GPS Navigation Data error correction : A Comparison of existing (15,11) Hamming with a new design using 1/3 8 state Convolutional Code

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ABSTRACT

Global Positioning System (GPS) navigation signal includes vital information such as orbital parameters, clock error coefficients etc. This received signal is affected by various errors during its propagation, is extremely weak and of the order of 10^{-16} W. The noise floor of this signal is 400 times higher than the transmitted signal. Accuracy of navigation data is essential to obtain precise GPS receiver position fix. Use of Forward Error Correction (FEC) scheme is a method used for obtaining such accuracy. In the present system (15, 11) Hamming error correction scheme is being used which can correct only one error. In this paper, the 1/3 8 state Convolutional coding scheme has been designed and is proposed in place of the existing Hamming codes. Finally their performance is also compared. At an E_b/N_0 value of 5dB, the Bit Error Rate obtained with the proposed 1/3 rate, 8-state, BPSK modulated convolutional code is 10^{-4} compared to the BER of 10^{-3} obtained using a (15, 11) Hamming code when passed through AWGN channel.

Keywords- Convolutional code, FEC scheme, GPS, Hamming code, Navigation data.

I. INTRODUCTION

Global Positioning System (GPS) is a modern satellite based navigation system designed and developed by the Department of Defence (DoD), USA and available anywhere in the world with minimal 24 satellite constellation [1]. It is an all weather, line of sight radio navigation and positioning system. GPS signals propagate 20,200 kilometers from medium-earth orbit to the surface of the Earth and so, the received signals are extremely weak and of the order of 10^{-16} Watts. The GPS satellite transmitted signal is modulated by two crucial components: Navigation data and Pseudorange (PRN) Code [2]. These two components have to be extracted accurately from the composite signal at the user side for precise GPS receiver antenna position computation. The navigation data signal consists of information such as satellite orbital parameters, ionospheric error correction coefficients for single frequency receivers, satellite health and clock correction polynomials. However, the navigation message signal is affected by various errors and weakened by Radio Frequency Interference (RFI) and signal obstructions. Satellite ephemeris errors are errors in the prediction of a satellite's position, which may then be translated into the receiver position computation. Measurement errors are also introduced by the propagation delays in the ionosphere and the troposphere, signal distortion due to multipath, relativistic effects and receiver noise. A small change in the value of an ephemeris parameter drastically alters the receiver position. As an example, any change in the angle of inclination, *'i'* leads to the identification of an entirely different satellite orbit thereby resulting in erroneous determination of the user position. Hence, to determine the navigation solution, it is important that the orbital parameters those are extracted from the navigation message are accurate and are not unduly affected by interference.

Accurate determination of satellite orbital parameters contained in the navigation signal can be achieved either by:-

1) Incorporating an advanced signal processing technique at the receiver.
2) Introducing a suitable FEC scheme for the transmitted navigation data.

In this paper, the design using second method is proposed wherein the convolution encoding techniques have been used and preliminary results of the work are also provided.
This paper is divided into 5 sections. The first section discusses the need for implementing FEC scheme in respect of GPS navigation data. The second section covers the features of the GPS system with including the format of the GPS navigation data. The third section introduces Hamming and Convolutional codes. The next section presents the results obtained from the proposed design and the concluding comments form the final section.

II. GPS NAVIGATION DATA

Navigation data is defined as a binary coded message consisting of data on the satellite health status, ephemeris, clock bias parameters, and an almanac giving reduced-precision ephemeris data on all satellites in the constellation.

A. Navigation Message Format

The navigation message transmitted by each GPS satellite contains the ephemeris of that satellite and the almanac data of all the satellites in the GPS satellite constellation [3]. The ephemeris is the satellite orbital parameters that include the satellite's position, velocity, and clock bias parameters. The almanac includes reduced precision information about all the GPS satellites in the constellation. Navigation message is a continuous data stream transmitted at the rate of 50bps (bits per second). The navigation message is required to calculate the current position of the satellites and to determine signal travel times. The navigation message from each satellite carries the following information to earth:

1) Satellite time of transmission
2) Satellite position (determined from the broadcast orbital data (ephemeris))
3) Satellite health
4) Satellite clock correction
5) Propagation delay effects
6) Time transfer to UTC
7) Constellation status (almanac)

Navigation message has the following characteristics:

1) Data is a continuous stream of 50bps.
2) It is modulated onto the carrier wave of each individual satellite and transmitted in logically grouped units known as frames or pages
3) A complete navigation message consists of 25 frames
4) Each frame is 1500 bits long and takes 30 seconds for transmission. The frames are divided into 5 sub frames.
5) Each subframe is 300 bits long and takes 6 seconds for transmission. It is in turn divided into 10 words, each containing 30 bits [6]. Each subframe begins with a telemetry word and a hand over word
6) Transmission time for the entire data is therefore 12.5 minutes.

The structure of the navigation message is illustrated in Fig. 1.

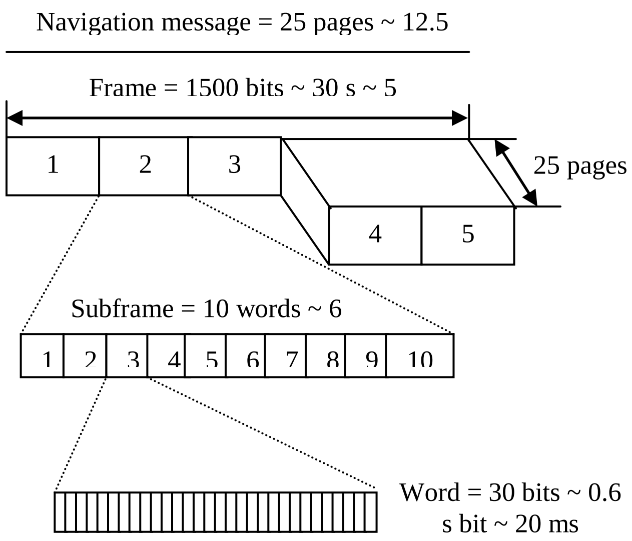

Fig. 1 Structure of the navigation message

A frame is divided into five subframes, each subframe is transmitting different information.

1) Subframe 1 contains the time values of the transmitting satellite including the parameters for correcting signal transit delay, onboard clock time as well as information on satellite health and an estimate of the positional accuracy of the satellite. It transmits the 10-bit week number.
2) Subframes 2 and 3 contain the ephemeris data of the transmitting satellite. This data provides extremely accurate information on the orbit of the satellite.
3) Subframe 4 contains the almanac data on satellite numbers 25 to 32, the difference between GPS and Universal Coordinated Time (UTC) and information regarding any measurement errors that are caused by the ionosphere.
4) Subframe 5 contains the almanac data on satellite numbers 1 to 24 (each subframe can transmit data from one satellite only). All 25 pages are transmitted along with the information on the health of satellite numbers 1 to 24.

III. ERROR CORRECTION CODING

Even without malicious intervention, ensuring uncorrupted data is a difficult problem. Data is sent through noisy pathways and it is common for an occasional bit to flip. This effect has always been present, but its effects have heightened as technology increased [4]. There is a provable maximum accuracy called the Shannon limit, but while it is theoretically interesting to know that there is fundamentally a 'best' code, it does not create a practical code that functions at this limit.

Research has led to a number of techniques that introduce redundancy to allow for correction of errors without retransmission. Channel coding protects digital data from errors by selectively introducing redundancies in the transmitted data. Coding involves adding extra bits to the data stream so that the decoder can reduce or correct errors at the output of the receiver [5]. These extra bits have the disadvantage of decreasing the data rate and thereby, increasing the bandwidth of the encoded signal. Channel coding techniques can be divided into five categories; block, Convolutional, TCM, concatenated and turbo codes. In this paper, a comparison of Hamming and Convolutional schemes for reliable transmission of GPS message signal is carried out.

A. Hamming Codes

Hamming Codes send *m* information bits padded with a specific *k* parity-check bits. They have the ability to correct any single error. They manage this by having the *k* parity-check bits set at positions 1, 2, . . ., 2^{k-1} and checking every element whose binary representation has a "1" in position k_i -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. Assume the bits to be sent are 100110. Then the encoded string would be k_1, k_2, 1, k_3, 0, 0, 1, k_4, 1, 0 where k_1 = 1, k_2 = 0, k_3 = 1, k_4 = 1. So the final sent string would be 1011001110. Now let us simulate introducing a random error at position 5, causing the string to become 1011101110. To decode, you would check each parity bit accuracy (if they are not correct make k_i = 1). So you get k_1 = (incorrect) = 1, k_2 = (correct) = 0, k_3 = 1, k_4 = 0 which numerically is 0101 = 5. Therefore you can determine that the flipped bit occurred at position 5.

This code is significantly more efficient then pure repetition. You only have to add on an additional log *n* bits, but it only has the capacity to correct one error per block of code. If two bits are flipped it will incorrectly decode to a different string. Hamming codes can detect any two bit errors even though they can still only correct a single error.

Disadvantages. Hamming codes have one distinct problem. They are relatively inefficient when sending small amounts of data, but they get increasingly inaccurate as the number of bits increases. They can only correctly locate one flipped bit for each codeword regardless of its length. Therefore you almost always have to encode strings of length *n* with about *n* parity checks in order to ensure accuracy of information.

B. Convolutional Codes

In Block code each individual block is encoded as an independent entity. Convolution codes encode bits based upon a state and the output is determined by summing a fixed set of previously bits. Each input bit is manipulated in a few different ways to produce several outputs bits. Therefore each output bit conveys the combined information of many different input bits.

Convolutional codes are powerful coding schemes for communication systems that encounter a fading channel. They are fundamentally different from block codes in that information sequences are not grouped into distinct blocks and encoded. Instead, a continuous sequence of information bits is mapped into a continuous sequence of encoder output bits. Fig. 2 shows the configuration of the convolutional encoder with a coding rate of 1/2 with constraint length (CL) of 3. The convolutional encoder consists of (CL - 1 = 2) shift registers and two modulo-2 adders connected to some of the shift registers. The input data sequence is fed to the shift registers, and two output data are calculated using the content of the shift registers. The generator polynomials determine the encoding process. The convolutional encoder shown in Fig. 2 has *k* = 1 and *n* = 2.

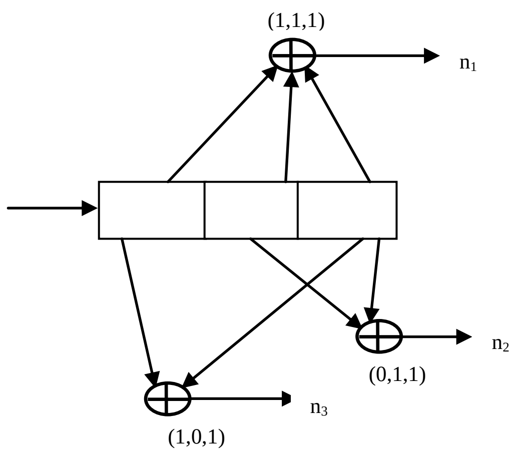

Fig. 2 Configuration of the convolutional encoder with 1/3 code rate and CL = 3

Generator polynomials: for rate 1/3, the generator polynomial can be expressed as follows:

$$G_1(x) = g_{k-1}^1 x^{k-1} + g_{k-2}^1 x^{k-2} + \cdots + g_2^1 x^1 + g_1^1 x^1 + g_0^1$$

$$G_2(x) = g_{k-1}^2 x^{k-1} + g_{k-2}^2 x^{k-2} + \cdots + g_2^2 x^1 + g_1^2 x^1 + g_0^2$$

$$G_3(x) = g_{k-1}^3 x^{k-1} + g_{k-2}^3 x^{k-2} + \cdots + g_2^3 x^1 + g_1^3 x^1 + g_0^3$$

where x indicates a 1-bit timing delay, $G_1(x)$ is the generator polynomial for the first an m-bit delayed source bit is added on the modulo-2 basis to obtain the n^{th} encoded bit.

The polynomial generators of a convolutional code are usually selected based on the code's free distance properties. The first criterion is to select a code that does not have catastrophic error propagation and that has the maximum free distance for the given rate and constraint length, then the number of paths at the free distance, d_{free}. The selection procedure can be further refined by considering the number of paths at d_{free}+1, at d_{free} + 2, and so on, until only one code or class of codes remains.

IV. RESULTS AND DISCUSSION

The block diagram of the process followed has been shown in Fig. 3.

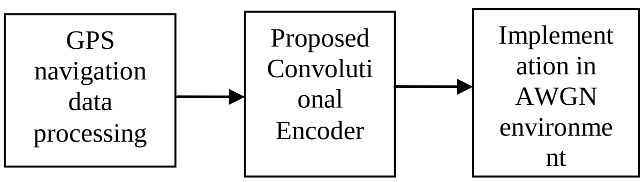

Figure 3 Block diagram of the process

The aim of the paper is to compare the performance of the existing (15, 11) Hamming with the newly designed 1/3 8 state Convolution codes in respect of GPS navigation data. The extracted GPS navigation data is encoded by the error correction scheme.

E_b/N_0	BER
1	0.062781
2	0.038327
3	0.020219
4	0.008869
5	0.003096
6	0.000818
7	0.000154
8	1.92E-05
9	1.44E-06
10	5.76E-08

Table 1 Performance of (15, 11) Hamming Code

This encoded data is then passed through the AWGN channel. The output of this channel is then decoded and the resulting data is compared with the extracted data. Fig. 4 shows the performance analysis in respect of the (15,11) Hamming Code for AWGN Channel. The graph is plotted between E_b/N_0 in the range 1 to 10dB and BER in the range 10^{-8} to 0.1.

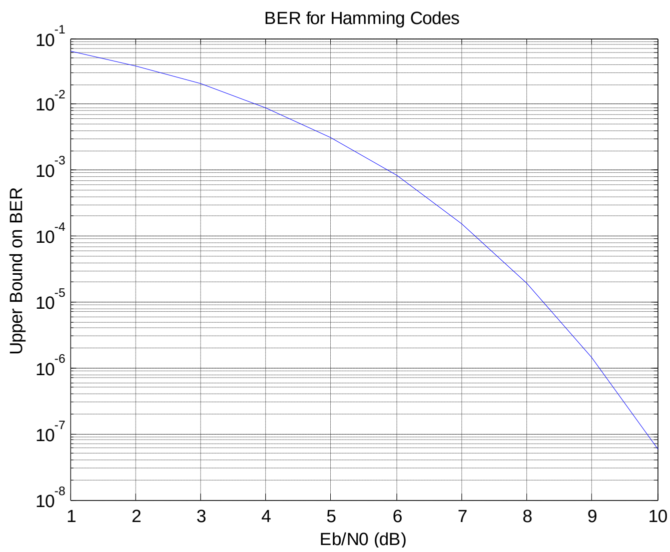

Fig. 4 Performance analysis of (15,11) Hamming Code

The performance of the (15,11) Hamming code is tabulated in Table 1 for different values of Eb/No in the interval 1 to 10dB in steps of 1dB.

Fig. 5 shows the performance analysis in respect of the 1/3 8-state Convolutional Code modulated by BPSK for AWGN

Channel. The graph is plotted between E_b/N_0 in the range 1 to 10dB and BER in the range 10^{-10} to 1.

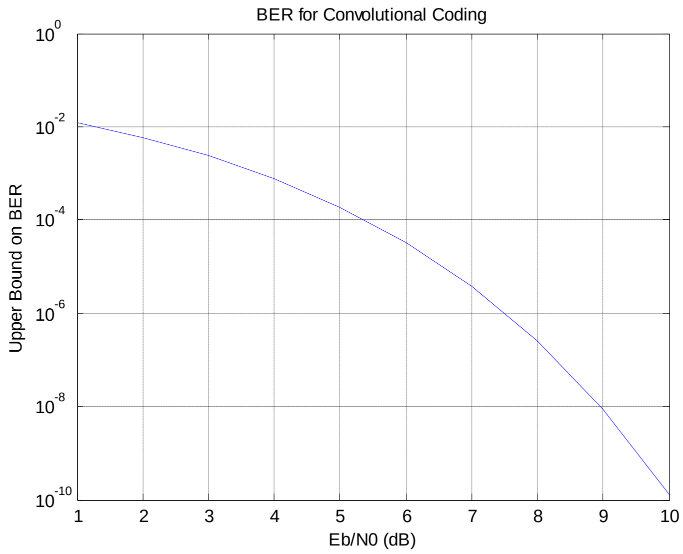

Fig. 5 Performance analysis of 1/3 8-state Convolutional Code modulated by BPSK

The performance of the 1/3 8-state Convolutional Code modulated by BPSK is tabulated in Table 2 for different values of Eb/No in the interval 1 to 10dB in steps of 1dB. It is clear that the Convolutional coding scheme shows better BER performance when compared to the Hamming Code and this improvement is more prominent at higher values of E_b/N_0.

E_b/N_0	BER
1	0.012415
2	0.005904
3	0.002363
4	0.000763
5	0.000188
6	3.3E-05
7	3.78E-06
8	2.53E-07
9	8.66E-09
10	1.27E-10

Table 2 Performance of 1/3 8-state Convolutional Code modulated by BPSK

V. CONCLUSIONS

In this paper a new desing based on rate 1/3 8 state convolutional code has been presented. It can be observed from the analysis that the performance of the newly designed FEC scheme 1/3 8 state convolutional code when compared with the existing (15,11) over AWGN channel is much superior at the heigher values Eb/No. For example at 9dB the Eb/No in respect of Hamming code 10^{-6} where as per convolutioanl code it is 10^{-8}. The work can be extended in respect of multipath fading channel such as Rayleigh and Rician channels .

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