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Performance Comparison of Latency for RSC-RSC and RS-RSC Concatenated Codes

Manish Kumar*, Jyoti Saxena
M.tech, Electronics and Communication Engg. Giani Zail Singh Punjab Technical University
Electronics and Communication Engg. Deptt. Giani Zail Singh Punjab Technical University
e-mail: manish_ece@ymail.com

Abstract
In this paper, we compare the latency of serially concatenated convolutional codes. In particular, we compare RSC-RSC concatenated codes using non-iterative concatenated Viterbi decoding to RS-RSC concatenated codes using concatenation of Viterbi & Berklelamp-Massey decoding. We have also used puncturing to obtain different code rates & analyzed the effect of code rate on latency. On the basis of simulations, it is shown that RSC-RSC code is better than RS-RSC codes for low latency applications. It is also shown that a trade-off is needed between BER & latency for concatenated codes.

Keywords*: serially concatenated convolutional codes; Reed-Solomon codes; recursive systematic convolutional codes; viterbi decoding; latency.*

1. Introduction

In 1948 Shannon in an article, “A mathematical theory of communication”, [1] proved that reliable communication is possible over a noisy channel as long as the transmission rate is below the channel capacity. It was found that if the code rate is less than the channel capacity, the average error probability decreases exponentially as the length of code increases. Since then communication engineers have been trying to design error-correcting codes that can achieve a small probability of error at a rate as close to the channel capacity as possible.

Forney in 1966 first studied the concatenation of two simple codes [2] as a class of codes whose probability of error decreases exponentially, while the decoding complexity increases only algebraically. In 1989, concatenation of multiple convolutional codes was introduced [3], and was used with Soft Output Viterbi Algorithm (SOVA). Then turbo codes, Parallel concatenated convolutional codes (PCCC) [4] & Serially Concatenated convolutional codes SCCC [5], came into existence, which provided error rate performance close to Shannon capacity with the use of iterative decoding [6].

However, the convolutional codes suffered from the problem of burst errors [7] & Reed-solomon codes suffered from problem of random errors [8]. To compensate this problem, a new solution was proposed in which a concatenation of a Reed-Solomon (RS) code and a Recursive systematic convolutional code (RSC) codes was used & it was shown that RS-RSC concatenated codes have good performance than RSC itself [9]. For SCCC codes, simple concatenated Viterbi decoding was proposed [10] with certain drawbacks. Recently a solution was provided where, RSC-RSC concatenated code with non-iterative concatenated Viterbi decoding was implemented & it was shown that RSC-RSC system has better BER performance than RS-RSC concatenated code [11].

In practical communication systems, a low error probability and a high transmission rate are not the only important factors. Another very important parameter is the latency i.e. the delay between the time a symbol is transmitted and the time it is decoded. This delay is introduced by the encoder, the decoder & the channel and has always been crucial for telephony, since high latency can seriously handicap a voice conversation. Also more recent applications like video conferencing and remote control have demanding latency requirements.

A low-latency decoder was proposed for Shortened/ punctured Reed-Solomon codes [12]. It was shown that significant reduction in the decoding latency is possible, if the code length of the punctured codes is much smaller than the original base codes. For applications not requiring low latencies, Low Density Parity Check (LDPC) codes of long length are considered to have good performance [13]. Furthermore, latency could also be affected by the

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concatenation of various codes. So there is a need of investigation in latency performance of concatenated codes.

In this paper, we compare the latency performance of RSC-RSC code using non-iterative concatenated Viterbi decoding [11] to RS-RSC code. The rest of the paper is organized as follows. In section II, system structure of concatenation scheme is presented. The simulation results and its discussion are given in section III. Finally, the section IV concludes the paper.

2. System Structure

In this section, structure of the simulated system with simulation parameters is described.

2.1. RSC-RSC System

RSC-RSC code is a concatenation of two convolutional encoders through an interleaver in between them. The simulation model of RSC-RSC concatenated system is shown in Figure 1 & simulation parameters are given in Table 1.We have used two RSC encoders of feed forward polynomial [133 177] & feedback polynomial of [133], with constraint length of 7. Their base code rate is 1/2 each and punctured code rates are 2/3, 3/4, 5/6. Various punctured code rates for inner and outer encoders are used to obtain different values of overall code rate.

Latency is computed as the total processing time of data transmission from the outer encoder to outer decoder as described by equation (1).

Let, t1 = processing time of Encoding
t2 = processing time of channel
t3 = processing time of Decoding

$$\text{Total Latency} = t1 + t2 + t3 \quad (1)$$

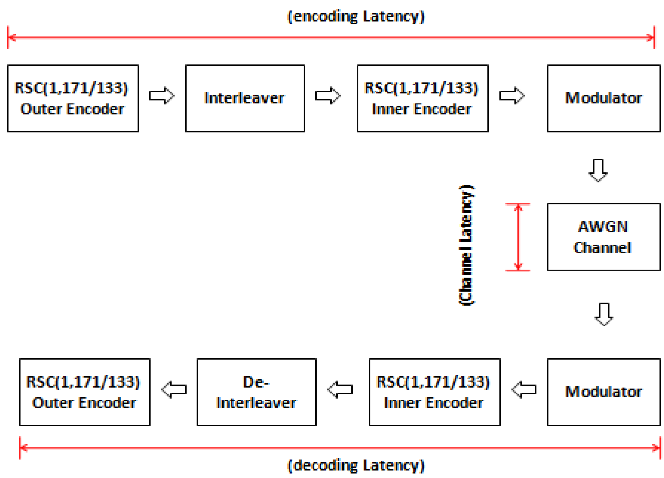

Figure 1. Simulation model of RSC-RSC system [11]

Table 1. Simulation Parameters of RSC-RSC system [11]

Outer Encoder	Inner Encoder
RSC (1,171/133)	RSC (1,171/133)
Constraint length = 7	Constraint length= 7
Base code rate = 1/2	Base code rate = 1/2
Punctured code rate = 2/3, 3/4	Punctured code rate = 2/3, 3/4, 5/6
Viterbi Algorithm (hard-decision)	Viterbi Algorithm (hard-decision)
Helical interleaver	
BPSK modulation	
AWGN channel	

2.1. RS-RSC System

RS-RSC code is a concatenated code of RS code as the outer code and RSC code as the inner code. The Simulation model of the RS-RSC concatenated system is shown in Figure 2 with its simulation parameters in Table 2. It uses (n, k) RS code in Galois field array (GF) 28 that has 5 symbol error-correcting capability. Decoding is done by concatenation of Viterbi decoder & Berlekamp-Massey decoder. Recursive systematic convolutional code (1,171/133) with constraint length of 7 is used. Their base code rate is 1/2 each and punctured code rates are 2/3, 3/4, 5/6. We have used various punctured code rates for inner and outer encoders to obtain different values of code rates. Similar to the description given in equation 1, overall latency for RS-RSC code is computed as the total processing time of data transmission from outer encoder to Berlekamp-Massey decoder.

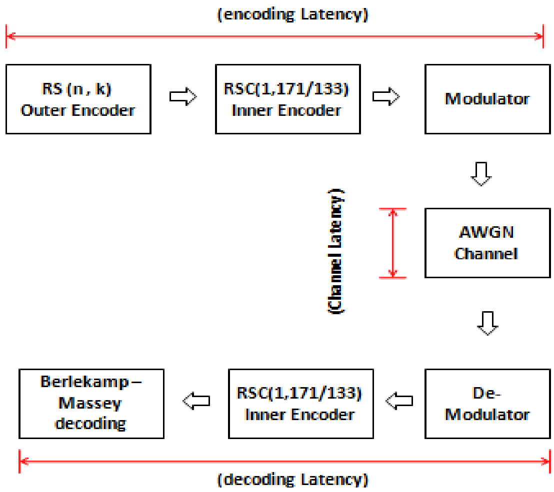

Figure 2. Simulation model of RS-RSC code system [4]

Table 2. Simulation Parameters of RS-RSC system [4]

Outer encoder	Inner encoder
Reed-solomon (n,k) over GF(28)	RSC (1,171/133)
k=255, n=145,185,215,245	Constraint length = 7
5-symbol error- correcting code	Base code rate = 1/2 Punctured code rate = 1/2, 2/3, 3/4, 5/6
Berlekamp-Massey decoding	Viterbi decoding (hard-decision)

3. Results & Discussion

The two systems described in section II were implemented using MATLAB and latency is observed for different combinations of code rates.

3.1. Latency of RSC-RSC System

After simulation using Matlab software results have been obtained as shown in Figure 3 & are noted down in table 3. It shows that RSC 1/2 -RSC 1/2 system has maximum processing time of 3.72 seconds & RSC 2/3–RSC 5/6 has minimum processing time of 2.17 seconds. Here we observe that as the code rate increases, latency decreases. In [11] it was observed that with the increase of code rate, BER increases. Hence a trade-off is needed to be considered between BER & latency in digital communication.

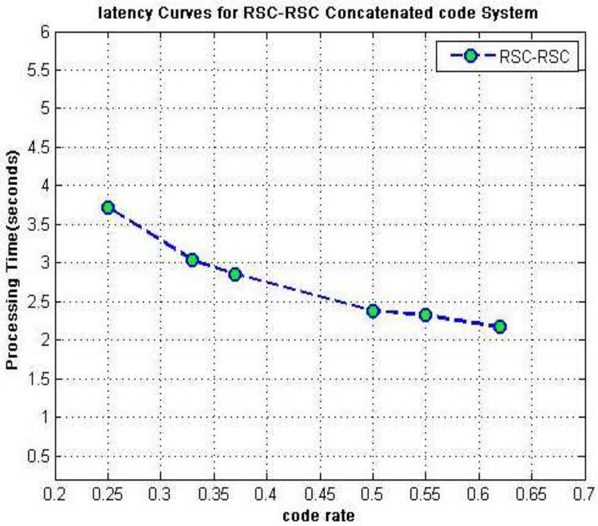

Figure 3. Latency analysis for RSC-RSC system

Table 3. Code rate versus signal processing time for RSC-RSC system

Coding scheme	Over all Code rate	Processing Time (Seconds)
RSC (1/2)-RSC (1/2)	0.25	3.72
RSC (1/2)-RSC (2/3)	0.33	3.03
RSC (1/2)-RSC (2/3)	0.37	2.85
RSC (2/3)-RSC (3/4)	0.50	2.38
RSC (2/3)-RSC (5/6)	0.55	2.32
RSC (3/4)-RSC (5/6)	0.62	2.17

3.2. Latency of RS-RSC system:

The results have been plotted in Figure 4 & tabulated in Table 4. We find that RS (145/255) - RSC (1/2) system has maximum processing time of 15.01 seconds & RS (245/255) - RSC (3/4) has minimum processing time of 3.90 seconds. Here we observe that as the code rate increases, latency decreases. In [11] it was observed that with the increase of code rate, BER increases. Hence a trade-off is needed to be considered between BER & latency in digital communication.

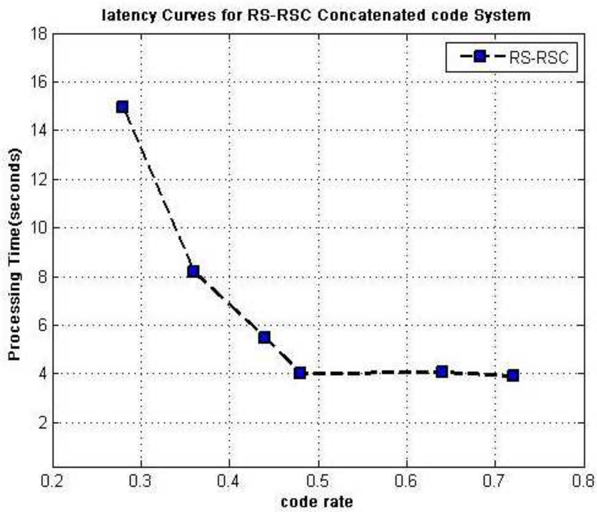

Figure 4. Latency analysis for RS-RSC system

Table 4. Code rate versus signal processing time for RS-RSC system

Coding Scheme	Over all Code rate	Processing Time (Seconds)
RS (145/255)-RSC (1/2)	0.28	15.01
RS (185/255)-RSC (2/3)	0.36	8.15
RS (215/255)-RSC (3/4)	0.44	5.86
RS (245/255)-RSC (1/2)	0.48	4.03
RS (245/255)-RSC (2/3)	0.64	3.97
RS (245/255)-RSC (3/4)	0.72	3.90

3.3. Latency Comparison of RSC-RSC & RS-RSC system:

We compared the latency performance of RSC-RSC system with that of RS-RSC system. In Figure 5, a blue color line shows the performance of RSC-RSC system & black color lines shows the performance of RS-RSC system. From Table 3 & Table 4, it is observed that RS (145/255) - RSC (1/2) system has processing time of 15.01 seconds & RS 1/2-RSC-1/2 system has processing time of 3.72 seconds for equal code rate. All the configurations of RSC-RSC code seems to be better than the RS-RSC code. Hence RSC-RSC code system has low latency performance.

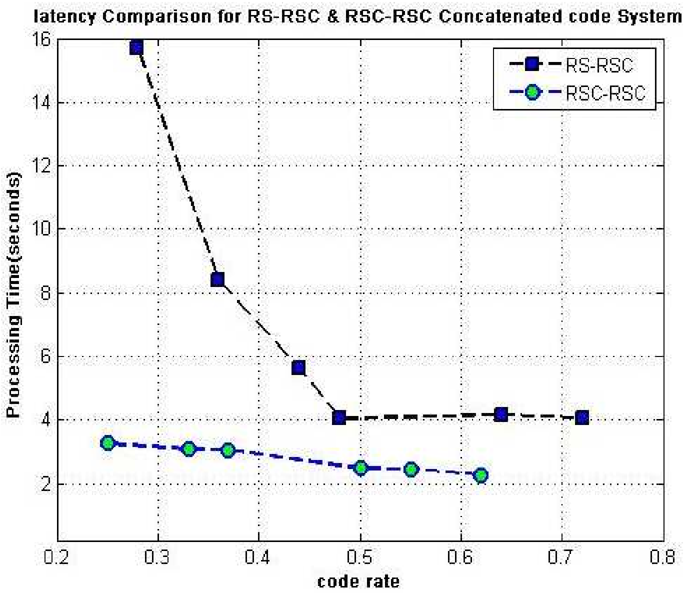

Figure 5. Comparison of RSC-RSC & RS-RSC system

4. Conclusion

In this paper we have analyzed & compared the latency performance of the RSC-RSC serial concatenated code using non-iterative concatenated Viterbi decoding to RS-RSC serial concatenated system. The simulation results show clearly that as the code rate increases, the latency decreases & RSC-RSC is to be a better code rather than RS-RSC; it has low latency. Hence RSC-RSC system is more suitable for low latency applications.

It is also concluded that with the increase of overall code rate of concatenated code system, the latency decreases but at the expense of increase in BER. Hence there is always a trade off needed between BER & latency in digital communication.

For a future work, the authors plan to consider further improvements in latency & BER for SCCC codes.

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