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# Performance Analysis of Viterbi Decoder for IEEE 802.16 Receiver using MATLAB

**Nirmala Kuthadi, T. Lakshmi Prasanna, M. Anusha**

Associate professor, Department of Electronics and Communication Engineering, Sree Vahini Institute of Science and Technology, Tiruvuru, Krishna District, AP, India

Assistant Professor, Department of Electronics and Communication Engineering, Sree Vahini Institute of Science and Technology, Tiruvuru, Krishna District, AP, India.

**ABSTRACT:** In wireless communication systems, error correction coding techniques play a very important role. Error correcting coding involves the addition of redundancy to transmitted data to provide the means for detecting and correcting errors. Forward Error Correction (FEC) techniques are utilized for correction of errors at the receiver end. Convolutional encoding with Viterbi decoding is a powerful method for forward error detection and correction (EDAC). Viterbi algorithm is popularly used for designing this decoder due to its high efficiency and robustness. It also has a fixed decoding time and well suited for hardware implementation. This Viterbi Decoder has been conceived as a building block of error correcting system for wireless transmission of data. In this work, Viterbi algorithm for Viterbi Decoder (VD) has studied and verified the algorithm in MATLAB using trellis diagram. Hard Decision and Soft Decision Viterbi decoders are also verified in MATLAB with a constraint length of 7 and a code rate of 1/2.

**KEYWORDS:** Convolution Encoder, Viterbi decoder, trellis structure, soft decision, hard decision.

## I. INTRODUCTION

Coding theory deals with transmission of data over noisy channels by adopting various source and channel coding/decoding schemes. The convolution codes are widely used as forward error correction codes [1]. The main decoding strategy for convolutional codes is based on the widely used Viterbi algorithm. Convolutional encoding with Viterbi decoding is a powerful Forward Error Correction technique [14] that is particularly suited to a channel in which the transmitted signal is corrupted mainly by Additive White Gaussian Noise (AWGN) which is shown in figure-1.

The purpose of forward error correction (FEC) is to improve the capacity of a channel by adding some carefully designed redundant information to the data being transmitted through the channel [2]. The Viterbi algorithm essentially performs maximum likelihood decoding to correct the errors in received data, which are caused by the channel noise [3]. Hence, minimize the bit error rate (BER) to improve the performance. Viterbi decoding has the advantage that it has a fixed decoding time and it is well suited to hardware decoder implementation.

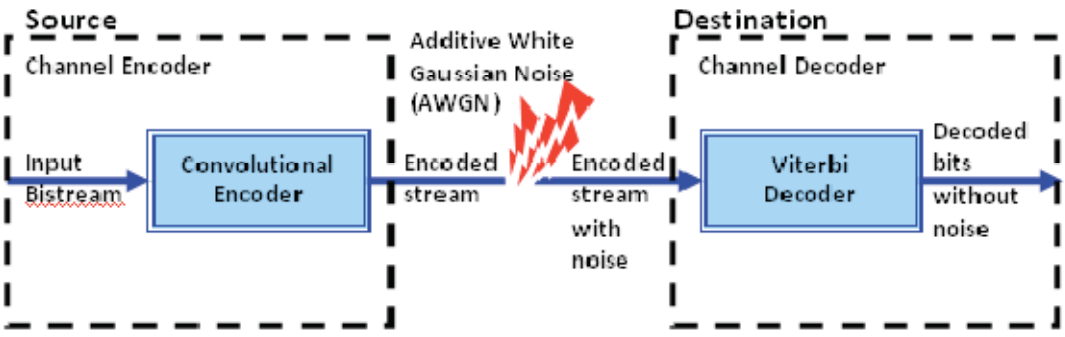


**Figure-1: Block diagram of digital communication system**

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### A. CONVOLUTIONAL ENCODER

Convolutional coding is a bit-level encoding technique. Convolutional codes are used in applications that require good performance with low implementation cost. As compared with the block codes, convolutional codes have a larger coding gain. Encoding of convolutional codes can be accomplished using simple shift registers. Each input bit enters a shift register and the output of the encoder is derived by combining the bits in the shift register [4]. The number of output bits depends on the number of modulo 2-adders used with the shift registers. The block diagram of convolutional encoder is as shown in figure-2[5]. It has native rate of 1/2, a constraint length of 7(K), six shift registers (m). The encoded bits depend not only on current k input bits but also on past input bits. The efficiency or data rate of a convolutional code is measured by the ratio of the number of bits in the input (k) and the number of bits in the output (n), therefore Bit Rate: r = k/ n.

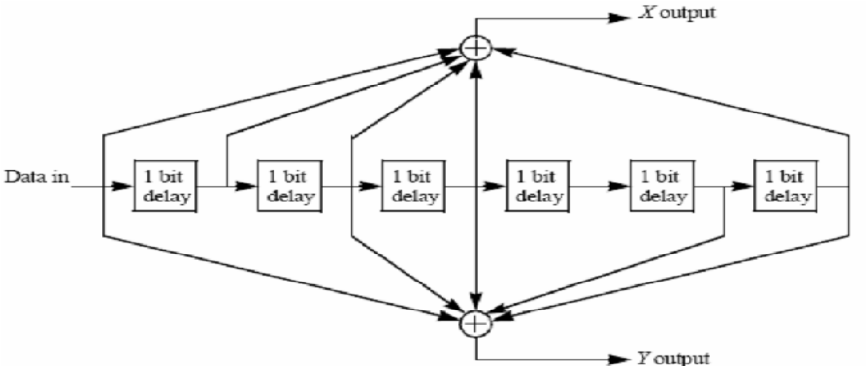


**Figure-2: Convolutional encoder of rate ½**

**Table 1. Convolutional encoder operation for rate= 1/2 and constraint length=3**

| Input Bit | Input State | Output Bits | Output State |
|---|---|---|---|
| 0 | 00 | 00 | 00 |
| 1 | 00 | 11 | 10 |
| 0 | 01 | 11 | 00 |
| 1 | 01 | 00 | 10 |
| 0 | 10 | 10 | 01 |
| 1 | 10 | 01 | 11 |
| 0 | 11 | 01 | 01 |
| 1 | 11 | 10 | 11 |

### B. VITERBI DECODER

In Viterbi Decoding, unlike in Sequential Decoding, the decoding time is fixed thus making it more suitable to hardware implementation. In this method the number of computations is very less at each trellis stage because of (i) The Infrequent occurrence of the error, so the probability of error is small (ii) The probability of two errors in a row is much smaller than the probability of single error, so that the errors are distributed randomly. These are the advantages of Viterbi Decoder compared to sequential decoding.

Viterbi algorithm can be explained by a trellis diagram it requires which comprises of minimum path and minimum distance calculation and retracing the path. Figure-3[6] shows the block diagram of the Viterbi decoder. It consists of following blocks:

a. Branch Metric Unit (BMU) b. Path metric calculation
c. Add Compare and Select Unit (ACS)
d. Trace Back Unit (TBU)

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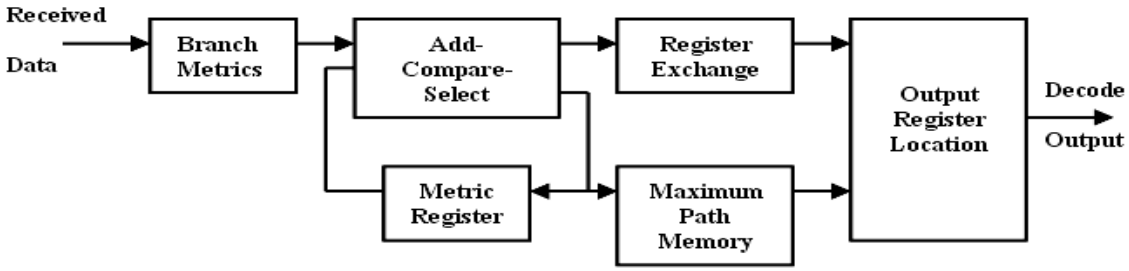


**Figure-3: Block diagram of the Viterbi decoder**

The Viterbi decoder examines an entire received sequence of a given length. The decoder computes a metric for each path and makes a decision based on this metric. All paths are followed until two paths converge on one node. Hence based on a decision one of the two paths is chosen. The paths selected are called the survivors. As discussed, when two paths converge on one node, only one survivor path is chosen based on a decision [7]. This decision can be achieved based on the type of Viterbi decoding. Generally, Viterbi decoding is two types:

(i) Hard decision Viterbi decoding
(ii) Soft decision Viterbi decoding

### B.1 HARD DECISION VITERBI DECODING

In hard decision Viterbi decoding technique the branch metric is calculated using the hamming distance for every branch in the trellis stage.

#### B.1.1 Maximum Hamming Distance

Hamming distance is the distance between the received code word and the allowable code word which is calculated by checking the corresponding bit positions of the two code words. For example, the Hamming distance between the code words 00 and 11 is 0 or the Hamming distance between the code words 00 and 00 is 2. The Hamming distance metric is cumulative so that the path with the largest total metric is the final winner. Thus, the hard decision Viterbi decoding makes use of the maximum Hamming distance in order to determine the output of the decoder.
*Note*: Hamming distances as explained, can only be calculated when we use the binary bits 0 and 1. Thus, before the corrupted data signal is fed to the input of the hard decision Viterbi decoder, voltages that are less than and equal to zero are represented by the bit 0, and voltages that are greater than 0 are represented by the bit 1.This is also known as one-bit quantization[8,11]

#### B.1.2. Demonstration of Viterbi Algorithm Using Trellis Representation

Graphically there are three ways to represent the encoder to gain a better understanding of its operation. These are:
1. State Diagram Representation
2. Tree Diagram Representation
3.Trellis Diagram Representation

The state diagram representation offers a complete description of the system. However, it shows only the instantaneous transitions and does not illustrate how the states change in time. Tree diagram representation also does not illustrate how the states change in time. To include time in state transitions, a trellis diagram is used. Each node in the trellis diagram denotes a state at a point in time [12]. The branches connecting the nodes denote the state transitions. Due to this reason's trellis representation has taken to implement Viterbi Algorithm.

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For constraint length (K) =7, the design takes six registers and it has 64 states (2^6). Drawing of a trellis structure for these 64 states is very difficult because for each and every state trellis has to calculate branch metric and if one of the nodes get two branches then it has to discard one of these two branches based on the decision.

For simplicity and easy to understand, trellis structure for K=3 has demonstrated [9] because for K=3 it has 4 states. The corrupted data bit stream at the input of the hard decision Viterbi decoder is assumed as [01 10 00 10 11]. The trellis structure is drawn for each time tick. Each time it receives a pair of channel symbols it computes a metric to measure the "distance" between what it received and all of the channel symbol pairs it could have received

Thus, the figure-4 is the hard decision Viterbi decoder, using maximum Hamming distances. It works and achieves the decoded data bit stream, from a convolutional encoded input data bit stream transmitted over an AWGN channel from the transmitter.

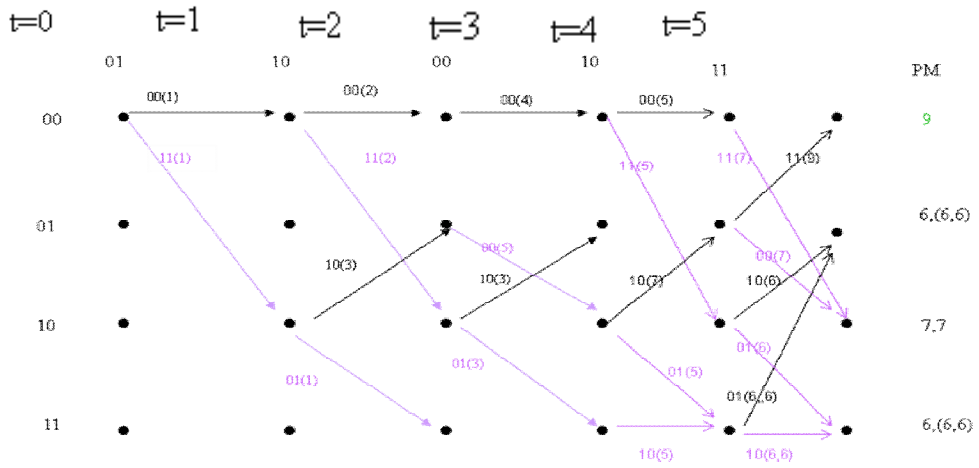


**Figure-4: Trellis Diagram Showing Hard Viterbi Algorithm Decoder and path metrics**

The path with the highest metric is looked for and a winner path is traced from the state which have the highest path metric to the beginning of the trellis. This step is called trace back. The path traced by the states 00, 10, 01, 10, 01, 00 and corresponding to the bits 10100 is the decoded sequence and is as shown in Figure 5:

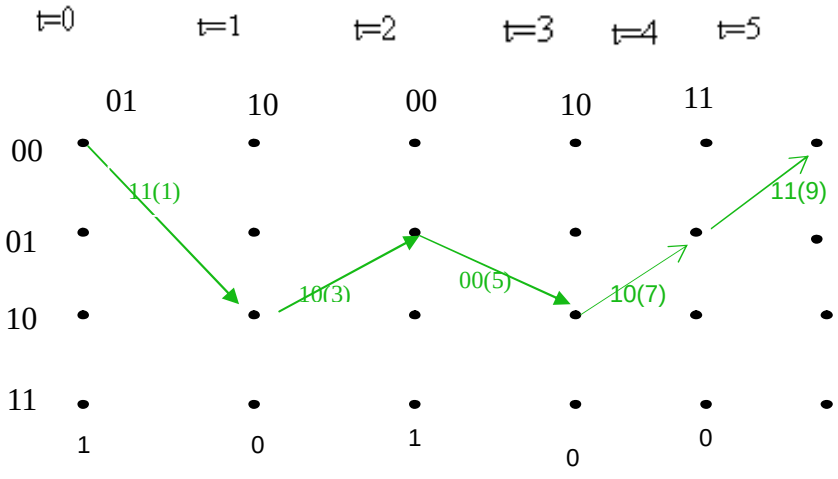


**Figure-5: Decoded sequence 10100 for the noisy encoded bit stream 01 10 00 10 11**

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The above is the demonstration for the working of the hard decision Viterbi decoder and how the input data bit stream [1 0 1] is obtained. This process is actually implemented using the Mat lab code.

### B.2 SOFT DECISION VITERBI DECODING (SDVD)

In soft decision Viterbi decoding technique the branch metric is calculated using Euclidean distance for every branch in the trellis stage [10,13].

#### B.2.1 Quantization

In practical systems, the quantization of the received channel data sequence with one or few bits of precision is done in order to reduce the complexity of the Viterbi decoder. In the hard decision Viterbi decoder, the received data stream is quantized to one-bit of precision, i.e., voltages that are less than or equal to 0 are represented by the bit 0, and voltages that are greater than 0 are represented by the bit 1.

Where as in the case of the soft decision technique, the variations of the signal at the output of the demodulator are sampled and quantified with two or more bits of precision. For a Gaussian channel with additive white noise (AWGN), the hard quantification of the received signal, compared with the fine quantification gives losses of about 2dB in S/N ratio [9,10]. Moreover 8-level quantification reduces this loss to a value of less than 0.25dB, compared to the fine quantification. This means that the 8-level quantification is adequate to this kind of decoding. Figure-6 shows the order of the sampled output of the demodulator with 8 decision thresholds and 8 levels of quantification. The level of transmitted signal is unity. The values {1, 2, 3, 4} represents the confidence of the received signal where the highest signal represents the number with the highest confidence. For instance, level ± 4 gives a high confidence that the bit is ± 1 logic, whereas ±2 gives less confidence.

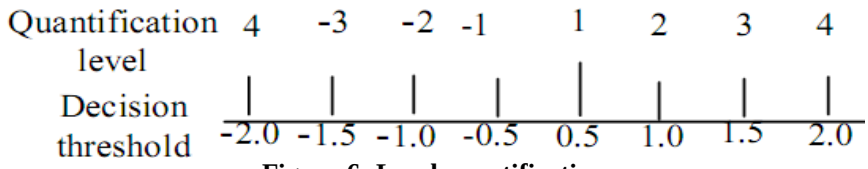


**Figure-6: Level quantification**

The soft decision Viterbi decoder discussed in this report uses a 3-bit quantizer to quantize the received channel data stream. The usual quantization precision is three bits as more bits provide little additional improvement. Soft decision Viterbi decoding offers better performance results than hard decision Viterbi decoding since it provides a better estimate of the noise, i.e., less quantization noise is introduced.

#### B.2.2 Minimum Euclidean Distance

Euclidean distance is the basic measurement used for calculating metrics when we use the soft decision Viterbi decoder [5,11]. The squared Euclidean distance (ED) is measured by the following formula:

$$ED(n, i) = \sum_{\text{all } k} [S_K(n) - G_k(n)]^2$$

Where
n = current state
i = input bit
k = encoded bits associated with a given input
S = received quantized bits
G = output bits (expected)

The hard decision Viterbi decoder is implemented by using the maximum Hamming distance for calculating the metrics. However, the soft decision Viterbi decoder is implemented using the minimum Euclidean distance for calculating the metrics.

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**B.2.3 Trellis Explanation**

The working of the soft decision Viterbi decoder follows almost the same principles as that of the hard decision Viterbi decoder. The only difference is the calculation of the path metrics. Since the working mechanism is the same as that of the hard decision Viterbi decoder, the explanation of the trellises is analogous to that discussed in Section 3.1.2[9,12]

The corrupted, and in this case quantized too, data bit stream at the input of the soft decision Viterbi decoder is assumed as [3 -4 -4 3 3 3 -4 3 -4 -4].

In the section 3.3.1.2 the trellis structure for hard decision Viterbi decoder is explained. By the same procedure the trellis structure for soft decision Viterbi decoder is represented in the figure 3.16. The input data to the SDVD is [3 -4 -4 3 3 3 -4 3 -4 -4], which is 3bit quantized data input. The difference in SDVD compared to the HDVD is calculation of the branch metric, which is done using the Euclidean distance formula in SDVD and Hamming distance in HDVD.

The rest of the procedure is same as the hard decision VD.But one more differance compared with the HDVD is that, in SDVD the path with the lowest metric is looked for and a winner path is traced . The path traced by the states 00, 10, 01, 10, 01, 00 and corresponding to the bits 10100 is the decoded sequence and is as shown in Figure -7.

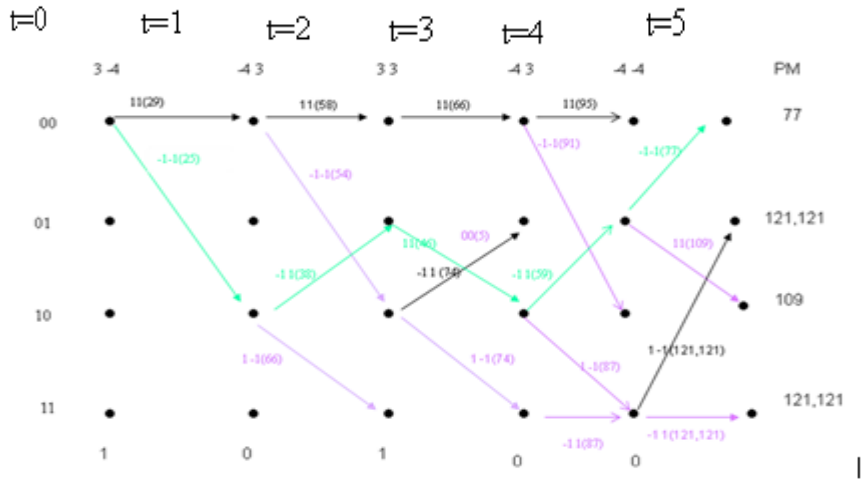


**Figure-7: Decoded sequence 10100 for the noisy encoded bit stream [3-4 -43 33 -43 -4-4]**

Thus, the above procedure shows the working of SDVD, using minimum Euclidean distances thus achieving the decoded data bit stream, from a convolution encoded input data bit stream, the decoded data is shown in figure-8. This process is actually implemented using the Mat lab codes.

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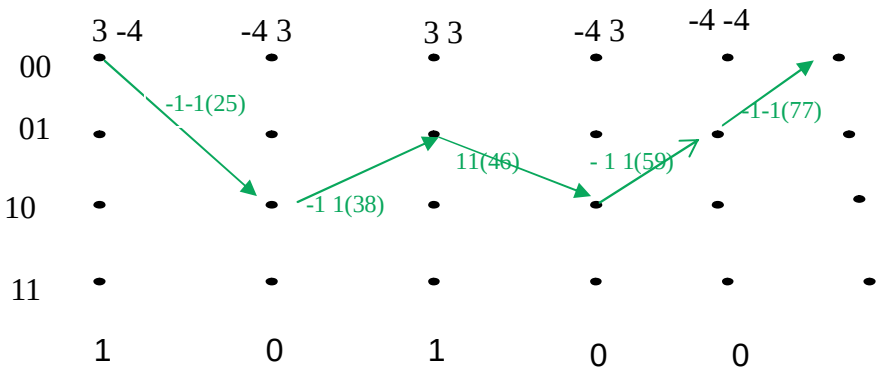


**Figure-8: Output of the soft decision Viterbi decoder – 10100**

## II. MAT LAB Simulation Results:

Hard decision Viterbi decoder: K=7, m=6, trace back length=60

```
Command Window
generator sequence[1 1 1 1 0 0 1;1 0 1 1 0 1 1]
din1[1 0 0 1 0 0 1 0 0 0 0 0 0 1 1 0 1 0 0 0 0 0 0 1 1 0 1 0 0 0 0 0 0 1 1 0 1 0 0 0 0 0 0 1 1 0 1 0 1 1]
din2[1 1 1 1 1 1 1 0 1 1 1 1 1 0 0 1 1 0 1 1 1 1 1 0 0 1 1 0 1 1 1 1 1 0 0 1 1 0 1 1 1 1 1 0 0 1 1 0 1 1 1 1 1 0 0 1 1 0 0 1]

ans =

  Columns 1 through 22

    1     0     1     1     0     1     0     1     0     0     1     0     1     1     0     1     0     1     0     0     1     0

  Columns 23 through 44

    1     1     0     1     0     1     0     0     1     0     1     1     0     1     0     1     0     0     1     0     1     1

  Columns 45 through 60

    0     1     0     1     0     0     1     0     1     1     0     1     0     1     0     0
```

Soft decision Viterbi decoder: K=7, m=6, trace back length=60

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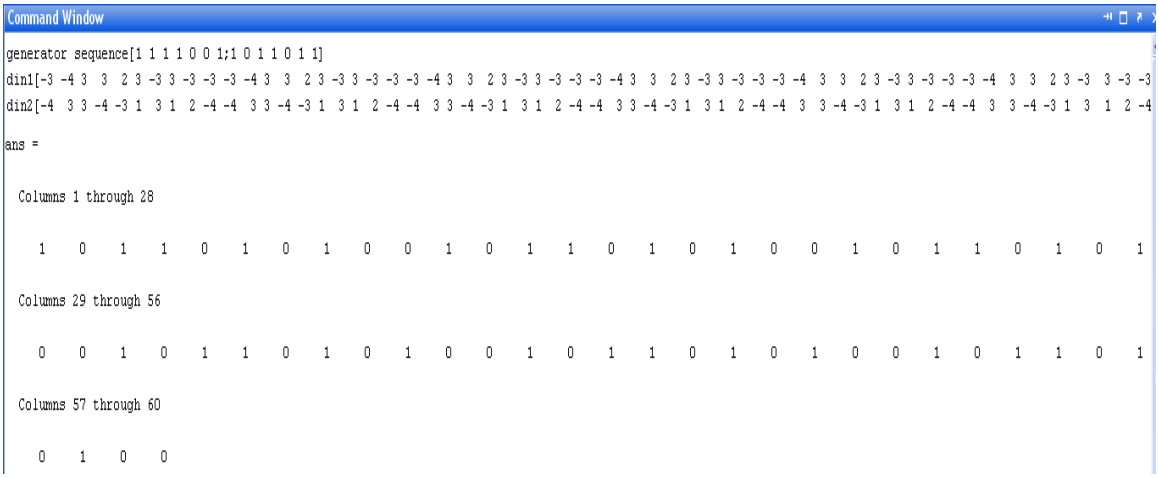


## III.CONCLUSION

The Viterbi algorithm based on hard decision and soft decision was studied and then verified this algorithm in MATLAB using trellis rule. Encoded and noise corrupted sequence was decoded and recovered using the concepts of Hamming distances and Euclidean distances for the hard decision Viterbi decoder and soft decision Viterbi decoder respectively.

From implementation results the observation is that, the performance of Viterbi decoder was greatly improved using soft decision, it makes more precision in quantization and is more powerful than hard decision Viterbi decoder. The soft decision Viterbi decoder design had been driven in such a way that it would calculate the decoding path with the minimum metric to be passed to the decoder output port. It provides better error performance than hard decision type Viterbi decoding.

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