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Weighted Block-wise Burst Error Correcting Codes

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Abstract

In this paper, we construct new types of codes, called Weighted Block-wise Burst Error Correcting Codes (Weighted BBEC Codes), which are an improvement on the previously known block wise burst error correcting codes in the sense of their weight, i.e., $(n = n_1 + n_2, k)$ linear codes that correct all the bursts of length b_1 (fixed) with the weight $w_1 (w_1 \leq b_1)$ or more (less) in the first sub-block of length n_1 and all the bursts of length b_2 (fixed) with the weight w_2 or more (less) in the next sub-block of length n_2.

Keywords: Burst; Optimal codes; Block-wise error correcting codes; Weight of burst; Error Pattern; Syndromes; Parity-check digits; Bounds; Sub-blocks; Parity-check matrix; Linear codes

MSC 2020 No.: 94A24, 94B35, 94B70

1. Introduction

Many studies have been carried out to develop different types of codes that correct the most common error (burst) that occur in communication systems. Such codes are named as burst error correcting (BEC) codes. Hamming (1950) obtained codes as well as bounds that are capable of detecting and correcting random errors. The work of Abramson (1959) can be considered as the starting point for all the other work on burst codes, which constructed a single error and double-adjacent error correcting code which is the extension of the work of Hamming (1950) work.

With respect to the usual definition of burst given by Sharma and Gupta (2007) and many authors obtained interesting results regarding bursts error, Chien and Tang (1965) have presented this in a slightly different way, named as Chein-Tang burst (CT-burst).

There are some channels which fall in the category to control CT-burst. But depending on the behavior of the channel, the nature of bursts vary from channel to channel. Dass (1980) noted that in several channels, errors do occur but not near the end of the code words. To overcome such situations, he modified CT-burst and presented a new definition of burst, called a CTD-burst. Accordingly, (100000) is considered as a burst of length at most 6. This definition has been found very useful in error analysis experiments on telephone lines (Alexander et al. (1960)). In some space channel models in which an amplitude modulated carrier are generated aboard a satellite are transmitted to an earth antenna and in systems where errors do not occur near the end of the code words with burst length very large.

Block-wise burst error correcting (BBEC) codes are codes in which a burst can occur only with in the selected parts of the code length or sub-blocks. In case of two sub-blocks, Dass et al. (2006a, 2006b, 2017) and others have published some interesting results for binary and non-binary cases. With respect to CTD-burst, Dass and Tyagi (1980) have studied a block-wise burst error correcting (BBEC) linear codes for two sub-blocks, in which the length of the sub- block is divided in two parts such that it can correct all bursts of different lengths in their respective sub-blocks. They obtained necessary and sufficient bounds over the number of parity check digits. Tyagi and Sethi (2009) generalized it into three sub-blocks and construct codes with all possibilities on the size of sub-blocks and the length of bursts. Such codes are more efficient and have better rate of transmission. Further, Tyagi and Sethi (2011), Sethi (2017), Tyagi and Sethi (2013) obtained some new types of BBEC linear and optimal codes with lower and upper bounds on the number of parity-check digits required for the existence of such codes.

Lightning or other disturbances which introduce burst errors usually operate in a way such that, over given length, some digits are received correctly while others are corrupted. Such situations demand the development of new codes which can correct those errors that are bursts of length with its weight constraint. Earlier, Dass (1974) gave bounds for code detecting burst error with weight constraints and extend this study to the correction of these codes, where Dass (1975) gave only the sufficient bound. The necessary bound on the number of parity check digits for such codes have been obtained by Sharma and Dass (1974).

Tyagi et al. (1979) had obtained some combinatorial results pertaining to the weights of burst. They gave an upper bound for a linear code which can correct all the burst of length (fixed) keeping in view the weight constraints.

In this paper, we generalize this study into two sub –blocks. We had developed a linear code which can correct all bursts of different lengths with their weight in their respective sub-block. By introducing such codes, we can economize in parity check digits required and suitably reducing the redundancy of the codes. In Section 2, we have proved the neccesary condition for the construction of above stated codes and corollaries stated for the conditions on the corresponding weight constraint. Section 3 gives illustrations of corollary 1 and corollary 2 with the help of examples for the burst error correcting codes with weight w_i or more (less) in the two sub-blocks of different length n_1 and n_2 which means if $w_1 = 2$ and $b_1 = 3$, then the error pattern for w_1 or more in the length of sub block $n_1 = 4$ is given by (1100, 0110, 0011, 1010, 0101, 1110, 0111), and if $w_1 = 2$ and $b_1 = 3$, then the error pattern for w_1 or less in the length of sub block $n_1 = 4$ is given by (1000, 0100, 1010, 0101, 1100, 0110). In Section 4, we have proved the sufficient bound for burst error correcting codes with weight constraints. In Section 5, some open problems has been discussed, and Section 6 includes the brief summary of the work carried out in this paper.

2. Necessary condition

In this section we give necessary bounds for the construction of codes that are capable of correcting burst errors with their weight constraints.

Theorem 2.1.

The total number of bursts of length b_1 with weight $w_1 (1 \leq w_1 \leq b_1)$ in the sub-block of length n_1 and burst of length b_2 with weight $w_2 (1 \leq w_2 \leq b_2)$ in the sub-block of length n_2 is given by

$$\binom{b_1 - 1}{w_1 - 1}(n_1 - b_1 + 1)(q-1)^{w_1} + \binom{b_2 - 1}{w_2 - 1}(n_2 - b_2 + 1)(q-1)^{w_2}. \tag{1}$$

Proof:

Since burst error of length b_1 (fixed) is to be corrected in the first n_1-tuple, then the starting position for the burst of length b_1 can be $(n_1 - b_1 + 1)^{th}$ component. There are $(q - 1)$ ways to choose the first non zero component of n_1-tuple for a burst of length b_1 (fixed). Also, out of the remaining $(b_1 - 1)$ components, $(w_1 - 1)$ components must be non zero, which can be chosen $\binom{b_1-1}{w_1-1}$ in ways. And each of these $(w_1 - 1)$ non zero components have $(q - 1)$ ways.

Therefore, the total number of bursts of length b_1 (fixed) with the weight $w_1 (1 \leq w_1 \leq b_1)$ in the sub-block of lengthn_1 is equal to

$$\binom{b_1 - 1}{w_1 - 1}(n_1 - b_1 + 1)(q-1)^{w_1}. \tag{2}$$

Similarly, the total number of bursts of length b_2 (fixed) with the weight $w_2 (1 \leq w_2 \leq b_2)$ in an

n_2-tuple is equal to

$$\binom{b_2-1}{w_2-1}(n_2-b_2+1)(q-1)^{w_2} \tag{3}$$

Thus, total number of bursts with their respective weights in an $(n_1, n_2 = n, k)$ linear code is given by

$$\binom{b_1-1}{w_1-1}(n_1-b_1+1)(q-1)^{w_1} + \binom{b_2-1}{w_2-1}(n_2-b_2+1)(q-1)^{w_2}. \tag{4}$$

■

Varying the values of w_1 and w_2 we can have the following corollaries.

Corollary 2.1.

The number of parity check digits required for $(n_1 + n_2 = n, k)$ linear codes that can correct all the bursts of length b_1 (fixed) with the weight w_1 or more $(\leq b_1)$ and all the bursts of length b_2 (fixed) with the weight w_2 or more $(\leq b_2)$ in the first n_1 components and next n_2 components, respectively, is at least

$$q^{n-k} \geq 1 + \sum_{l=w_1}^{b_1} \binom{b_1-1}{l-1}(n_1-b_1+1)(q-1)^{l} + \sum_{m=w_2}^{b_2} \binom{b_2-1}{m-1}(n_2-b_2+1)(q-1)^{m}. \tag{5}$$

Corollary 2.2.

The number of parity check digits required for $(n_1+n_2 = n, k)$ linear codes that can correct all the bursts of length b_1 (fixed) with the weight $w_1(w_1 \leq b_1)$ or less and all the bursts of length b_2 (fixed) with the weight $w_2(w_2 \leq b_2)$ or less in the first components and next components, respectively, is at least

$$q^{n-k} \geq 1 + \sum_{i=1}^{w_1} \binom{b_1-1}{i-1}(n_1-b_1+1)(q-1)^{i} + \sum_{j=1}^{w_2} \binom{b_2-1}{j-1}(n_2-b_2+1)(q-1)^{j}. \tag{6}$$

3. Illustration

In this section we illustrate Corollary 1 and Corollary 2 with the help of an example.

Example 3.1. (Ilustration for Corollary 1)

For $n_1 = 4, n_2 = 7, b_1 = 3, b_2 = 4; w_1 = 2, w_2 = 3$. Consider the following parity check matrix as

$(11, 5)$ code,

$$H = \begin{bmatrix} 1\,0\,1\,0 & 1\,1\,0\,0\,1\,1\,0 \\ 0\,1\,0\,0 & 1\,0\,1\,0\,1\,0\,0 \\ 0\,0\,0\,1 & 1\,1\,0\,0\,1\,0\,0 \\ 0\,0\,0\,0 & 1\,0\,0\,0\,1\,1\,0 \\ 0\,0\,0\,0 & 1\,0\,0\,0\,0\,1\,0 \\ 0\,0\,1\,0 & 1\,0\,0\,0\,0\,0\,1 \end{bmatrix}.$$

It can be verified from Table 3.1 the code is weighted burst error correcting code.

Table 3.1. Error-Pattern Syndrome Table

Error-Pattern	**Syndromes**
1100 0000000	110000
0110 0000000	110001
1010 0000000	000001
0101 0000000	011000
1110 0000000	010001
0111 0000000	111001
0000 1110000	001111
0000 1011000	100111
0000 1101000	010111
0000 0111000	111000
0000 0101100	011100
0000 0110100	000100
0000 0011100	101100
0000 0010110	000010
0000 0011010	111110
0000 0001110	011010
0000 0001011	101111
0000 0001101	111101
0000 1111000	000111
0000 0111100	001100
0000 0011100	001010
0000 0001111	011011

Example 3.2. (Illustration for Corollary 2)

For $n_1 = 4, n_2 = 7; b_1 = 3, b_2 = 4; w_1 = 2, w_2 = 3$. Consider the following parity check matrix of

$(11, 5)$ code,

$$H = \begin{bmatrix} 1\,0\,1\,0 & 1\,1\,0\,0\,1\,1\,0 \\ 0\,1\,0\,0 & 1\,0\,1\,0\,1\,0\,0 \\ 0\,0\,0\,1 & 1\,0\,0\,1\,0\,0\,0 \\ 0\,0\,0\,0 & 1\,0\,0\,0\,1\,1\,0 \\ 0\,0\,0\,0 & 1\,1\,0\,0\,0\,1\,0 \\ 0\,1\,1\,0 & 1\,0\,0\,0\,0\,0\,1 \end{bmatrix}.$$

It can be verified from Table 3.2 the code is weighted burst error correcting code.

Table 3.2. Error-Pattern Syndrome Table

Error-Pattern	Syndromes
1000 0000000	100000
1100 0000000	110001
0100 0000000	010001
0110 0000000	110000
1010 0000000	000001
0101 0000000	011001
0000 1000000	111111
0000 1100000	011101
0000 1010000	101111
0000 1001000	110111
0000 0100000	100010
0000 0110000	110010
0000 1010000	101010
0000 0100100	010110
0000 0010000	010000
0000 0011000	011000
0000 0010100	100100
0000 0010010	110110
0000 0001000	001000
0000 0001100	111100
0000 0001010	101110
0000 0001001	001001

4. Sufficient bound for the burst error correcting codes

Theorem 4.1.

Given positive integers b_1, b_2, w_1 and w_2, there exists an (n,k) linear code that corrects all bursts of length b_1 (fixed) with weight w_1 in the first sub-block of length n_1 and all bursts of length b_2 (fixed) with weight w_2 in the second sub-block of length n_2 $(n = n_1 + n_2)$ satisfying the inequality

$$q_{n-k} > max\left[\binom{b_2-1}{w_2-1}(q-1)^{w_2}\left[(n_2-b_2+1)\binom{b_2-1}{w_2-1}(q-1)^{w_2-1}\right],\right.$$
$$\binom{b_1-1}{w_1-1}(q-1)^{w_1}\left[1+(n_1-2b_2+1)(q-1)^{w_1}\binom{b_1-1}{w_1-1}\right]$$
$$\left.+\binom{b_1-1}{w_2-1}(q-1)^{w_1}(n_2-b_2+1)\binom{b_2-1}{w_2-1}(q-1)^{w_2}\right]. \quad (7)$$

Proof:

By constructing appropriate parity check digits $H = [H_1, H_2]$, we will show the existence of such codes. In order to construct the matrix H, we shall construct the matrix $H^{'} = [H_2^{'}, H_1^{'}]$. We shall obtain matrix H by reversing the order of the columns of $H^{'}$.

Choose any non zero $(n-k)$ tuple as the first column of $H^{'}$. Subsequent columns are added such that after having selected $n_1 - 1$ columns $h_1, h_2, ..., h_{n_1-1}$, a column h_{n_2} is added, provided that

$$h_{n_2} \neq (x_{n_2-b_2-1}h_{n_2-b_2-1} + ... + x_{n_2-1}h_{n_2-1}) + (y_j h_j + ... + y_{j+b_2-1}h_{j+b_2-1}), \quad (8)$$

where $j + b_2 - 1 < n_2 - b_2 + 1$, the number of non zero x_i is $w_2 - 1$ and that of y_i is w_2. This constraint assures that the code which is the null space of the finally constructed matrix H will be capable of correcting all bursts of length b_2 (fixed) with weight constraint w_2 in the second sub-block of length n_2. The number of ways in which x_i can be chosen is $\binom{b_2-1}{w_2-1}(q-1)^{w_2-1}$.

Choosing y_j is equivalent to enumerating the number of bursts of length b_2 (fixed) with weight constraint w_2 in an $(n_2 - b_2)$ tuple (refer to Theorem 2.1) is

$$\binom{b_2-1}{w_2-1}(n_2-2b_2+1)(q-1)^{w_2-1}. \quad (9)$$

Hence, the total possible number of distinct combinations which h_{n_2} cannot be equal is given by

$$\binom{b_2-1}{w_2-1}(q-1)^{w_2}\left[(n_2-b_2+1)\binom{b_2-1}{w_2-1}(q-1)^{w_2-1}\right]. \quad (10)$$

Now we shall start adding $(n_2+1)^{th}$, $(n_2+2)^{th}$, ... columns to $H^{'}$.

We wish to assure that the code so constructed is capable of correcting all bursts of length b_2 (fixed) with weight constraint w_2. For that we lay down following requirements.

As the first requirement, the general t^{th} column $(t > n_2)$ to be added should not be a linear combination of immediately preceding b_1-1 columns $h_{t-b_1+1}, h_{t-b_1+2}, ..., h_{t-1}$ $(t-b_1+1 > n_2+1)$ together with any b_1 consecutive columns amongst $h_{n_2+1}, h_{n_2+2}, ..., h_{t-1}$,

$$h_1 \neq (u_{t-b_1+1}h_{t-b_1+1} + ... + u_{t-1} + h_{t-b_1}) + (v_r h_r + ... + v_{r-b_1+1}h_{r-b_1+1}), \quad (11)$$

where $r - b_1 + 1 < n_1 - b_1 + 1$ and the number of nonzero u_i's is $w_1 - 1$ and that of v_i's is w_1.

The number of ways in which u_i's can be selected is $\binom{b_1-1}{w_1-1}(q-1)^{w_1}$.

To choose v_i is equivalent to enumerating the number of bursts of length b_2(fixed) with the weight constraint w_1 in the vector of length $(t-n_2-b_1)$. Their number is

$$(t-n_2-2b_2+1)(q-1)^{w_1}\binom{b_1-1}{w_1-1}. \tag{12}$$

The second requirement is that the t^{th} column $(t>n_2)$ to be added should not be the linear combination of the immediately preceding b_1-1 columns $h_{t-b_1+1}, h_{t-b_1+2}, ..., h_{t-1}$ $(t-b_1+1 \geq n_2+1)$ together with any b_2 consecutive columns among all the $h_1, h_2, ...h_{n_2}$. Thus, we have

$$h_{n_1} \neq (u_{t-b_1-1}h_{t-b_1-1}+........+u_{t-1}h_{t-1})+(v_ih_i+....+v_{i+b_2-1}h_{i+b_2-1}), \tag{13}$$

where $(t-b_1+1)<(n_1-b_1+1)$ and the number of non zero u_i is $\binom{b_1-1}{w_1-1}(q-1)^{w_1}$.

Choose the coefficient to enumerating the burst of length b_2 (fixed) in a vector of length n_2 with the weight constraint w_2. Their number is

$$(n_2-b_2+1)(q-1)^{w_2}\binom{b_2-1}{w_2-1}. \tag{14}$$

Thus, the total number of combinations to which h_1 cannot be equal is

$$\binom{b_1-1}{w_1-1}(q-1)^{w_1}\left[1+(t-2n_2-2b_2+1)(q-1)^{w_1}\binom{b_1-1}{w_1-1}\right] + \binom{b_1-1}{w_2-1}(q-1)^{w_1}(n_2-b_2+1)\binom{b_2-1}{w_2-1}(q-1)^{w_2}. \tag{15}$$

Taking $t=n_1+n_2$ as the last column of the first sub-block, the above expression becomes

$$\binom{b_1-1}{w_1-1}(q-1)^{w_1}\left[1+(n_1-2b_2+1)(q-1)^{w_1}\binom{b_1-1}{w_1-1}\right] + \binom{b_1-1}{w_2-1}(q-1)^{w_1}(n_2-b_2+1)\binom{b_2-1}{w_2-1}(q-1)^{w_2}. \tag{16}$$

The first requirement assures that, in the code so constructed, the syndromes of any two bursts each of length b_1 (fixed) with weight constraint w_1 are not equal, whereas the second requirement assures that the syndrome of two bursts, one of which is the burst of b_1 (fixed) in block of length n_1 with weight constraint w_1 and the other is a burst of length b_2 (fixed) with weight constraint w_2 in sub-block of length n_2 are different.

At worst, all linear combinations considered in (14) or (20) may be distinct. Thus, while choosing the n_2^{th} column, we must have

$$q^{n-k}>(14), \tag{17}$$

whereas choosing the nth column $(n=n_1+n_2=t)$, we must have

$$q^{n-k}>(20). \tag{18}$$

However, the matrix $H^{'}$ can be completed if

$$q^{n-k}>max(14),(20).$$

The required parity check matrix $H = [H_1, H_2]$ is obtained by reversing the columns of H' all together. ∎

Corollary 4.1.

Given positive integers b_1, b_2, w_1 and w_2, there exists an (n,k) linear code that corrects all bursts of length b_1 (fixed) with weight w_1 or more in the first sub-block of length n_1 and all bursts of length b_2 (fixed) with weight w_2 or more in the second sub-block of length n_2 $(n = n_1 + n_2)$ satisfying the inequality

$$q_{n-k} > max \Bigg[\binom{b_2-1}{w_2-1}(q-1)^{w_2} \sum_{i=w_2}^{b_2} [(n_2-b_2+1)\binom{b_2-1}{i-1}(q-1)^{i-1}], \binom{b_1-1}{w_1-1}(q-1)^{w_1} \sum_{j=w_1}^{b_1} \left[1+(n_1-2b_2+1)(q-1)^j \binom{b_1-1}{j-1}\right] + \binom{b_1-1}{w_1-1}(q-1)^{w_1} \sum_{i=w_2}^{b_2} (n_2-b_2+1)\binom{b_2-1}{i-1}(q-1)^i \Bigg] \quad (19)$$

Corollary 4.2.

Given positive integers b_1, b_2, w_1 and w_2, there exists an (n,k) linear code that corrects all bursts of length b_1 (fixed) with weight w_1 or less in the first sub-block of length n_1 and all bursts of length b_2 (fixed) with weight w_2 or less in the second sub-block of length n_2 $(n = n_1 + n_2)$ staisfying the inequality

$$q_{n-k} > max \Bigg[\binom{b_2-1}{w_2-1}(q-1)^{w_2} \sum_{i=1}^{w_2} \left[(n_2-b_2+1)\binom{b_2-1}{i-1}(q-1)^{i-1}\right], \binom{b_1-1}{w_1-1}(q-1)^{w_1} \sum_{j=1}^{w_1} \left[1+(n_1-2b_2+1)(q-1)^j \binom{b_1-1}{j-1}\right] + \binom{b_1-1}{w_1-1}(q-1)^{w_1} \sum_{i=1}^{w_2} (n_2-b_2+1)\binom{b_2-1}{i-1}(q-1)^i \Bigg] \quad (20)$$

5. Discussion

In this paper, we have obtained upper bounds on the number of parity-check digits for (n, k) linear codes. Without following any systematic procedure, we have shown the existence of linear codes for different values of the parameters $n_1, n_2, k, b_1, b_2, w_1, w_2$ by constructing appropriate parity-check matrices. There may be a constructive way of obtaining the parity check matrices. Some of these codes have close proximity with byte-correcting codes.

However, the problem needs further investigation to find the

(1) possibilities of the existence of such linear codes in non-binary cases,
(2) possibility of the existence of such optimal codes in binary and non-binary cases.

6. Conclusion

We have constructed block-wise burst error correcting codes with weight constraints which can correct all the burst of different length b_i with their weight w_i in the selected parts (sub-block) of code length. We also obtained the necessary condition on the number of parity check digits of the code correcting bursts with weight $w_i(w_i \leq b_i)$ or more (less) in their respective sub-block. Such codes can reduce the redundant vectors and economize the required parity-check digits. At the end, we suggest some open problems and give a summary of the work comparisons in the paper.

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