Combination of RS and Polar Codes for Efficient Channel Coding in Wireless Networks

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Abstract

In digital communication channel coding plays a very vital role in reliable communication. In communication systems error detection and correction also plays a very important role. In this paper, a joint combination of Reed Solomon (RS) channel coding and polar code is proposed.RS codes belong to linear codes and perform error correction and channel coding. The RS encoding is performed prior to polar encoding followed by polar decoding which includes cyclic redundancy check (CRC) based successive cancellation of list (SCL) and stack. This successive cancellation-based decoding depends on log likelihood ratio (LLR). The relay is decoded with RS decoder and it provides higher performance than the existing techniques. The symbol error probability is analysed with various K/N values and various modulation schemes like BPSK, QPSK and QAM. The proposed technique outperforms with the existing techniques. The proposed technique outperforms with the existing techniques.

Key Words: Reed Solomon, CRC, Polar Codes, Encoding, Decoding.

DOI Number: 10.14704/nq.2022.20.8.NQ44229 **NeuroQuantology 2022 ;20(8):2106-2112**

Introduction

The recent advancements in wireless networks have helped researches to develop new coding techniques which will help in secure communication. For reliable transmission in wireless systems, it is necessary to have an appropriate channel coding scheme. Error detection and correction is an important area in communication systems. Many successful advanced codes are formulated for error correction (Ahlswede et al. 2000). These also help in channel coding. More advancements in technology is essential for solving complex communication systems. Channel bandwidth plays a vital role in transferring of data to the receiver (Tal and Vardy 2015(a); 2013 (b)). In order toprovide secure and efficient communication many channel coding techniques and modulation methods are followed. Reduntancy or repetition of code is essential for transferring of data from source to destination as a means to reduce symbol error rate. In case of block codes, the information is fragmented into blocks and send to the receiver (Chen et al. 2014). Parity check matrix will help to enhance the quality of the block so that the quality of the transmission will get enhanced. In modulo convolutional codes, there is serial transmission of data with redundancy. if the data which is given as input is repeated then it is said to be systematic in nature. Turbo codes are systematic with parallel nature. These codes may be non-recursive or recursive (Faraji-Dana and Mitran 2012). If certain bit gets deleted to

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Received: 13 March 2022 **Accepted:** 18 April 2022

check the error, then it is said to be punctured one.

Literature Survey

In state of art methods, nodes can only send specific datas from dissimilar sources but nowadays channel coding techniques has helped to process the independent datas. A network coded message, which is a combined form of several incoming messages is distributed to every destination (Hernaez et al. 2011). This technique will optimize the system in terms of throughput, utilization of resources, gain in diversity and safety of data. A low-density lattice codes in a channel with many accesses has two source nodes transferring with destination through a relay (Guo et al. 2012). In two different slots of time, two dissimilar sources send the lattice coded message to the relay which decodes and send it to the destination where an active decoding is done. In destination an XOR operation is performed. Together with pulse amplitude modulation, modulo addition LDLC provides good diversity and coding gain than superposition LDLC. In non-binary M-PSK modulation convolutional code and RS code is used. In BPSK code LDPC code is used (Bahl et al. 1974). This proves that nonbinary constellation provides good result than binary one. There are two source nodes transferring data through a sink via relay network. Combining Linear network coding along with LDPC codes in time division multiplexed, multiple access quasi state orthogonal channel (Viterbi et al. 1967). Here nonbinary LDPC code outperforms binary one (Chen et al. 2012; Niu and Chen, 2012). Nonbinary joint network channel fading is performed in Rayleigh channels along with LDPC coded symbols and quadrature amplitude modulation. LT and Raptor codes are used to provide quick encoding and decoding. In MIMO data is transmitted from multiple senders to their appropriate receivers (Berrou et al. 1993).

Polar codes help to provide symmetric capacity of binary input discrete memory less channel using a successive cancellation decoder (Luby et al. 2002). Belief propagation and linear programming will help to overcome the disadvantage of finite length presentation successive cancellation list and stack will act as maximum likelihood decoder with small limitations. Recursive decoding provided to RM codes will enhance SC. Cyclic redundancy codes along with SCL/SCS will outperform the turbo codes (Murch et al. 2002). SCL decoding will improve the block error probability and employ a modified polar code by concatenation of CRC with polar code. But this increases the complexity by reducing the block error probability. A variant of SCL and CRC will enhance the block error probability but complexity remains in a moderate level (Agrell et al. 1996).

This SCL decoding algorithm can also use likeilihoods which improve the performance. But his is unstable. Log likelihood will solve the stability problem but lead to irregular memory, large elements, inefficiency in terms of area and throughput (Arikan et al. 2009). In joint source decoding, polar codes will help to decrease the redundancy, which in turn improve the reliability of decoded words from the dictionary. Inoint decoding the poar codes will inturn reduce the correlation between different sources. Polar codes can be applied for source encoding since it has the capability to handle polarization but this source polar code cannot be applied for joint source channel polarization in a direct form, due to its efficiency and less complexity (Balatsoukas-Stimming et al. 2014). A double polar code has two types of codes one called source coding and other is channel coding. Here the coding process will form a recursive structure in generator matrix (Dumer and Shabunov, 2006; Stolte et al. 2000). Turbo like belief propagation helps for joint source and channel decoding. In decoder side channel decoder gives soft information of compressed bits and soft information of systematic bits (Balatsoukas-Stimming et al. 2015; Leroux et al. 2012; Le et al. 2014).

Proposed Method

In this proposed method, A data bits are send to the Reed- Solomon encoder and the K bits obtained are send to the rate K/E encoder where the K bits are applied to the polar encode and the N data bits are subjected to rate match and the obtained E bits are subjected to modulation. Here various types of modulation such as BPSK, QPSK QAM are analysed. The modulated signal is send through additive white Gaussian noise channel. The signal is again demodulated into E bits and then the rate recover,

recovers N bits and polar decoder decodes and subjected to RS decode to retrieve the A bits show in Fig 1.

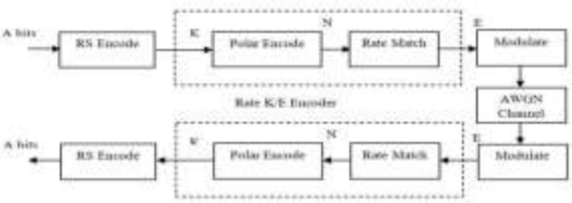

Fig. 1. Rate K/E Decoder

1. RS Encoder

Multiplication and division operation must be performed over the galois field. The message M(x) is divided using the generator G(x), which gets a remainder B(x) which must be added with the message. This forms the data which is in encoded form which has to be recovered at the destination. Consider a RS code of lenth $P = 2^M - 1$.The codeword is predicted by c(x)=M(x)+B(x)

M(x) is the message polynomial given by

M(x)=$A_{(m-1)}x^{(m-1)} + A_{(m-2)}x^{(m-2)} + - - - - - A_1x^1$+$A_0$ (1)

B(x)=$x^{n-k}M(x)mod\,G(x)$(2)

The generator polynomial is given by $G(x) = (x - \beta)(x - \beta^2)(x - \beta^3)(x - \beta^4)(x - \beta^5)$

2. RS decoder

Decoder will identify and correct up to three errors. The succeeding stages are provided.

3. Computation of the syndrome

The data received gets divided along with the generator polynomial. If there is no remainder then there will be no error and vice versa. FFT is applied to the polynomial which is a vector

$$s_i = \sum_{i=1}^{n} c_i\beta^{n-1-i}(3)$$

Error Position:

After finding the syndrome, position of error is calculated using Berlekamp Massey algorithm. The value of error is obtained as $\propto' (z)s(z) = \emptyset(z)z^{2t}$

4. Error Correction

Error value is reduced from the received data which gives the original data.

$$E^{im} = \emptyset(E^{im})/\beta^{-im}(4)$$

Where E^{im} *is the magnitude of error*. m is a value lower than error correcting capability. $\emptyset(z)$ is the error magnitude polynomial α which is the error locator polynomial $\emptyset(z)$.

5. Polar codes

Polar codes are concatenation of many kernels which ease the encoding and decoding process with high speed. A channel transformation matrix is created which is of the form

$g_n = g_2^{\oplus}$

This is the n fold Kronecker product of g_2 which is estimated recursively as$g_n = \begin{bmatrix} g_{n/2} & 0 \\ g_{n/2} & g_{n/2} \end{bmatrix}$

This forms channels which are full of noise or noiseless.The channels present in the intermediate will be partially noise.The polar codes willbe applied to code length n=2^N.Thetotal number of informations transmitted is given by k.The aim of this code is to determine the best channels with high reliability and convey the information bit.Estimating the reliability value and sorting it and assign k information bit to the channels which has the index of information Ɽ. The n-k index creates the frozen set f= $Ɽ^c$ which has no informative data.

6. Encoding

The channel transformation matrix is given by $g_n = g_2^{\oplus}$ *and its information set* Ɽ.The sub matrix of channel transformation matrix forms the generator matrix which is the index of information. The recursive structure of g_n will ease the encoding process as an auxillary vector is added as input which is of length n. The input vector is framed such as $U = [U_0, U_1, - - - - -U_{n-1}]$.The value of $u_i = 0$, if value of i belongs to the frozen set.The information bit is present in the remaining entries.Codeword$D = [D_0, D_1, - - - - -D_{n-1}]$ is estimated as D=U.g_n.Matrix multiplication can be done by performing multiple matrix $g_2$multiplications in parallelmanner by easing the encoding process. Decoding is done in log_2n each having n/2 kernels.

The desired rate r=a/e where a is amount of information and e is codeword length. Rate matching is a length matching problem and this can be removed in 5G. By means of puncturing and shortening the length of the code by not sending it in matching form (Afisiadis et al. 2014). In puncturing bits that are not transmitted are taken as erased at the decoding process. In shortening this bit is taken as zero which is known by decoder. Shortening will work for higher rate and puncturing will work for low rate. Puncturing U code will reduce the bit reliability causing, U bit channel as reliable (Tal et al. 2015; Hashemi et al. 2016). The position of these bits are determined from matching pattern. To improve the error correcting performance the incapable bits must be frozen, inorder to prevent random decision at the decoder. Shortening will enhance bit channel reliability by over capable bits which are decoded correctly (Li et al. 2012; Condo et al. 2018). The matching pattern bits will be determined by the frozen bits which freeze the most reliable bit channels and hence worse the error correction performance.

In order to obtain the optimum value of frozen set, bit channel reliabilities has to be recalculated, since rate matching will change the sequence. DE/GA method isperformed for this purpose. Combination of matching pattern and optimization increases the complexity (Richardson and Urbanke, 2008). If the code length isgreater than power of 2 then it is not possible for

transmission, since mother polar code length is of power 2.A smaller mother polar code is used by combination of likelihoods for the data under retransmission. The retransmission of bits will change the bit channel reliability without any issues in puncturing and shortening. This allows 3 GPP to focus on puncturing and shortening (Bioglio et al. 2017). Circular buffer rate matching is used as a combination of three techniques.

7. Decoding

Decoding algorithm is successive cancellation represented as depth first binary search with priority to the left branch and information on the root node of received code.2^T soft inputs α from parent is send to the left child with 2^{T-1} soft outputs $\propto^L$ given by $\propto_i^L$ =F($\propto_i, \propto_{i+2}^{T-1}$).Then 2^{T-1} hard decisions obtained from left node is combined inorder to produce soft outputs for 2^{T-1} right node as $\propto_i^T = g(\propto_i, \propto_{i+2}^{T-1}, \beta_i^L)$.Finally

2^{T-1}hard decisions from right node is combined fr om right node and provided to the parent node as $\beta_i = \beta_i^L + \beta_i^\gamma$ if i<$2^{T-1}$and $\beta_i = \beta_{i-2^{T-1}}^\gamma$.Frozen bits will be deciphered as zeros (Shin et al. 2013).

Update f and g for both right and left nodes which depends on channel model. The soft value depend on set{0,1,e} where e represents erasure. Update rules are given by $f(\propto_1, \propto_2) = \propto_1 \oplus \propto_2$ and $g(\propto_1, \propto_2, \beta) = \propto_2 \nu(\propto_1 \oplus \beta)$.

8. Design of Frozen set

Bhattacharya parameter along with Monte Carlo simulations help to approximate channel reliabilities. Density evolution is used which estimates accuracy with high cost. A bit channel reliability estimation method along with Gaussian known as DE/GA provides good accuracy with less complexity. A unique bit channel reliability sequence help to provide individual reliability (Wang and Liu, 2014). This sequence consist of 124 bit channel index arranged in reliability order, can be applied to design frozen set. It can be also used to generate the sub sequences for shorter codes, which reduce the storage space. Good result is achieved with short polar codes, list of decoders and assistant bits (Chandesris et al. 2017). Assistant bits are additional bits which help in decoding polar code and hence improve the error performance. Introducing CRC code will advance the error performance by minimizing distance of polar codes.

9. SC based decoding

The soft information in SC is denoted by likelihoods which are not stable and appropriate for implementation of hardware. This is reduced by log-likelihoods and then by log-likelihood ratios (Zhang et al. 2014). This is suitable for implementation in both software and hardware due to low complexity, but error correction is suitable with few code lengths. The list-based decoding has a set of decoders arranged in parallel manner with different code words at a time (Saber and Marsland, 2015; Miloslavskaya, 2015; Chen et al. 2013). Whenever the leaf node is got the bit value is given as 0 and 1 by doubling the number of codewords. This enhances the error correction ratio but the code will be concatenating with other code called cyclic redundancy check. This combination of CRC with SCL will be applied in to network with list size 8. Partitioned SCL can be applied for different list size by reducing the memory requirements. Adaptive SCL decoding will increase list size in case of failed decoding, but hardware decoder with flexible list size is used.

10. CRC based decoding

This decoder is based on the codeword selection process.The performance of this polar code is enhanced by means of combination of both successive cancellation list and successive cancellation stack.

11. Successive cancellation list decoding

The steps in this algorithm are

12. Initial Step

Let level I of the code tree has l^i candidate path. In initialization process one null path is set to zero l^0 ={Φ},m{Φ}=0.The candidate path gets doubled by concatenation of new bits with 0 and 1 respectively.

$$l^i = \{(D_1^{i-1}, D_1) | D_1^{i-1} \in l^{i-1}, D_i \in \{0,1\}\} \quad (5)$$

13. Expansion step

For each and every D_1^i ,estimate the following metrics of path

$$M_N^i(D_1^i|Y_1^N) = \begin{cases} M_N^i(D_1^{i-1}|Y_1^N) \ i\varepsilon A^c \\ logP_N^i(D_1^i|Y_1^N) \ i\varepsilon A \end{cases} (6)$$

Recursive operation finds the path metric for each i∈A as given below

$$M_N^{2i-1}(D_1^{2i-1}|Y_1^N) = \max\{M_{\frac{N}{2}}^i(D_{1,0}^{2i} \oplus (D_{1,e}^{2i} \left| Y_1^{\frac{N}{2}} \right.) + M_{\frac{N}{2}}^i(D_{1,e}^{2i} \left| Y_{\frac{N}{2}+1}^N \right.), M_{\frac{N}{2}}^i(D_{1,0}^{2i} \oplus (D_{1,e}^{-2i} \left| Y_1^{\frac{N}{2}} \right.) + M_{\frac{N}{2}}^i(D_{1,e}^{-2i} \left| Y_{\frac{N}{2}+1}^N \right.)\} (7)$$

$$M_N^{2i}(D_1^{2i}|Y_1^N) = M_{\frac{N}{2}}^i(D_{1,0}^{2i} \oplus (D_{1,e}^{2i} \left| Y_1^{\frac{N}{2}} \right.) + M_{\frac{N}{2}}^i(D_{1,e}^{2i} \left| Y_{\frac{N}{2}+1}^N \right.) \quad (8)$$

If the number of paths are more than the required value of l then retain the l best paths and remove the others.

14. Path selection step

Repeat the above steps till the required level N is got. The path in the list are decoded with declining metrics. The decoder yields the first path with CRC detection as the estimation step (El-Khamy et al. 2017). If no such path is detected then it declares failure in decoding process.

15. Successive cancellation stack decoding

The steps of this algorithm are given below:

1)Initial step: The null path is put into the stack, and make the metric m(Φ) as zero. Make the vectorQ_1^N *as zero* and set T as 1.

2)Pop step:

Pop the path D_1^{i-1}which is at the head of the stack $with\ T = T - 1$.Put $Q_{i-1} = Q_{i-1} + 1$

3)Competition step:

If Q_{i-1}=Q delete the path which has length lower than i-1 and update the depth of stack T.

4)Expansion step:

If D^i is the frozen bit, then$D_1^i = \{D_1^{i-1}$,0}. IfD^i is info bit, then spread the path to $\{D_1^{i-1}$,0} and$\{D_1^{i-1}$,1}.Update the path metrics in previous algorithm given in equation

5) Pruning step:

For information bit remove the path from bottom and set T=T-1 and push two prolonged path into it and update T=T+2.If the bit is frozen bit, push $D_1^i = \{D_1^{i-1}$,0} into stack and fix T=T+1.

6)Sorting step:

Sort the path from head totail in descending order.

7)CRC decision:

If the top of the stack is the leaf node then pop it and set $Q_N = Q_{N+1}$ and T=T-1.CRC check is accomplished. If the algorithm passed D_1^N is the decision or $Q_N = Q$ and he stack is made empty.The decoding is declared as failure.

In both successive cancellation list and stack decoding LLR technique is included which is explained below.

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16. LLR based SCL decoding

Choose L most likely children from 2L parents. The decoder in likelihood domain is obtained by recursive method, by computation of likelihood $W_N^i(Y, U_0^{i-1}|U_1), U_1 \in \{0,1\}$ from channel likelihoods $w(Y_i|X_i), x_i \in \{0,1\} i \in [N]$.At each intermediate step update the likelihood by a common factor $P_{t,u} = w(Y, U_0^{i-1}[l]|u)$,u∈{0,1}.This step is avoided by computing in log likelihood domain such as ln$(w(Y_i|X_i), x_i \in \{0,1\} i\ [N]$ This gives a more stable system.

For each and every path l and level i∈N,path metric is given by

$$p_l^i = \sum_{j=1}^{i} \ln(1 + e^{-(1-2u_j[l]l_{n[l]}^j})(9)$$

$$\text{Where } l_{n[l]}^j = \ln(\frac{w_N^i(Y, U_0^{i-1}|0)}{w_N^i(Y, U_0^{i-1}|1)})(10)$$

If the bits are uniformly distributed then,$w_N^i(Y, U_0^{i-1}[l_1]|U_1, [l_1]) < w_N^i(Y, U_0^{i-1}[l_2]|U_1, [l_2])$if $p_{l1}^i > p_{l2}^i$

The metrics are updated by setting p_l^i=Φ($p_l^{i-1}, l_{n[l]}^j$,$u_j[l]$)

Where $\emptyset(\mu, \varepsilon, u) = \mu + \ln(1 + e^{-(1-2u)\epsilon})$

Since $\ln(1+e^{z}) = \begin{cases} 0 \; if \; x < 0 \\ x \; if \; x \geq 0 \end{cases}$

Φ is replaced with Φ+ which is defined as $\emptyset(\mu, \varepsilon, u) = \begin{cases} \mu & if \; u = 1/2[1 - sign(\in)] \\ \mu + \epsilon & otherwise \end{cases}$

$1/2[1 - sign\left(l_{n[l]}^{j}\right)$ is the direction provided by LLR.

This will be the decision taken by the decoder if it has to decide from the past values.Similarly if the path metric has a frozen bit then the path is updated based on this metric.

Result and Discussion

The proposed technique is simulated in MATLAB. A set of SNR values are formed in the range of 0 to 9 decibels with a step size of 1 decibel (Lin et al. 2007; Cardarilli et al. 2007). For each modulation technique around 1000 integer values are selected in the corresponding field GF(m). Based on the RS coder having the code rate K/N, the values are coded as 1000N/K values. Each simulation is performed in 1000 iterations to get accurate result.

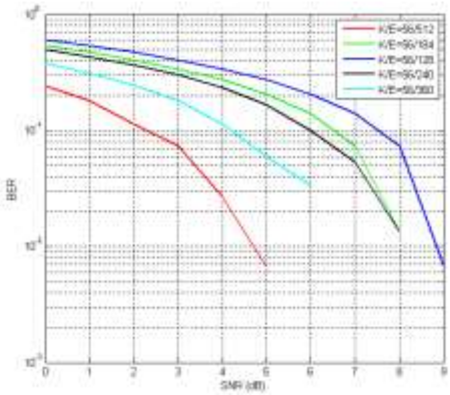

Fig. 2. SNR versus BER of proposed system for various K/N values

Fig 2 shows the SNR versus BER of proposed method with various K/N values. Fig 3 shows the SNR versus BER ofproposed method with various modulation schemes such as BPSK, QPSK, QAM. When comparing the performance, it is observed that BPSK modulation outperforms the modulations such as QPSK and QAM (Arikan et al. 2009; Arikan et al. 2008).

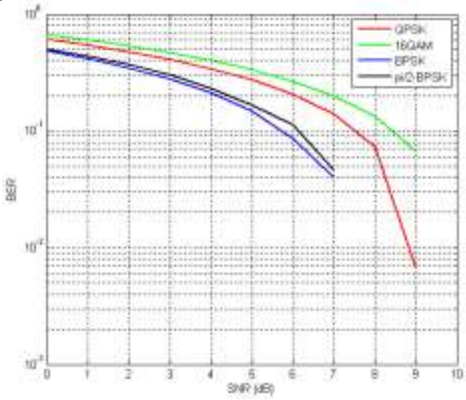

Fig. 3. SNR versus BER of proposed system for various modulation schemes

By certain computations in the relay with this proposed technique the transmission energy can be decreased. The number of symbols in transmission is N/K times greater in other techniques compared to proposed method (Hussami et al. 2009; Goela et al. 2010).

Conclusion

This work emphasis on the combined performance of RS codes and polar codes, based on SCL decoding and successive cancellation stack decoding. This successive cancellation decoding depends on the log likelihood ratio. With high throughput gain, diversity and transmission energy the RS channel coder will improve the symbol error rate. The proposed system provides good performance since it deals with Galois field elements. The performance is detected with various K/N values and with various modulation schemes such as BPSK, QPSK QAM techniques. It is experimental that
the SER decreases with QPSK modulation scheme.

Acknowledgment

The Author with a deep sense of gratitude would thank the supervisor for his guidance and constant support rendered during this research.

Conflict of Interest

Authors do not have any conflicts.

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