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# Reed-Solomon Hybrid Codes For Optical Communications

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**Abstract** :

***The astonishing performance of concatenated codes attracted many researchers and this has resulted in an explosive amount of literature since their introduction few years ago. As concatenation between codes did not actually arise from applying a pre-existing theory, most of their outstanding features remain to be explained. This paper gives some explanation of the concatenation between Reed Solomon (RS) code and convolutional code.***

***The aim of this work is to evaluate the performance of serial and hybrid concatenated convolutional and RS codes in optical communication. We consider the on-off keying (OOK) modulation and LOG MAP algorithms with iterative decoding.***

***Key word: Forward-Error Correction (FEC),Convolutional Codes, Reed Solomon( RS) code, , OOK, Concatenation .***

## شفرات Reed Solomon الهجينة للاتصالات البصرية

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**الخلاصة**

***ادى الاداء المدهش لتجميع الشفرات الى جذب العديد من الباحثين والى التوصل الى العديد من النتائج منذ عدة سنوات ونظرا لان فكرة تجميع الشفرات لم تبنى من نظريات سابقة،لذلك فأن مميزات هذه الشفرات تبقى قيد التوضيح.ومن اجل تقييم أداءهذه الشفرات في الاتصالات البصرية،تم استخدام تضمين اشارة من نوع (OOK)والتصحيح التكراري باستخدام خوارزمية (LOG MAP).***

## 1. Introduction:

The field of channel coding has undergone major advances for the last twenty years. With the invention of cancatunatrd codes [1] , it is now possible to approach the fundamental limit of channel capacity within a few tenths of a decibel over several channel models of practical interest [2]. Although this has been a major step forward, there is still a need for improvement in forward-error correction (FEC), notably in terms of code flexibility, throughput and cost.

The FEC technique has been used to compensate for the transmission quality degradation from noise and pulse distortion in optical communication systems. In particular, the Reed-Solomon (RS) (255, 239) code is now commonly used and standardized in ITU-T G.975 [3,4] and G.709 [5].

This code provides 5.6 dB net coding gain (NCG) with 6.69% redundancy. With the increasing development of optical communication technologies toward longer distance, larger capacity and higher bit rate, people have been paying more attention to the BER those results from the noises in optical communication systems. Thus, more powerful novel super forward error correction (Super-FEC) codes have became necessary in order to compensate for serious transmission quality degradation. There are both the simple random independent error and the certain outburst error in optical channels. The interleaved code, the product code and the concatenated code can be chosen to effectively deal with these mixed errors. Among the above three code types, the concatenated code has the best performance, the highest efficiency and is most often used, so it can be selected as one of the candidates for Super-FEC code types [6,7,8]. ITU-T has also constituted the recommendation G975.1 that describes the eight code types that have better error correction performance than RS (255, 239) code in ITU-T G.975 [3,9]. Investigation of using Reed-Solomon (RS) turbo product codes for 40 Gb/s transmission over optical transport networks and 10Gb/s transmission over passive optical networks in[10].

Optical networks have evolved significantly over the past few years, moving from data rates of 2.5 Gbits/s to 10 Gbits/s and looking forward to 40 Gbits/s and beyond. As the transmission speed increases on one hand, the transmission impairments also increase on the other. In many cases, the impairments increase in a nonlinear fashion, even though the transmission rates are increasing linearly. The same phenomenon is also true for WDM systems. Hence, FEC becomes vital in single channel as well as multi-channel WDM systems for delivering error free transmission between 10-100 Gbits/s for next generation optical systems [4].

## 2. Reed Solomon Code

Reed Solomon (RS) codes are the subset of BCH codes as well as linear block codes. A particular RS code is specified as RS(n, k )with s-bit symbols [8]. This means that the encoder takes k s-bit data symbols each time and encodes them into a codeword of n s-bit symbols.

There are $n - k$ parity symbols of s bits each. A RS decoder can correct up to t symbols that contain error in a codeword, where $2t = n - k$ [9]. **Figure.(1)**shows a typical RS codeword

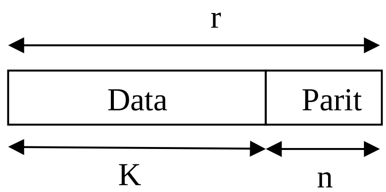


**Fig (1). Typical RS**

RS codes are particularly suitable to correct burst errors, where a series of bits in the codeword are received in errors.

Reed Solomon coding is a well-known technique for FEC; it has been used for such applications as the Compact Disk. Data is collected into a specific size and is provided with a distinctive checksum of a specific size. This checksum allows not only errors to be detected but also a definite number of errors to be corrected.

## 3. Serial Concatenated Codes

Convolutional codes are efficient especially when errors caused by the communication channels are statistically independent. For the Free space optics (FSO) channel, however, we are subject to burst errors due to fading. A more efficient coding scheme can be obtained by concatenating convolutional and RS codes as shown in **Figure.(2).** This is, for instance, what is defined in the DVB-S (Digital Video Broadcasting - Satellite) standard [11]. Encoded data by the outer (RS) code are first interleaved by an interleaver $\pi$ before passing to the inner (convolutional) encoder. The interleaver is a pseudo-random and of depth NF. The decoding and modulation are done according to the block diagram of **Figure. (2).** At the receiver, after soft symbol detection and channel de-interleaving , we first perform SISO decoding of the inner (convolutional) code based on Log-MAP decoder algorithm, Next, after de-interleaving($\pi^{-1}$), we perform soft-input soft output (SISO) channel decoding, because as it is well known, soft decoding provides a better performance, compared to hard-decoding of the outer (RS) code. The second scheme is serial concatenated of two RS codes.

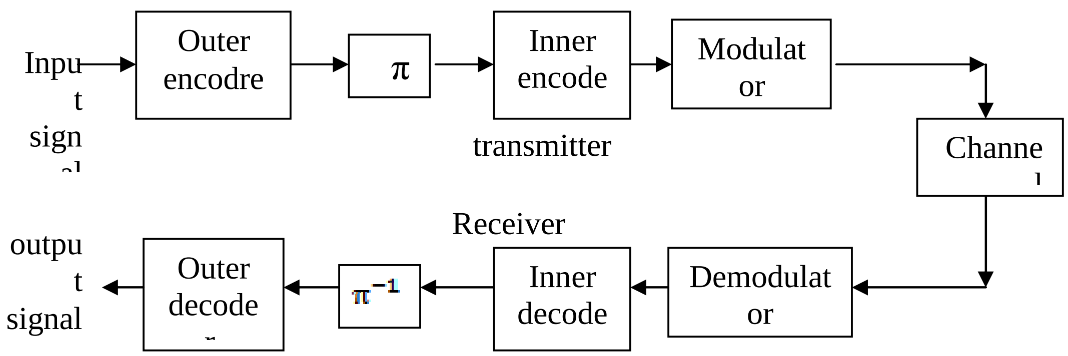


**Fig.(2): serial concatenated codes**

## 4. RS Parallel Concatenation codes:

Let C1 and C2 be linear block codes over the Galois field GF(2m), with parameters (N1;K1;D1) and (N2;K2;D2), respectively. The product code P = C1 C2 consists of all N1 _N2 matrices such that each column is a codeword in C1 and each row is a codeword in C2. It is well known that P is an (N1N2; K1K2) linear block code with minimum distance D1D2 over GF(2m). The direct product construction thus offers a simple way to build long block codes with relatively large minimum distance using simple, short component codes with small minimum distance. When C1 and C2 are two RS codes over GF (2m), we obtain an RS product code over GF(2m). Starting from a K1 _ K2 information matrix, systematic encoding of P is easily accomplished by first encoding the K1 information rows using a systematic encoder for C2. Then, the N2 columns are encoded using a systematic encoder for C1, thus resulting in the N1 _ N2 coded matrix [10].

## 5. Encoder and decoder for Hybrid schemes

For the general suggested system shown in Figure.(2),there are three schemes will be discussed the first and second schemes are discussed in section(3). The first one is the serial concatenation of RS code as outer encoder and convolutional code as inner encoder (RS-CC) codes and the second scheme is serial concatenated of RS codes. The third scheme consists of an outer encoder that consists of two RS codes in parallel concatenated connected by a random interleaver (π1) of length N which the data that passes through the second RS is passes through it. The data sequence and the two parity sequences are punctured to the desired rate by omitting specific bits. The MUX function of the MUX-puncture converts two or more parallel sequences to a single serial sequence then this sequence is passed through a second interleaver π2 and inner encoder. The inner encoder is a convolutional code.

The decoding process of Concatenated Code has been done by iterative decoding using Log-MAP decoder. The decoder circuit consists of three (SISO) detector one for the inner encoder and two for outer parallel encoders as shown in **Figure.(3).** the DEMUX-puncture block reverses the process of MUX-puncture block and converting the serial sequence to parallel sequences, and placing 0's or 1's as necessary in locations of the punctured bits. And by exchanging reliability information between the decoders until a reliable decision can be made on the transmitted bits.

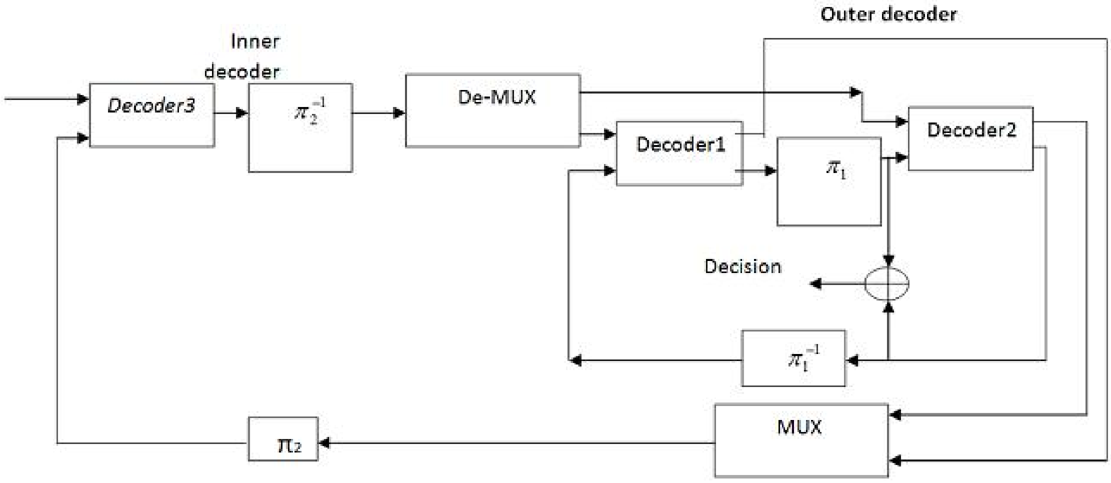


**Fig (3): Decoder structure for hybrid codes.**

## 6. Simulation Results

To evaluate the performance of proposed serial concatenated RS codes, comparison was done with ITU-T standard and two product codes in (4). The three codes of deferent rates: RS(255,239)+RS(255,127), RS (255, 239) + RS (255, 239) and RS (255, 239) + RS (255, 223). The simulation results are expressed in term of BER(Bit- Error- Rate) Vs the signal to noise ratio(SNR) in dB and for (OOK) modulation. The rates for these codes are 0.46, 0.87 and 0.819 respectively and as we will see ,the rate with redundancy for the proposed code offered a net coding gain NCG of around 3.4dB at BER≤ $10^{-8}$ as shown in **Figure(4).**

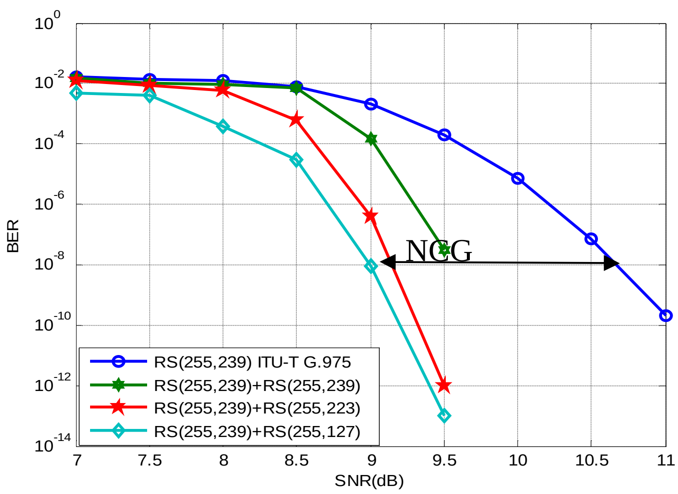


**Fig.(4): simulated BER of concatenated RS codes**

As mentioned earlier the BER requirement for optical communication systems is ≤$10^{-12}$. It can be observed from **Figure.(4)**that the three serial concatenated RS codes have at least twice the redundancy compared to the ITU-T standard. This increased redundancy pays roughly more than 1 dB additional NCG for each code.

Further improvement in coding gain was achieved by hybrid codes. The coding gain performance of the hybrid codes evaluated through iterative decoding with soft-input/soft-output decoder. It was shown that the redundancy in the code and error correcting capability are crucial code parameters, which define the computational complexity of the encoder and decoder respectively.

To do a fair comparison of the performances of different coding schemes, we set the rate Rc to 1/2 for all coding schemes. Again the simulation results are expressed in term of BER Vs (SNR) in dB. For the case of RS-CC coding, we use the convolutional code with generator polynomial (g1=133,g2=171) and (n,k) equals to (2,1) of constraint length L = 7 as the inner code and RS(255,239) as the outer code. We have Rc ≈ 0.46, which close to 0.5. This scheme corresponds to that proposed in the DVB-S standard-2004 [11]. And the concatenated of two RS code is implemented by RS(255,127) of rate Rc = 127/255 ≈ 0.5 and RS(255,239)of rate 0.937, then the overall Rc =0.46≈0.5

The hybrid scheme can be achieved by two parallel RS code each of (255,247) with convolutional code as inner encoder with rate 1/2, so the overall rate Rc =0.469≈0.5. **Figure.(5)** shows the performance of the three systems for three iteration of decoding. As we see, the serial concatenated of RS code offers roughly more than 4,8dB additional NCG and approximately more than 6.8dB additional coding gain at BER≤ $10^{-8}$is offered by the hybrid codes.

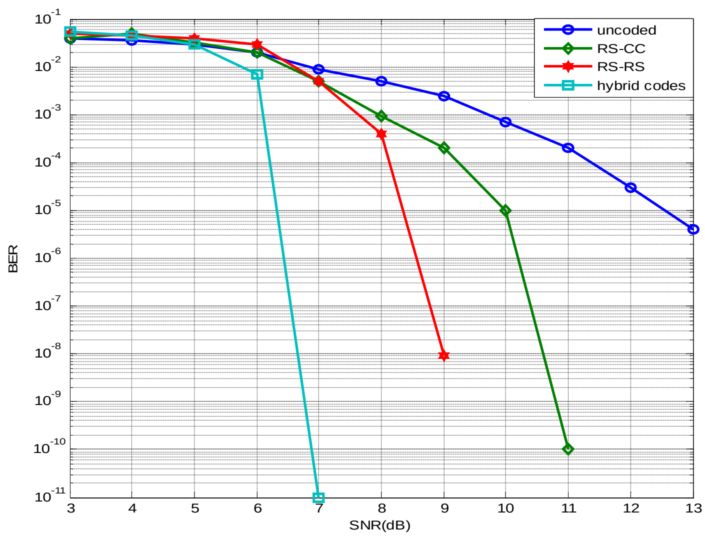


**Fig.(5):simulated performance of (RS-CC,RS-RS,Hybrid codes )**

## 7. Conclusions:

The main objective of this paper was to investigate the advantages of different concatenation of error correction codes. Concatenated RS codes provide better random as well as burst error correction capability. The comparison between three types of serial concatenated code and the ITU-T standard was taken and with hybrid scheme which offered about 6.8dB NCG. If sufficient buffer memory is available, further improved performance can be achieved by four iterations of the decoding process. The presented work could be further continued with a hardware implementation of an encoder/decoder in a fiber-optic transceiver. A scalable RS encoder/decoder operating at low data rate could be initially implemented with a FPGA for single channel as well as multichannel systems.

## 8. References:

1. C. Berrou, A. Glavieux, and P. Thitimajshima, “Near shannon limit error correcting coding and decoding: Turbo-Codes,” in Proc. IEEE Int. Conf. Commun. ICC’93, vol. 2, Geneva, Switzerland, , pp. 1064–1070, May 1993.
2. D. J. Costello, Jr and G. D. Forney, Jr, “Channel coding: The road to channel capacity,” Proc. IEEE, vol. 95, no. 6, pp. 1150–1177, June 2007.
3. ITU-T G.975,” Forward error correction for submarine systems”, 1996.
4. Mohammed Abdul-Alwahab, Sabah Abdul-Hassan Gitaffa and Raidh Adnan Kadhim”Error Correction Code in Optical Fiber” Journal of Engineering and Development, Vol. 11, No. 3, ISSN 1813-7822 December (2007).
5. ITU-T G.709,” Network node interface for the optical transport network (OTN)”[S],2001.
6. O. A.Sab, J. Fang, “Concatenated forward error correction schemes for long-haulDWDM optical communication systems”, in:Proceedings of the ECOC’99 Conference, , p. 290 September 1999 .
7. S. Benedetto, G. Montorsi, IEEE” Transactions on Communications” 591 44 (May) (1996).
8. Fang Xu, Ali Khalighi, Patrice Causs´e and Salah Bourennane”Channel coding and time-diversity for optical wireless links” Vol. 17, No. 2 / OPTICS EXPRESS 875/19 January 2009.

**9.** ITU-T G.975.1, ” Forward error correction for high bit rate DWD submarine systems”, 2003.

**10.** Rapha¨el Le Bidan, Camille Leroux, Christophe J´ego, Patrick Adde, Ramesh Pyndiah”Reed-Solomon Turbo Product Codes for Optical Communications: From Code Optimization to Decoder Design”published in "Eurasip Journal on Wireless Communications and Networking 2008 (2008) 1 -- 14

**11.** Digital Video Broadcasting (DVB);” Framing Structure, Channel Coding and Modulation for Digital Terrestrial Television”. (ETSI EN 300 744 V1.5.1, European Standard (Telecommunications series), 2004.