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Swaminathan, Ramabadran; Madhukumar, A. S.

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Joint Recognition of Error Correcting Codes and Interleaver Parameters in a Robust Environment

Swaminathan R
School of Computer Science and Engineering
Nanyang Technological University
Singapore
Email: sramabadran@ntu.edu.sg

A.S.MadhuKumar
School of Computer Science and Engineering
Nanyang Technological University
Singapore
Email: asmadhukumar@ntu.edu.sg

***Abstract*—To improve the error performance of digital storage and communication systems, forward error correcting (FEC) codes and interleaver play a significant role by counteracting random and burst errors, respectively. In most of the applications, accurate information about the type of FEC codes, coding and interleaving parameters are known at the receiver in order to successfully decode and de-interleave the message bits, respectively. However, in certain applications such as spectrum surveillance, adaptive modulation and coding (AMC)-based communication systems, cognitive radio, etc., all the coding and interleaving parameters need not be known at the receiver and blind/semi-blind recognition of the same is mandatory. Therefore, in this paper, innovative algorithms for automatic recognition of type of FEC codes along with the parameter estimation of helical scan interleaver are proposed considering both erroneous and non-erroneous scenarios without any prior knowledge about the encoding scheme used in the transmitter. Note that the proposed algorithms will classify among block coded, convolutional coded, and uncoded data streams.**

***Index Terms*—Automatic recognition, blind/semi-blind estimation, block codes, convolutional codes, forward error correcting (FEC) codes, helical scan interleaver.**

I. Introduction

Modern digital communication and storage systems demand the need for forward error correcting (FEC) codes and interleaver to counteract random and burst errors, respectively. In 1948, Shannon demonstrated that by using proper encoding schemes, noise introduced by the channel can be controlled to a desired level. Since Shannon's pioneering paper, efficient encoding and decoding methods have been proposed to control and correct the errors introduced by the noisy channel. In general, block and convolutional codes are two different types of FEC codes. In the case of block codes, a unique sequence of k data symbols is fed into a block encoder. The encoder adds redundancy and produces a unique sequence of n data symbols, which is called a codeword. The code rate r is given by k/n. In the case of convolutional codes, since the encoder has memory m, the output coded sequence of n symbols not only depends on the present input sequence of k symbols, but also depends on the previous input sequence of m symbols.

There are different types of block interleavers such as matrix interleaver, helical scan interleaver, random interleaver, etc. proposed in the literature to counteract the burst errors introduced by the noisy channel. In this paper, our discussions will be restricted to helical scan interleaver. In the case of helical scan interleaver, the data symbols are divided into multiple blocks of size equal to interleaver matrix size or interleaver period β, where $\beta = N_r \times N_c$, N_r and N_c indicate the number of rows and columns of the helical scan interleaver matrix, respectively. Similar to matrix interleaver, the helical scan interleaver stores each block of data symbols row-wise. However, unlike matrix interleaver, the data symbols will be interleaved using matrix diagonals in a helical fashion according to helical array step size d. In [1], a detailed explanation for helical scan interleaver operation is given with an example. The main reason for considering helical scan interleaver is because of better distribution of burst errors compared to matrix interleaver.

In most of the applications, exact information about the coding and interleaver parameters is required at the receiver to successfully decode and de-interleave the information bits, respectively. But in certain applications, blind/semi-blind estimation of coding and interleaver parameters provide additional advantages. For example, in the case of adaptive modulation and coding(AMC)-based wireless communication systems, the information related to AMC parameters will be usually signalled to the receiver by control channel. However, blind/semi-blind estimation of the same will lead to conservation of channel resources. Similarly, due to evolution of modern digital communication systems, designing communication equipments for every standards around the world is a costly as well as a tedious process. To negate this problem, software-defined radio (SDR) or cognitive radio systems are introduced. Therefore, blind/semi-blind estimation of transmission parameters from the received data stream is mandatory for cognitive radio receiver, since signaling the transmission parameters at every instant to the receiver is a time consuming process.

In the previous works, blind/semi-blind estimation techniques for automatic recognition of FEC code and interleaver parameters were proposed and investigated by assuming the type of FEC codes and interleaver are known at the receiving end. Parameter estimation algorithms for convolutional codes were proposed and investigated rigourously in [2] and [3] based on dual-code concept. In [4], a semi-blind recognition technique for estimating binary cyclic code parameters was proposed. In [5], a methodology for semi-blind estimation of puncturing pattern along with the recognition of parent convolutional code parameters were reported for erroneous scenario assuming the punctured code parameters are known at the receiver. Furthermore, semi-blind parameter estimation algorithms for matrix and convolutional interleavers were investigated in [6]-[9] assuming block encoded data and erroneous scenario. But only interleaver period is estimated in the case of matrix interleaver and rest of the parameters like N_r and N_c were not estimated. Finally, in [10], the estimation of type of FEC codes and code parameters was studied only for non-erroneous scenario . Hence, to the best of our knowledge, joint recognition of type of FEC codes and helical scan interleaver parameters over erroneous scenario has not been investigated in any of the prior works.

A. Contributions

Therefore, the main contributions of our work are as follows:

- Firstly, a block diagram explaining the process of automatic recognition of type of FEC codes and helical scan interleaver parameters is given.
- Secondly, steps for joint recognition of type of error correcting codes and interleaver period β are given considering both erroneous and non-erroneous scenarios. In addition, algorithm for estimation of N_r, N_c, and d is proposed for robust environment.
- Finally, to justify the proposed claims, simulation results and related discussions are given for erroneous scenario.

It is to be noted that the proposed algorithms will differentiate among block coded, convolutional coded, and uncoded data. Further, the automatic recognition techniques are proposed by assuming the type of interleaver is known at the receiver and it is also assumed that the received data is synchronized. If the data is not synchronized, then the type of FEC codes cannot be recognized. However, interleaver period and helical scan interleaver parameters can be estimated. Moreover, if the type of interleaver is not known, then the interleaver period can be identified. However, the individual parameters like N_r, N_c, d, etc cannot be identified, as the type is not known.

The rest of the paper can be organized as follows. In section II, a brief explanation for joint recognition techniques is given using a block diagram. Section III describes the rank-based methodology for joint estimation of interleaver period and type of FEC codes in an ideal environment. Further, in section IV, the joint estimation steps are given for robust environment. In Section V, algorithm for estimating helical scan interleaver parameters such as N_r, N_c, and d are given considering erroneous scenario. Simulation results and related discussions are reported in Section VI. Finally, concluding remarks are given in Section VII.

II. Joint Estimation Process

In this section, a block diagram explaining the joint estimation process is given in Fig. 1. After receiving the data symbols with errors at the receiver, firstly, interleaver period along with the type of FEC codes will be estimated. Secondly, by de-interleaving, rest of the interleaver parameters will be estimated. Finally, corresponding code parameters will be recognized. In this paper, our discussions are restricted to recognition of type of FEC codes and helical scan interleaver parameters.

III. Code Classification and Interleaver Period Estimation over Non-Erroneous Scenario

Convolutional code is represented as $C(n,k,K)[g_1^1,...,g_i^j,...,g_k^n]$, where $n,k,$and K denote number of outputs, number of inputs, and constraint length, respectively, and g_i^j indicates the octal representation of generator polynomial between input i and output j. Similarly, linear block code is represented as $B(n,k)$. The steps for estimating the type of FEC codes and interleaver period over non-erroneous environment is given below.

- Step 1: Let us assume that the incoming data symbols are either block coded or convolutional coded or uncoded and interleaved using helical scan interleaver.
- Step 2: The received data symbols are reshaped into a matrix form of size $a \times b$, where a and b indicate the number of rows and columns of data matrix S, respectively.
- Step 3: For simplicity without loss of generality, assume $a \geq 2 \times b$.
- Step 4: Using Gauss elimination process, the data matrix S is transformed into column echelon form F.
- Step 5: The rank ratio is evaluated by calculating the number of non-zero columns in F and the same is given by $p{=}\rho(S)/b$, where $\rho(S)$ denotes rank of S.

Proposition 1:

Firstly, if the incoming data symbols are **convolutional encoded**, then while varying the number of columns b, the rank deficiency will be obtained only for the case when $b = \alpha \times \beta$ provided the interleaver period β is a multiple of n (i.e. $\beta = \gamma \times n$), where α and γ are positive integers. Now $\rho(S)$ and p are, respectively, given by

$$\begin{aligned} \rho(S) &= \alpha{\times}\gamma{\times}k + m\,, \\ p &= \frac{\rho(S)}{b}\,. \end{aligned} \tag{1}$$

After substituting $b{=}\alpha{\times}\beta$, where $\beta{=}\gamma \times n$, in (1), p can be written as

$$p{=}r + \lambda\,, \tag{2}$$

where $r = \frac{k}{n}$ and $\lambda = \frac{m}{b}$. Similarly, while varying b, if $\beta \neq \gamma \times n$, then rank deficiency for convolutional encoded data will be obtained only for the case when $b = \alpha \times lcm(n, \beta)$ provided $lcm(n,\beta) = \gamma{\times}n$ and the rank ratio expression is given by (2). However, if $b{\neq}\alpha{\times}\beta$ or $b{\neq}\alpha{\times}lcm(n,\beta)$, then full rank will be obtained i.e. $\rho(S){=}b$ and therefore, $p{=}1$.

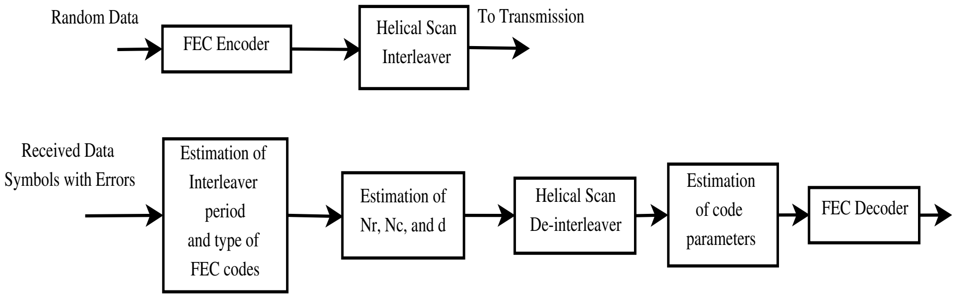


Fig. 1. Block diagram for joint estimation process considering helical scan interleaver

Proof:

Note that for convolutional codes, n output data symbols not only depend on k present input data symbols but also depend on previous m input data symbols, where $m = K - 1$. Similarly, block of output data symbols (i.e. $\alpha \times n$ symbols) depend on $\alpha \times k$ present and m previous input symbols (i.e. $\alpha \times k + m$ symbols). Hence, $\alpha \times \beta$ or $\alpha \times lcm(n, \beta)$ output data symbols, where β or $lcm(n, \beta) = \gamma \times n$, will depend on $\alpha \times \gamma \times k + m$ symbols. Alternatively, if $b = \alpha \times \gamma \times n$, then $\alpha \times \gamma$ codewords in a particular row of S will be a linear combination of $\alpha \times \gamma \times k + m$ input symbols in the same row and it is also applicable to all the other rows of S. Further, it can be observed that $\alpha \times \gamma$ codewords in all the rows will be aligned properly in the same column for the case when $b = \alpha \times \gamma \times n$, which will eventually lead to rank deficiency, since there will be only $\alpha \times \gamma \times k + m$ independent columns out of b columns. However, if $b \neq \alpha \times \gamma \times n$, then $\alpha \times \gamma$ codewords will be segregated in different rows and will not be aligned properly in the same column resulting in full rank.

Proposition 2:

Secondly, if the incoming data symbols are **block encoded**, then while varying b, the rank deficiency will be obtained only for the case when $b = \alpha \times \beta$ provided $\beta = \gamma \times n$. Now $\rho(S)$ and p are, respectively, given by

$$\begin{aligned} \rho(S) &= \alpha \times \gamma \times k, \\ p &= r. \end{aligned} \tag{3}$$

Similarly, while varying b, if $\beta \neq \gamma \times n$, then rank deficiency for block encoded data will be obtained only for the case when $b = \alpha \times lcm(n, \beta)$ and the rank ratio is given by (3). However, full rank will be obtained for both the cases if $b \neq \alpha \times \beta$ or $b \neq \alpha \times lcm(n, \beta)$.

Proof:

It is to be noted that for block codes, n output data symbols depend only on k input data symbols unlike convolutional codes, since there is no memory. Hence, $\alpha \times \beta$ or $\alpha \times lcm(n, \beta)$ output data symbols, where β or $lcm(n, \beta) = \gamma \times n$, in a particular row of S will depend on $\alpha \times \gamma \times k$ symbols in the same row. Furthermore, $\alpha \times \gamma$ codewords in all the rows will be aligned properly in the same column for the case when $b = \alpha \times \gamma \times n$. This will result in rank deficiency, since there will be only $\alpha \times \gamma \times k$ independent columns out of b columns However, if $b \neq \alpha \times \gamma \times n$, then $\alpha \times \gamma$ codewords in all the rows will not be aligned properly in the same column resulting in full rank.

Proposition 3:

Finally, if the data is uncoded, then while varying b, full rank will be obtained irrespective of the number of columns. Hence, $\rho(S) = b$ and $p = 1$.

Proof:

Since the incoming uncoded data symbols are independent of each other, full rank will be obtained irrespective of the value of b.

Therefore, uncoded, block, and convolutional encoded data can be categorized easily from (2) and (3). It can be inferred that the deficient rank ratio remains constant at code rate value r when $b = \alpha \times \gamma \times n$ for block codes. For convolutional codes, the deficient rank ratio decreases rapidly for lower values of b and for larger values of b, the rank ratio tends to remain constant slightly above r when $b = \alpha \times \gamma \times n$. Finally, the rank ratio remains constant at unity for all the values of b in the case of uncoded data symbols.

From $\rho(S)$ given by (1) and (3), observe the difference between successive columns of S with rank deficiency. The interleaver period β (i.e. for the case when β is a multiple of n) or $lcm(n, \beta)$ (i.e. for the case when β is not a multiple of n) can be estimated by calculating the most frequent value obtained from the difference between successive columns with rank deficiency. Let us assume $b = \alpha \times \gamma \times n$ and $b' = (\alpha + 1) \times \gamma \times n$ denote the two rank deficient columns and their difference is given by

$$\begin{aligned} b' - b &= (\alpha + 1) \times \gamma \times n - \alpha \times \gamma \times n \\ &= \gamma \times n \\ &= \beta \text{ or } lcm(n, \beta) \end{aligned} \tag{4}$$

IV. Code classification and interleaver period estimation over robust environment

The methodology proposed in the previous section is restricted to non-erroneous scenario and also for erroneous scenario until BER=10^{-3}. However, the proposed methodology fails for the case when BER$> 10^{-3}$. Because, full rank will be obtained for both convolutional and block codes irrespective of the value of b and the estimation of type of FEC codes cannot be performed from the full rank matrix. Therefore, an alternate methodology to evaluate $\rho(S)$ and p is given in this section. We know that the number of independent columns in a matrix or number of non-zero rows/columns in a row/column echelon form indicate the rank of a matrix. Note that the dependent columns in the column echelon form F of the data matrix will be converted into all-zero-columns in the case of non-erroneous scenario. However, for erroneous scenario, due to erroneous bits, the dependent columns will not get transformed into all-zero-columns, which will eventually give rise to full rank for all the values of b. Therefore, the number of dependent/independent columns from F can be calculated by evaluating the mean value of number of zeros $\mu(c)$ in each columns for a particular value of b, where $c \in \{1, 2, ..., b\}$, instead of evaluating the number of all-zero/non-zero columns. Note that for dependent columns, $\mu(c)$ will be higher compared to independent columns. Thus, the number of independent columns or rank $\rho(S)$ and rank ratio p for a given value of b considering erroneous scenario are, respectively, given by

$$\rho(S) = \textbf{card}\left(c \in \{1, 2, ..., b\} \mid \mu(c) < \Gamma^{th}\right), p = \frac{\rho(S)}{b}, \quad (5)$$

where card$(\cdot)$ denotes the cardinality operation, $\mu(c) = \frac{\phi(c)}{a}$, $\phi(c)$ indicates the number of zeros in c^{th} column, a indicates the number of rows in S, and Γ^{th} represents the threshold value. Similarly, $\rho(S)$ and p are evaluated for other values of b and the propositions given in the previous section will be used to classify the incoming data symbols. Moreover, using (4), β or $lcm(n, \beta)$ can be evaluated for erroneous scenario.

V. Estimation of rest of the interleaver parameters

After recognizing β or $lcm(n, \beta)$, rest of the helical scan interleaver parameters such as N_r, N_c, and d can be estimated using the following algorithm.

Algorithm

Input : $\zeta = \beta$ or $lcm(n, \beta)$ **Output** : N_r^{est}, N_c^{est}, and d^{est}

- Step:1 Assume $\beta = N_r \times N_c$ and N_r', $N_c' > 1$.
- Step:2 Fix a maximum value for codeword length n_{max} depending upon the type of FEC codes.
- Step:3 **For** $i = 1 : n_{max}$
  Find all possible combinations of N_r' and N_c'
  that satisfy $N_r' \times N_c' = \frac{\zeta}{i}$
  end
- Step:4 Fix b as a multiple of β or $lcm(n, \beta)$.
- Step:5 De-interleave and calculate the mean of zero ratio $\mu'(b)$ for all possible values of N_r' and N_c' by varying helical array step size $d' = 1 : N_r' - 1$
- Step:6 Find $[N_r^{est}, N_c^{est}, d^{est}] = \underset{N_r', N_c', d'}{argmax}(\mu'(b))$.

In the above algorithm, the mean of zero ratio $\mu'(b)$ is given by

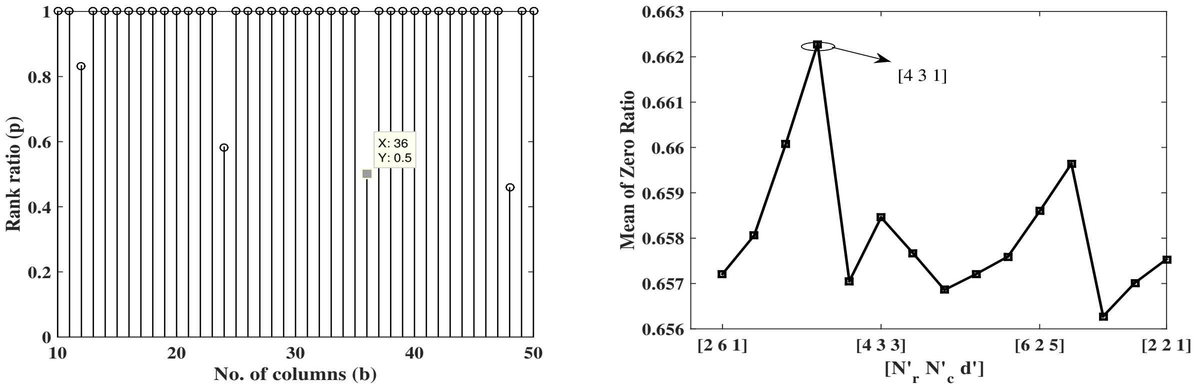
$$\mu'(b) = \frac{\sum_{c=1}^{b} \mu(c)}{b} \quad (6)$$

VI. Simulation Results and Discussions

In Fig.2(a), the variation of rank ratio p with b is shown for $C(3, 1, 7)[133, 165, 171]$ considering helical scan interleaver assuming $N_r = 4$, $N_c = 3$, $d = 1$, and BER = 2×10^{-2}. As the rank ratio curve is given for erroneous scenario, the methodology proposed in Section IV is utilized for plotting p versus b. As stated in proposition 1, it is observed from the figure that the deficient rank ratio is not constant and decays for lower values of b considering the case when $b = \alpha \times \beta$, where $\beta = 12$. Moreover, as b increases, the deficient rank ratio values remain approximately constant above the code rate value of 0.33. This particular trend in the rank ratio curve is mainly due to λ given in (2). Therefore, from Fig.2(a), the incoming data symbols can be identified as convolutional coded symbols. Further, from the difference between successive columns with rank deficiency, interleaver period $\beta = 12$ can be estimated. After estimating β, the variation of mean of zero ratio $\mu'(b)$ is shown in Fig. 2(b) by fixing b as a multiple of β considering the same case after de-interleaving. According to the proposed algorithm in Section V, the incoming helical scan interleaved data symbols is de-interleaved with all possible combinations of N_r' and N_c' that satisfy $N_r' \times N_c' = \frac{\zeta}{i}$, where $\zeta = \beta$ and $i = 1, 2, ..., n_{max}$. Hence, the possible combinations can be listed as $[N_r' \ N_c']$={[2 6],[3 4],[4 3],[6 2],[2 3],[3 2],[2 2]}. Now $\mu'(b)$ as given by (6) is calculated for all possible combinations of $[N_r' \ N_c']$ by simultaneously varying the helical array step size d' from 1 to $N_r' - 1$ as mentioned in the algorithm. Note that for helical scan interleaver, $d < N_r$. It has been observed from the figure that among all possible combinations, $\mu'(b)$ is maximum for $N_r' = 4$, $N_c' = 3$, and $d' = 1$. Hence, the helical scan interleaver parameters are successfully recognized using the proposed algorithm.

In Fig.3(a), the variation of p with b is shown for $B(8, 5)$ assuming $N_r = 4$, $N_c = 4$, $d = 3$, and BER=10^{-2}. From the figure, it can be observed that the deficient rank ratio remains constant at the code rate value of 5/8. Therefore, according to proposition 2, the incoming data symbols can be recognized as block coded symbols. Further, the difference between successive columns with rank deficiency is observed to be equal to 16, which gives the correct estimate of β. The variation of $\mu'(b)$ by fixing b as a multiple of β considering the same case after de-interleaving is shown in Fig.3(b) for all possible combinations of $[N_r' \ N_c' \ d']$. From the figure, it can be observed that $\mu'(b)$ is maximum for $N_r' = 4$, $N_c' = 4$, and $d' = 3$, which exactly matches with the assumed helical scan interleaver parameters at the transmitter.

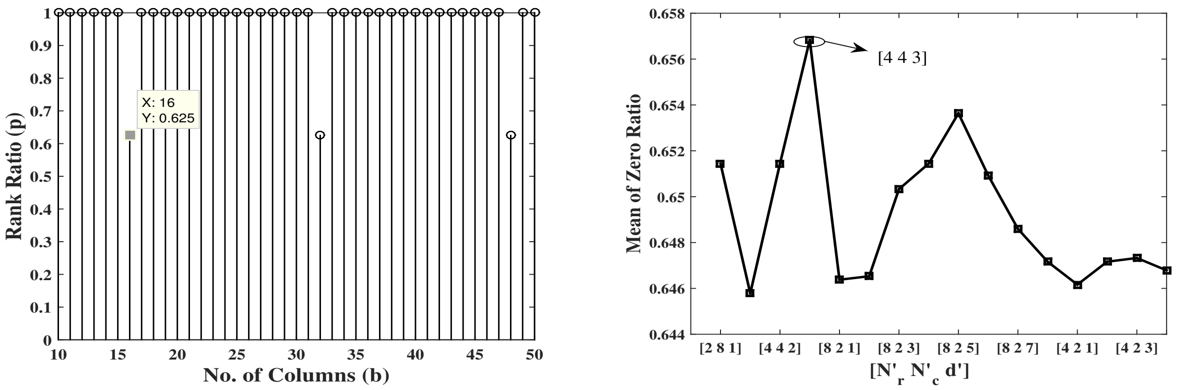
The histogram plot for mean value of number of zeros $\mu(c)$ in each columns considering $b = 36$, where $c \in \{1, 2, ..., b\}$, assuming $N_r = 4$, $N_c = 3$, $d = 1$, $C(3, 1, 7)[133, 165, 171]$, and BER=$2 \times 10^{-2}$ is shown in Fig.4(a). It can be observed from the figure that the value of $\mu(c)$ for 18 columns out of 36 is approximately around 0.5. Further, the value of $\mu(c)$ is greater than 0.58 for the rest of 18 columns. As more than 58% of the elements in 18 columns are zeros, they can be classified as dependent columns. It is to be noted that in the case of non-



(a)

(b)

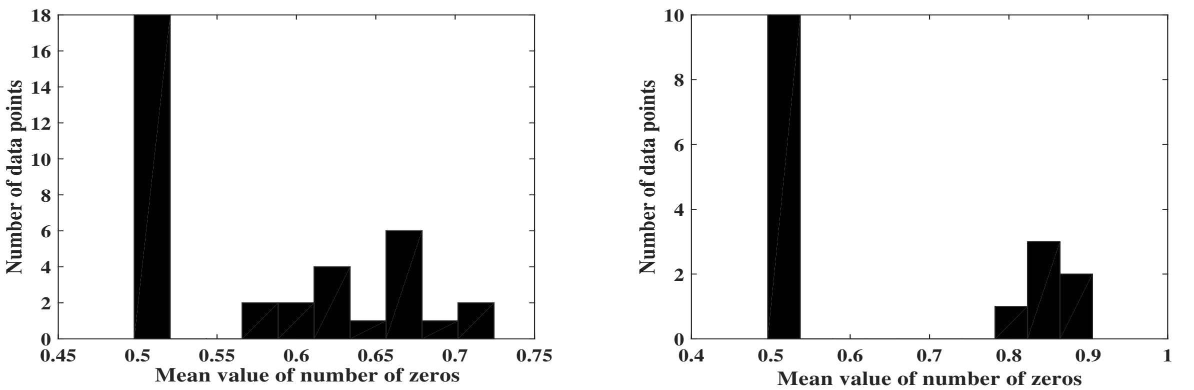
Fig. 2. (a) Variation of rank ratio p with b for $C(3,1,7)[133,165,171]$ considering helical scan interleaver assuming $N_r=4$, $N_c=3$, $d=1$, and BER=2×10^{-2}. (b) Variation of mean of zero ratio $\mu'(b)$ with all possible values of $[N_r'\ N_c'\ d']$ for $C(3,1,7)$ considering helical scan interleaver with $N_r=4$, $N_c=3$, $d=1$, and BER=2×10^{-2}



(a)

(b)

Fig. 3. (a) Variation of rank ratio p with b for $B(8,5)$ considering helical scan interleaver assuming $N_r=4$, $N_c=4$, $d=3$, and BER=10^{-2}. (b) Variation of mean of zero ratio $\mu'(b)$ with all possible values of $[N_r'\ N_c'\ d']$ for $B(8,5)$ considering helical scan interleaver with $N_r=4$, $N_c=4$, $d=3$, and BER=10^{-2}



(a)

(b)

Fig. 4. (a) Histogram plot for $\mu(c)$ assuming $b=36$, $N_r=4$, $N_c=3$, $d=1$, $C(3,1,7)[133,165,171]$, and BER=2×10^{-2}. (b) Histogram plot for $\mu(c)$ assuming $b=16$, $N_r=4$, $N_c=4$, $d=3$, $B(8,5)$, and BER=10^{-2}.

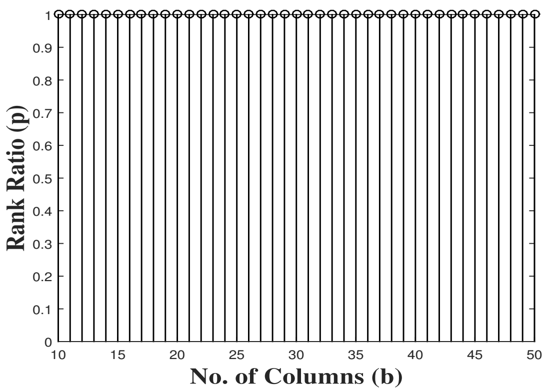


Fig. 5. Variation of rank ratio p with b for uncoded data stream assuming BER=10^{-2}

erroneous scenario, these 18 columns should have been all-zero-columns with high probability. Therefore, dependent and independent columns can be classified by fixing Γ^{th} between 0.53 to 0.56. Moreover, it can be inferred from the figure as well as from (5) that the number of independent columns or $\rho(S)=18$ and it is also justified in Fig.2(a), as $p=0.5$ for the case when $b=36$.

Similarly, the histogram plot for $\mu(c)$ in each columns considering $b=16$, where $c \in \{1, 2, ..., b\}$, assuming $N_r=4$, $N_c=4$, $d=3$, $B(8,5)$, and BER=10^{-2} is shown in Fig.4(b). It can be inferred from the figure that $\rho(S)=10$ or $p=0.625$ by setting Γ^{th} between 0.55 to 0.75 and the same can also be justified using Fig.3(a), since $p=0.625$ for the case when $b=16$. Hence, $\rho(S)$ and p are calculated for other values of b considering $C(3,1,7)[133,165,171]$ and $B(8,5)$ assuming $\Gamma^{th}=0.55$ and the rank ratio curves are plotted as shown in Fig.2(a) and Fig.3(a). Since Γ^{th} varies from case to case, the same can be obtained by plotting the histogram curves for a particular scenario.

From the histogram plots, it can be inferred that as the BER decreases, the range for choosing Γ^{th} to segregate dependent and independent columns increases. This is mainly due to increase in the value of $\mu(c)$ for dependent columns due to less number of erroneous bits.

In Fig.5, the variation of p with b is shown for uncoded data stream assuming BER=10^{-2}. From Fig.5, it can be inferred that full rank is obtained irrespective of the value of b and hence, the incoming data symbols can be classified as uncoded according to proposition 3.

From the simulation studies, it has also been observed that the code classification and interleaver parameter estimation can be performed with 100 % accuracy until BER=2×10^{-2} for most of the test cases, however, by setting appropriate threshold value Γ^{th} from the histogram plots as well as by increasing the number of rows a. Note that for BER=10^{-2}, it has been assumed that $a=20\times b$. But for the case when BER=2×10^{-2}, the number of rows relative to number of columns has been increased (i.e. $a=50\times b$) for successful estimation. Further, the proposed algorithm fails to classify the FEC codes for the case when BER $> 2\times10^{-2}$, since identifying all the dependent and independent columns from the histogram plots will become difficult, despite increasing the data size. However, in spite of failing to classify the FEC codes, the helical scan interleaver parameters along with interleaver period can be successfully recognized until BER=4×10^{-2}. Moreover, it is also observed that using the proposed algorithm, longer interleaver period value until $\beta=90$ has been estimated successfully. However, for estimating longer value of β, the number of columns of S should be increased for evaluating rank ratio p accurately. Hence, more data size and computational time will be required for estimating the interleaver parameters.

Finally, once the type of FEC codes is recognized, algorithms proposed in [2]-[5] can be used for recognizing the corresponding code parameters.

VII. Conclusions

In this paper, innovative algorithms for joint estimation of type of FEC codes and helical scan interleaver parameters have been proposed for erroneous and non-erroneous scenarios. In a nutshell, firstly, estimation of interleaver period along with code classification among block, convolutional coded, and uncoded data symbols is performed. After that while de-interleaving, rest of the helical scan interleaver parameters are estimated. It can be concluded that the deficient rank ratio remains constant at r for block codes considering the case when $b = \alpha\times\beta$ or $b = \alpha\times lcm(n,\beta)$. However, for convolutional codes, the deficient rank ratio decays rapidly and remain approximately constant slightly above r for the case when $b=\alpha\times\beta$ or $b=\alpha\times lcm(n,\beta)$. Moreover, irrespective of the number of columns, full rank is obtained for uncoded data stream. To justify the proposed claims, simulation results for recognizing the type of FEC codes and interleaver parameters are shown for erroneous scenario considering two different BER values.

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