Blind Classification and Estimation of FEC codes and Interleaver Parameters in a Noisy Environment

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ABSTRACT

The digital communication systems used may have random errors and in case of multipath channels there may be a occurrence of burst errors. Channel encoder with forward error correcting (FEC) codes followed by an interleaver acts as a solution for overcoming these errors. The type of the FEC code, interleaver and its parameters are crucial to be known at the receiver for the effective decoding and de-interleaving of the received data. Certain latest applications like Adaptive modulation, cognitive radio receiver, etc. may require blind estimation of the parameters. In this paper, we propose an effective algorithm to classify the FEC codes among convolutional, block or uncoded and its parameters, to find the bock interleaver size, the length and width of the matrix and the delay introduced in the data stream. The proposed algorithm is implemented for erroneous channel condition and the threshold is set using histogram approach. The algorithm is done for various bit error rate values and the performance is analysed.

***Keywords* — Forward error correcting(FEC) codes, block interleaver, convolutional code, block code.**

I.INTRODUCTION

Forward Error Correcting (FEC) codes are used in the digital communication system to correct the random errors introduced by the channel. Usually the memory less channel will introduce random errors in the data streams which can be corrected using the FEC. The FEC codes introduce redundant bits in a controlled manner to the data stream which in turn affects the spectral efficiency of the code. The FEC codes generally are of two types namely convolutional codes and block codes.

The time-correlation nature of the channel sometimes results in channel with memory i.e. statistical dependence among successive symbol transmission. A channel with multipath fading is one such type. Some channels with or without memory may have burst noise. Burst noise is continuous occurrence of error in the data stream. The most FEC codes are suitable for the correction of independent random errors and they may not be efficient for burst errors. Interleaver is used for such cases with burst errors.e symbols in time effectively

Interleaver is used for channels with memory and it will separate the symbols in time which in turn will transform a channel with memory to a memory less channel thereby enabling the error-correcting codes to be efficient in a burst noise scenario.

The interleavers used are of three types: i) Convolutional interleaver ii) Helical interleavers and iii)Block interleavers. The block interleaver can be further classified into two classes namely matrix interleaver and helical scan interleaver. Since block interleavers are more significantly used in the error control units our algorithm considers the same.

The block interleaver receives a block of data symbols and rearranges them without removing or adding any symbols to it. In particular, a matrix based block interleaver stores each block of data symbols as an interleaver matrix row-wise and then reads them column-wise for transmission such that the neighbouring data symbols encounter independent fading. The interleaver size or period of the matrix-based block interleaver is given by $S=N_r X N_c$, where N_r and N_c denote the length and width of the interleaver matrix and an example for interleaver operation is shown in Fig. 1.

In most of the applications, the type of the FEC codes, code and interleaver parameters are known at the receiver. With the evolution of modern digital communication systems, designing separate receiver decoding system for every broadcast application is a costly and a tedious process. Hence there is a need to design an intelligent broadcast receiver system which adapts itself to any specific broadcast applications. Intelligent or cognitive receiver systems require the blind estimation of code and interleaver parameters in order to adapt to the variations in the channel coding schemes for estimating the original data.In Adaptive Modulation and Coding (AMC) based systems, the blind estimation of the code and interleaver parameters will lead to the conservation of channel resources.

In wireless sensor networks, the blind estimation technique will reduce the energy consumption, as the nodes need not frequently update the change in the code and modulation parameters. As the overheads are not transmitted the data transmission rate of the sensor nodes are also increased. The blind estimation technique will also be valuable in the non-cooperative systems.

II.RELATED WORKS

The blind/semi blind estimation of the code parameters is previously done in many works assuming the type of the code is known at the receiver.

In [1], [2] the blind estimation of interleaver parameters are done using linear algebra based algorithm from a delayed and corrupted interleaved sequence of the binary data stream considering the binary symmetric channel. The above works are validated only for interleaver size S which is a multiple of codeword length n.

The author in [3] proposed algorithm to blindly estimate interleaver period for non-binary data streams. The error correcting method assumed was Reed Solomon Codes. In [4] the author has examined an methodology for error free non binary data streams to blindly estimate convolutional interleaver parameters using less number of intercepted bits.

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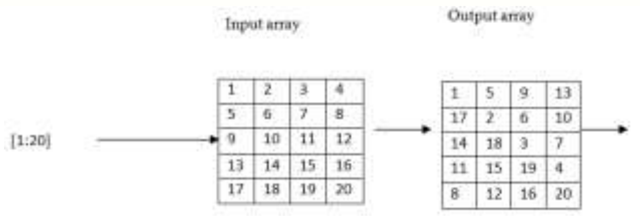

Fig. 1. Matrix based block interleaver operation assuming $N_r = 5$ and $N_c = 4$.

In [5] the fast blind recognition of FEC code type is done using the calculation of Syndrome Posterior Probability (SPP). The automatic classification of FEC codes are explained in detail in [6] and the parameters are also identified.

The paper [7] has discussed about a low complexity algorithm for the blind estimation of convolutional parameters in a non-cooperative index with improved computational efficiency. In [8] blind identification technique for LDPC codes is explored for BPSK signals which is promising even for low SNR values. The author in [9] has discussed a novel method for recognition of error correcting codes and interleaver parameters in a Robust environment.

The above discussed literature has done blind parameter estimation for known code type and estimated interleaver parameters for interleavers whose size is a multiple of n.

The organization of the paper goes as Section III explains the block diagram and the methodology. Section IV explains the proposed methodology for code classification, interleaver period estimation and the estimation of interleaver parameters and the delay value. The results and discussion were deeply analyzed in Section V. The brief conclusion is given in Section VI.

III.CLASSIFICATION AND PARAMETER ESTIMATION

The block diagram explaining the joint classification of FEC code and the estimation of parameters is given in Fig. 2. At the transmitter side we send the encoded and the interleaved data symbol to the modulator and after modulation the signal is send to the channel.

At the receiver side, after receiving the erroneous data streams, we first classify the type of the FEC code used among convolutional. block or uncoded and also the interleaver size is estimated. Then we use a separate algorithm to estimate the other interleaver parameters like the length and width of the interleaver matrix and the bit position to start de-interleaving is estimated. After estimating the code type and parameters the decoding and de-interleaving can be done efficiently.

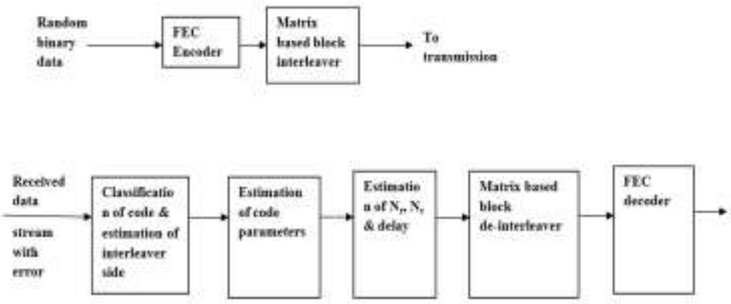

Fig.2. Basic block diagram for our proposed method.

IV.PROPOSED METHODOLOGY

In this paper, we propose a FEC code classification and estimation of code and interlaver parameter method for erroneous transmission environment.

Our proposed methodology goes by following steps: (A) Classification of code type and Estimation of Interleaver size. (B) Estimation of code parameters. (C) Estimation of length and width of the interleaver and the delay value.

A. Classification of Code Type and Estimation of Interleaver size:

The code classification technique for error free data streams usually involves the formation of data matrix and converting it into an column echelon form. Then the rank of the matrix is calculated by counting the number of non-zero columns. But in erroneous scenario the dependent columns will not become all zero due to the presence of random errors in the data stream. So, in case of erroneous scenario we are in a need to follow a different scenario in which the mean values of the number of ones and number of zeros are required. The steps for the classification procedure is given below.

Input:

data: Received coded data symbols with error

n_data: Number of received data symbols

Output: $\rho(s)$ and p

- Step 1: Assume $x \geq p1.y$, where x is the number of rows, y is the number of columns of the data matrix D and p1 is a constant.
- Step 2: Initialize data, n_data, x and y such that n_data > x.y.
- Step 3: Calculate number of frames from

N_{frame} = floor(n_data/y) and initialize N= N_{frame}-x+1.

- Step 4:

For j=1:N

S_j = data (1 + (j – 1)y : xy + (j - 1)y)

D_j = reshape S_j with x rows and y columns

$F_j = D_j \times \chi_j$, where F_j is the column echelon form of the data matrix. The column echelon form is derived using Gauss Jordan Elimination through Pivoting [10] using column transformations only.

A_j = compute $\omega_j(c)$ or $\delta_j(c)$ for each column in F_j where $c \in \{1,2,\ldots,y\}$ where $\omega_j(c) = \phi_j(c)/x$, $\delta_j(c) = \bar{\phi}_j(c)/x$, $\phi_j(c)$ and $\bar{\phi}_j(c)$ denotes the number of ones and zeros in the c^{th} column of the F_j, respectively.

end For

- Step 5: Compute mean (A), where $A=[A_1\ A_2\ldots\ A_N]^T$,

$A_j=[\ \omega_j(1)\ \omega_j(2)\ldots.\ \omega_j(y)]$ or $A_j=[\ \delta_j(1)\ \delta_j(2)\ldots.\ \delta_j(y)]$, and mean(A) = $[\lambda(1)\lambda(2)\ldots.\lambda(y)]$ is a row vector of size 1Xy, and $\lambda(c) = \frac{\sum_{j=1}^{N}\omega_j(c)}{N}$

- Step 6:

If A_j is computed based on $\omega_j(c)$

$\rho(s) = card(c \in \{1,2,\ldots y\} |\ \lambda(c) < \Gamma_{opt}^{th})$

end If

- Step 7: Compute $p=\frac{\rho(S)}{y}$
- Step 8: Evaluate the rank $\rho(S)$ by varying b.
- Step 9: Observe the difference between the successive number of columns with rank deficiency. The difference gives S or lcm(n,S) for the case with interleaver. For the case without interleaver the difference gives n.

Histogram Approach:

The optimal threshold value Γ_{opt}^{th} can be fixed by plotting the histogram [11] for mean(A), where *mean(A)* = $[\lambda(1)\lambda(2)\ldots.\lambda(y)]$ is a row vector of size 1Xy, considering a particular number of column value y, which results in rank deficiency. In histogram approach we have simulated, we calculate $\lambda(c)$ for each column in F_j, where $c \in [1,2,\ldots y]$, based on $\omega_j(c)$.

The histogram plot shows the segregation between independent and dependent columns. From the histogram plot a range of possible threshold value is obtained for the differentiation between independent and dependent columns. From the range of values an appropriate optimum value is fixed Γ_{opt}^{th}. The same threshold value is suitable for all values of the column y to classify the dependent and independent columns. In section V the optimum value is fixed from the simulation.

B) Classification of Code and Estimation of Code Parameters:

The classification of the code type [11] is done by using the rank ratio value for the range of column values y.

1) Convolutional codes:

The rank ratio p is given by,

$$p = \frac{\rho(s)}{y} \quad (1)$$

and the rank ratio for the convolutional codes is given by

$$p=r+\lambda \quad (2)$$

where $r=\frac{k}{n}$ and $\lambda=\frac{m}{y}$ where k is the length of the message sequence, n is the codeword length, y is the number of columns and m is the memory of the convolutional encoder.

2) Block Codes:

The rank ratio for the block codes is given by

$$p=r \tag{3}$$

since the memory element in the block codes is zero (i.e.) m=0.

3)Uncoded data:

If D is the data matrix of uncoded data symbols with y columns. then

$$\rho(s)=y \tag{4}$$

is always a full rank matrix.

Classification of codes:

The incoming data symbols are classified among the FEC code types using the rank ratio equations of convolutional and block codes given by (2) and (3). From (2) it can be understood that the deficient rank ratio will be much greater than r for for lower values of y. As y increases the p value sill tend to remain constant slightly above r. Thus for convolutional codes with or without block interleaver, he deficient rank ratio will decay rapidly for lower values of y and will almost remain constant slightly above r for higher values of y. Also for block codes, the deficient rank ratio will remain constant equal to the r for all the values of y from equation (3). Finally, for the uncoded data there will be no rank deficiency i.e. the rank ratio will be equal to unity for all values of b.

Estimation of code parameters:

The interleaver size S or lcm(S,n) can be calculated by observing the difference between the successive number of columns with rank deficiency.

The code parameters for convolutional code and the block codes can be estimated as follows. The code rate r is given by

$$r=\frac{\rho'(s)-\rho(s)}{y'-y} \tag{5}$$

The message length k and the codeword length n are given respectively by

$$k=\rho'(s)-\rho(s) \tag{6}$$

$$n=y'-y \tag{7}$$

Thus the type of the FEC code, the code parameters and the interleaver size is estimated from the above illustration.

C)Estimation of the length and wodth of the interleaver parameter and the delay

After estimating the interleaver size S, the other interleaver parameters like the N_r and N_c can be estimated using the following steps.

Input: α = S or lcm(n,S) **Output:** N_{re} and N_{ce}

- Step 1:Fix a value for codeword length n_len = u.n , where u s a constant.
- Step 2:
  For i=1:n_len
  Get all possible combinations of N_r' and N_c' that satisfy $N_r' \times N_c' = \frac{\alpha}{i}$
  end For
- Step 3: Fix y as a multiple of α.
- Step 4: De-interleave D_j , where j∈ {1,2,…, N_{frame}-x+1 }, with all possible combinations of N_r' and N_c'and calculate *mean(A) = [λ(1)λ(2)….λ(y)]* as before.
- Step 5: Compute the zero mean ratio δ'(y), which is given by

$$\delta'(y) = \frac{\sum_{i=1}^{y} \lambda(c)}{y} \quad (8)$$

  for all possible combinations of N_r' and N_c'.
- Step 6: Find *$[N_{re}, N_{ce}] = argmax(\delta'(y))$*

The estimation of interleaver parameters are done using above steps and the delay is calculated by leaving the bits from one to S, and the sequence is de-interleaved and zero mean ratio is calculated like the above scenario and the delay or the number of bits to leave if fixed as the argmax(δ'(y)).

V.PERFORMANCE EVALUATION

In this paper, the linear block code is reperesented as B(n,k), where n is the code word length and k the code dimension. Further, the convolutional code is denoted as C(n,k,K)[g_i^j,…, g_i^j,… g_k^n], where Y represents the constraint length and g_i^j the generator polynomial between i^{th} input and j^{th} output and is represented in octal form. The bit error rate values considered here are after demodulation and before FEC decoding in the general communication system. Our concentration in this paper is mainly on the estimation of parameters in the noisy scenario. The standard BER value required for a smooth transmission post-FEC for Digital Video Broadcasting(DVB) is 2 x 10^{-4}[12]. Considering the BER values together with the coding gain, the pre-FEC BER value for acceptable performance will be greater than 10^{-3}.

Without the loss of generality, the BER for our methodology is considered within the range of 3 x 10^{-3} and 9 x 10^{-2}. The simulations are done using these BER value for the value BER=10^{-2} and the results are given in this section.

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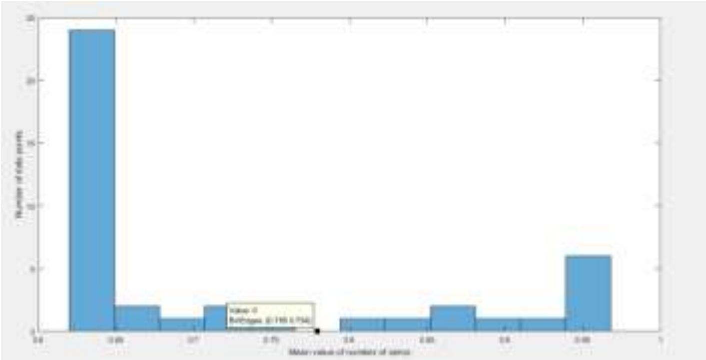

Fig.4. Histogram for mean(A), b=42, B(6,3) N_r=3 and N_c=2

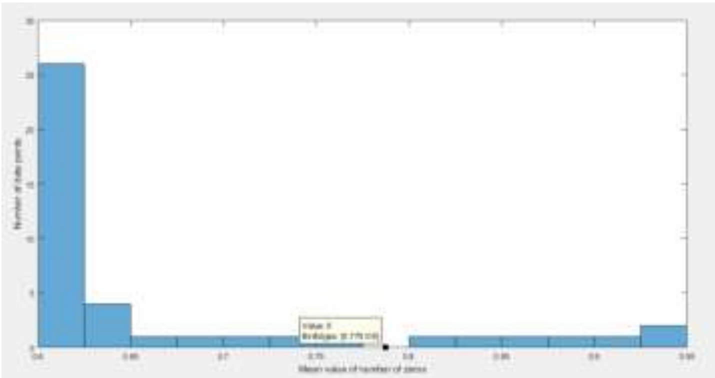

Fig.5. Histogram for mean(A),b=42,B(7,4) without interleaver

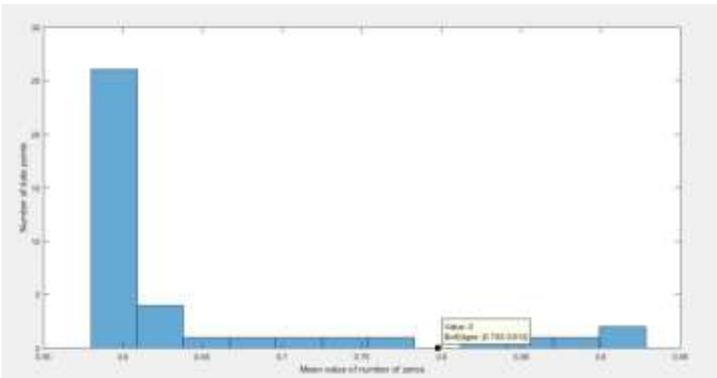

Fig. 6. Histogram for mean(A), b=40, B(8,5) N_r=4 and N_c=2

A) Histogram method for optimum threshold Γ_{opt}^{th} :

The histogram plot for mean(A) considering b=42 B(6,3) with interleaver N_r=3 and N_c=2 is shown in Fig.4. From the plot we can infer that the independent and dependent columns can be classified by choosing a threshold value between the range 0.765-0.794. Similarly the histogram plot for mean(A) considering b = 42 B(7,4) without interleaver in Fig.5., b = 40 B(8,5) with interleaver N_r=4 and N_c=2 in Fig. 6., b = 48 C(3,1,7)[133 165 171] without interleaver in Fig. 7., b = 36 C(3,1,7)[133 165 171] with interleaver N_r=4 and N_c=3 in Fig. 8. are shown.

The corresponding range of threshold values for all the cases considered are tabulated in the Table.1 and the safe and optimum threshold value is selected from the table as

Γ_{opt}^{th} = 0.786 .

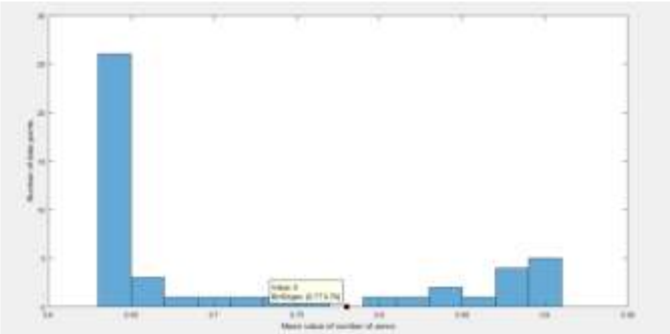

Fig.7. Histogram for mean(A), b = 48 C(3,1,7)[133 165 171] without interleaver

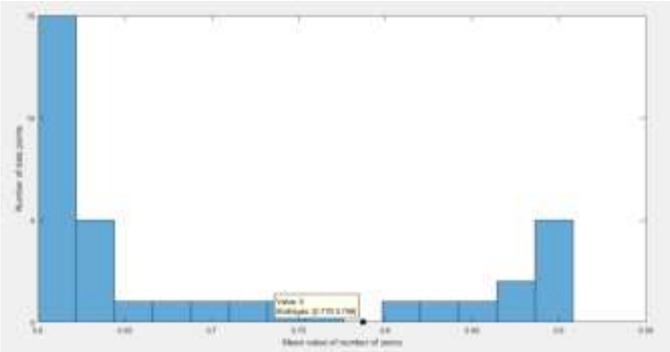

Fig.8. Histogram for mean(A), b = 36 C(3,1,7)[133 165 171] with interleaver N_r=4 and N_c=3

S.No.	Code Type	Threshold Range
1.	B(6,3) with interleaver Nr=3, Nc=2 and b=42	0.765-0.794
2.	B(8,5) with interleaver Nr=4, Nc=2 and b=40	0.783-0.812
3.	B(8,5) without interleaver and b=42	0.775-0.8
4.	C(3,1,7)[133 165 171] without interleaver and b=48	0.77-0.79
5.	C(3,1,7)[133 165 171] with interleaver Nr=4 and Nc=3 and b=36	0.776-0.798

Table1. Threshold ranged for possible combinations considered with BER=10^{-2}

B)Simulation Results for the Case without interleaver:

The rank ratio plot for the B(7,4) is shown assuming BER = 10^{-2} in Fig. 9. From the plot we can observe that we get deficient rank ratio for the column value which is multiple of n=7. The deficient rank ratio also remains constant at the value of r=4/7 for all values of y. Then the difference between the deficient rank ratio y'-y, gives the value of n=7.

The rank ratio plot for C(3,1,7)[133 165 171] is shown in Fig. 10. where you can observe deficient rank ratio value decays rapidly for the case y value is high and for lower y values the rank ratio remains almost constant slightly above r=1/3. The codeword length is calculated as y'-y = n which is 3. Similarly, the rank ratio plot for C(2,1,4)[15 17] is shown in Fig. 11.

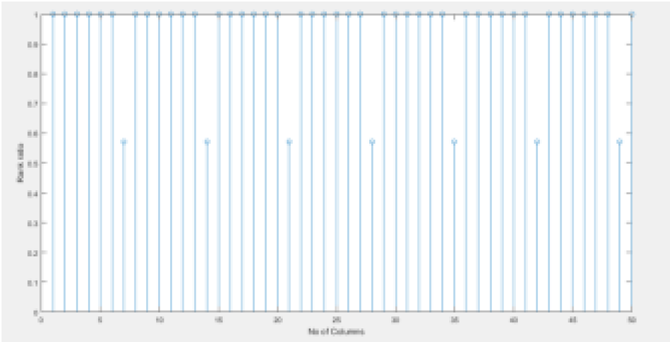

Fig.9. Rank ratio plot for B(7,4) without interleaver

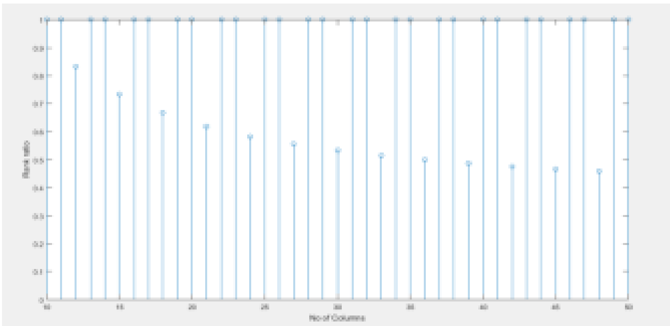

Fig.10.Rank ratio plot for C(3,1,7)[133 165 171]

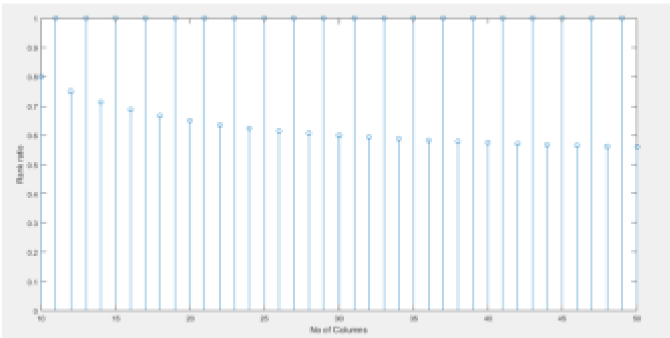

Fig.11. Rank ratio plot for C(2,1,4)[15 17]

C) Results for Case with Interleaver:

The rank ratio plot for the linear block codes B(6,3) with interleaver N_r=3 and N_c=2 and B(8,5) with interleaver N_r=4 and N_c=2 are shown in Fig. . and Fig. 12. , respectively. The rank ratio plot for the convolutional code

C(3,1,7)[133 165 171] with interleaver N_r=5 and N_c=2 is shown in Fig. 13. In all the above figures the rank deficiency can be observed at the multiple of interleaver size S or lcm(S,n).

The rank ratio plot for uncoded data streams is shown in Fig. 14. where you can see that all the rank ratio values stays at unity i.e. there is no rank deficiency for any values of y.

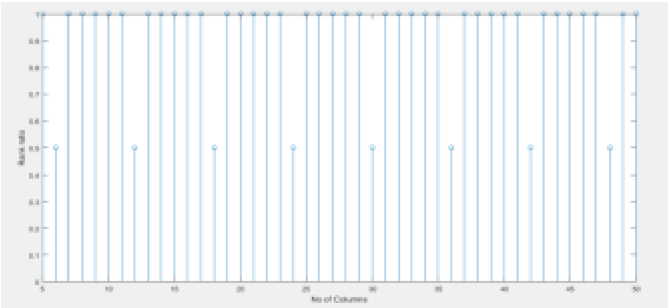

Fig.12. Rank ratio plot for B(6,3) , N_r=3 and N_c=2

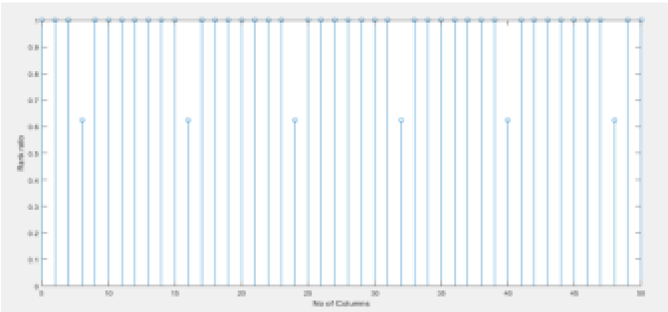

Fig.13.Rank ratio plot for B(8,5), N_r=4 and N_c=2

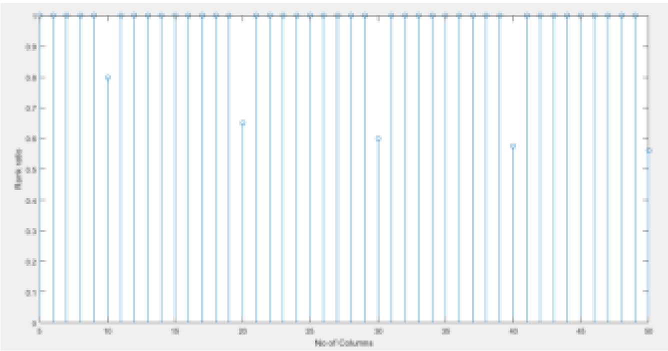

Fig.14. Rank ratio plot for C(3,1,7)[133 155 171], N_r=4 and N_c=2

D) Results for the estimation of interleaver length and width:

The plot for the variation of zero mean ratio δ'(y) for all possible combinations of Nr' and N_c' considering the case for B (6,3) with N_r=3 and N_c=3 is shown in Fig.15. in which the peak value is reached in [3 3]. Similarly zero mean ratio for C (3,1,7)[133 155 171], N_r=4 and N_c=4 and the peak is reached at [4 4] in Fig.16.

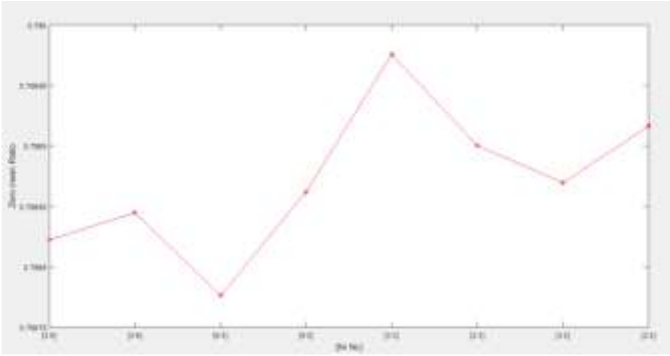

Fig.15. Zero mean ratio δ'(y), B(6,3) with N_r=3 and N_c=3

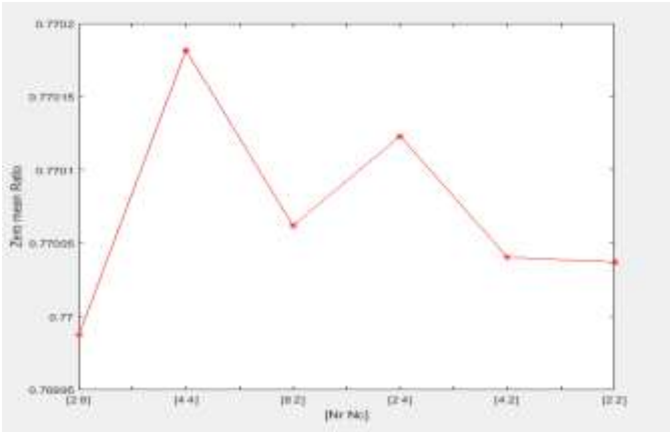

Fig.16. Zero mean ratio δ'(y), C (3,1,7)[133 155 171], N_r=4 and N_c=4.

VI.CONCLUSIONS

In this paper, we have proposed an efficient algorithm for classification of error correcting codes and the estimation of interleaver parameters like size of the matrix, number of rows, number of columns and the delay, and the estimation of code parameters like codeword length, message dimension and the constraint length depending on the type of the code detected. The algorithm is simulated under erroneous transmission scenario considering a range of BER values from 3 x 10^{-3} and 9 x 10^{-2}. The threshold value, Γ_{opt}^{th}, is selected using the histogram approach and the optimum value is chosen from the table. The algorithm works with accuracy and efficiency within the given BER range.

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