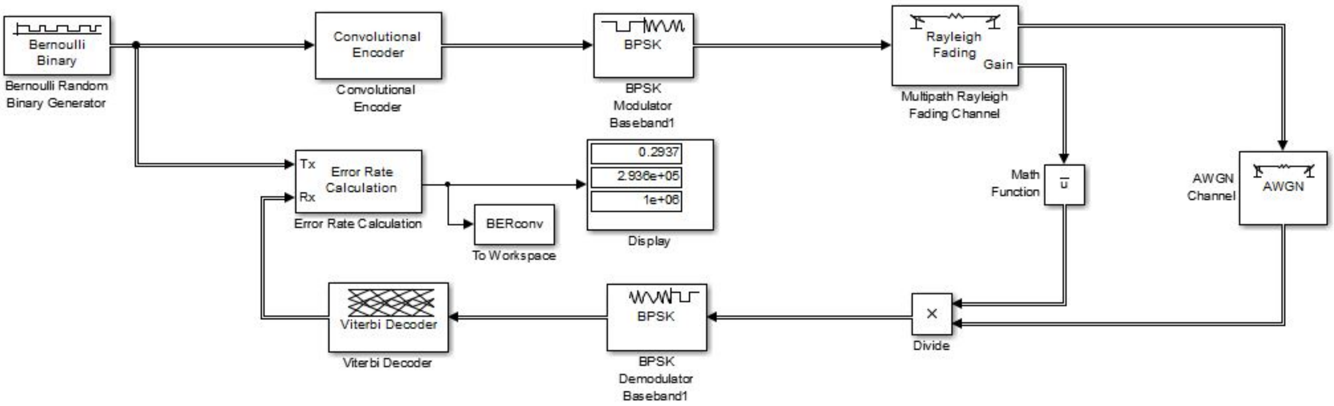

Fig 2. Convolutional encoded GPS signal during ionospheric scintillation using simulink

The convolutional encoded GPS signal during ionospheric scintillation using simulink and the flowchart of Convolutional and Hamming coded GPS signal during ionospheric scintillation are shown in Fig. 2 and Fig. 3 respectively.

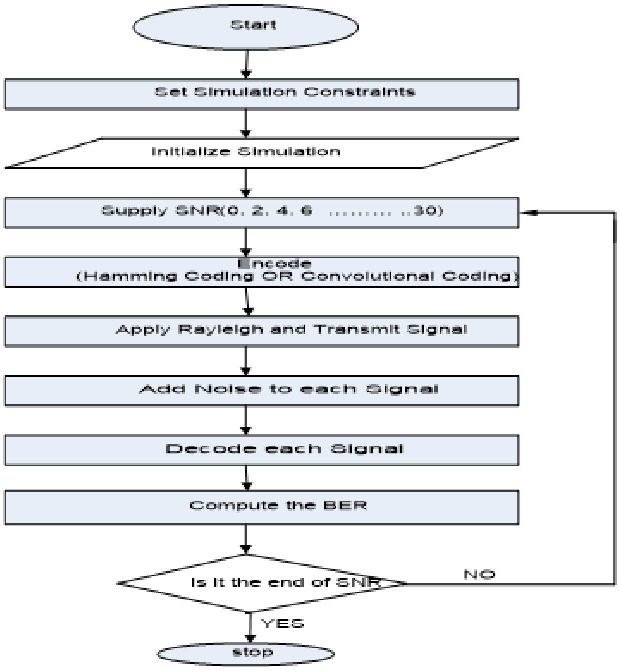

Fig. 3. Flowchart of Convolutional and Hamming coded GPS signal during ionospheric scintillation.

## 3 RESULTS AND DISCUSSION

The codes are implemented through simulations in the Matlab R2013a software package. The results obtained show an optimal mitigation against ionospheric scintillation in GPS using coding techniques compare to uncoded signals by transmitting 106 symbols. The BER performance of Coded and Uncoded Signals is presented in Table 1.

The effect of ionospheric scintillation on GPS signal is shown in Fig. 4. GPS signals transmitted between 0dB and 12dB fluctuate resulting in distortion in the signal received at the GPS receiver`s end which results in unreliable information. However, as SNR increases from 13dB to 20dB, the BER becomes constant at a value of 10-0.3006, (which is 0.5005 as shown in Table 1) thereby reducing the fluctuating effect of ionospheric scintillation on GPS signal but can be affected if the strength of the scintillation increases in which the SNR of the GPS must be increased to have a stable BER as it is observed between SNR of 22dB to 30dB. This has a direct effect on the cost of transmitting GPS since more power is required to transmit at such high level and does not bring about (effectiveness and compatibility) making the cost of subscription by consumers high.

Table 1. BER Performance of Coded and Uncoded Signals

| SNR | Hamming coded | | convolutional | | Uncoded | |
|---|---|---|---|---|---|---|
| | BER | Errors | BER | Errors | BER | Errors |
| 0 | 0.1166 | 100 | 0.2937 | $2.936e^{5}$ | 0.5003 | $5.003e^{5}$ |
| 2 | 0.08914 | 101 | 0.205 | $2.05e^{5}$ | 0.5002 | $5.002e^{5}$ |
| 4 | 0.08494 | 100 | 0.1309 | $1.309e^{5}$ | 0.5002 | $5.002e^{5}$ |
| 6 | 0.0487 | 105 | 0.07922 | $7.922e^{4}$ | 0.5002 | $5.004e^{5}$ |
| 8 | 0.02725 | 101 | 0.04554 | $4.554e^{4}$ | 0.5004 | $5.003e^{5}$ |
| 10 | 0.02108 | 101 | 0.02517 | $2.517e^{4}$ | 0.5003 | $5.004e^{5}$ |
| 12 | 0.01574 | 102 | 0.01346 | $1.346e^{4}$ | 0.5006 | $5.005e^{5}$ |
| 14 | 0.00779 | 100 | 0.006976 | 6976 | 0.5005 | $5.005e^{5}$ |
| 16 | 0.004492 | 101 | 0.003392 | 3392 | 0.5005 | $5.005e^{5}$ |
| 18 | 0.003389 | 101 | 0.001651 | 1651 | 0.5005 | $5.005e^{5}$ |
| 20 | 0.002199 | 101 | 0.000728 | 728 | 0.5005 | $5.004e^{5}$ |
| 22 | 0.00112 | 101 | 0.00034 | 340 | 0.5004 | $5.004e^{5}$ |
| 24 | 0.0007828 | 101 | 0.000138 | 138 | 0.5004 | $5.004e^{5}$ |
| 26 | 0.000384 | 103 | 0.000032 | 32 | 0.5004 | $5.004e^{5}$ |
| 28 | 0.0001714 | 101 | 0.000017 | 17 | 0.5004 | $5.004e^{5}$ |
| 30 | 0.000099 | 99 | 0.00008 | 8 | 0.5004 | $5.004e^{5}$ |

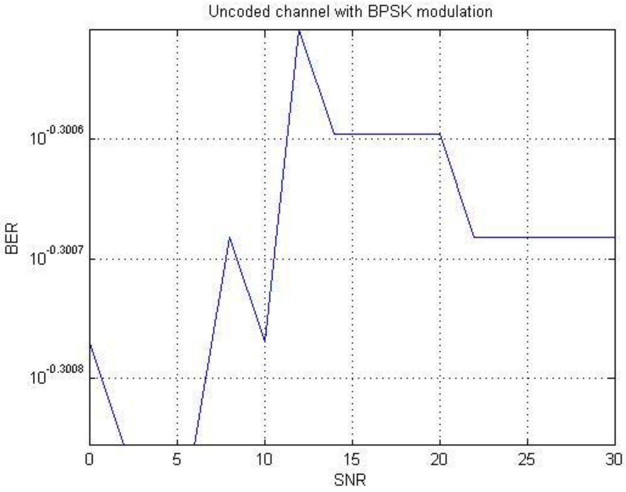

Fig. 4. Graph of BER against SNR of GPS signal during ionospheric scintillation for an uncoded channel.

The performance of BER against SNR (dB) of Hamming Coded, Convolutional Coded and Uncoded signals of GPS signal during Ionospheric Scintillation is shown in Fig. 5. At all SNR (0-30dB), a steady decrease in the BER performance when compared to the uncoded GPS signal shows that Hamming code has about 93.3% capability more in reducing the effect of ionospheric scintillation which reduces the power needed to transmit at the same signal to noise ratio as observed between SNR of 10dB and 15dB, thereby conserving the power generated by solar panel. At SNR of 30dB, there is more protection for the GPS signal against signal fading; it is thereby advisable to transmit at a high transmitting power during ionospheric scintillation.

Consequently, a steady decrease in the BER performance when compared to the uncoded GPS signal shows that Convolutional code has 89.9% capability more in reducing the effect of ionospheric scintillation which also reduces the power needed to transmit at the same signal to noise ratio as observed between SNR of 0dB and 27dB, thereby conserving the power generated by the power source. It is observed that from SNR of 27dB, there is a sharp increase in the BER of Convolutional coded signal which signifies an increased number of errors in GPS signal, to avoid this, transmitting power during ionospheric scintillation should be limited to 27dB.

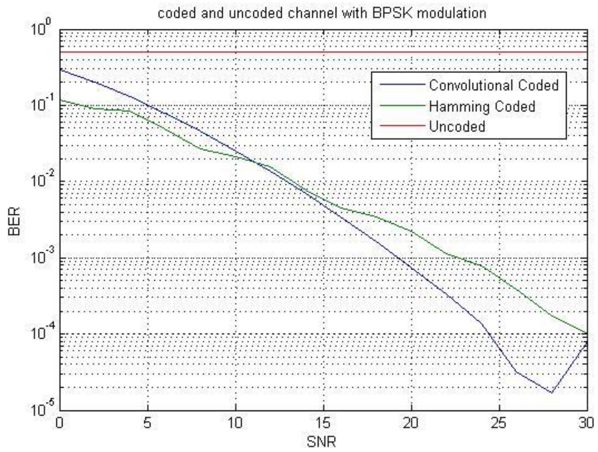

Fig. 5. BER Performance against SNR (dB) of Hamming Coded, Convolutional Coded and Uncoded Signals of GPS Signal during Ionospheric Scintillation.

## 4 CONCLUSION

This paper has shown the impact of mitigation of ionospheric scintillation on GPS signal using coding techniques. It is observed that Hamming code has better capability to correct errors in GPS signal at SNR higher than 27dB which might be required based on the strength of ionospheric scintillation in different regions of the world than Convolutional code. Furthermore, between 0dB and 27dB, Convolutional code corrects error 47% better than Hamming code, signifying a signal to noise ratio (threshold dB) with which Convolutional code is to be used in mitigating ionospheric scintillation on GPS signal. Based on the results of the graphs, it is evident that there was a 30.4% and 58% improvement on coding gains between reference points of 0dB and 30dB for the two codes used. This improvement can be attributed to the introduction of the Hamming code and Convolution code.

## 5 RECOMMENDATIONS

This research can be extended to other schemes of modulation such as QAM, PSK, M-PSK and other models of ionospheric scintillation such as Rician fading and Klobuchar model. Higher rates of Hamming code and Convolutional code can also be used.

## 6 ACKNOWLEDGEMENTS

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