Enhanced Turbo Codes for URLLC

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1 Introduction

This document describes the error rate performance of the enhanced Turbo Coding scheme proposed in R1-164635 at RAN1#85 meeting and detailed in R1-167413.

The simulation conditions of the decoding process are the following:

- Max-Log-MAP decoding of codes C1 and C2 with application of scaling factors to extrinsics: 0.6 for the first decoding iteration, 1.0 for the last decoding iteration, 0.7 for the other iterations; a short training is used for having an estimate of forward and backward recursions at trellis edges only at first iteration.
- Floating-point representation of the LLR (Log-Likelihood Ratio) values;
- 8 decoding iterations (1 iteration = decoding of code C1 + decoding of code C2);
- AWGN transmission channel;
- QPSK and 16QAM modulations;
- The lowest points in the curves were obtained with at least 50 erroneous blocks.

2 Interleaver and puncturing parameters

The proposed enhanced Turbo code represents a rate compatible design where the same interleaver parameters are kept for all the considered coding rates. Therefore, only the puncturing is varied from one coding rate to the other. In addition, the puncturing is incremental with the coding rate. In other words, the puncturing for a higher coding rate is the same as the one with the lower rate with an additional punctured position. Therefore, incremental redundancy is natively supported between all proposed puncturing schemes. In addition, the extension to one-bit codeword granularity can be easily supported with a guarantee on stable performance.

2.1 Almost Regular Permutation (interleaver design)

The interleaving function is detailed in R1-167413 and given by the following equation:

$$\pi(i) = \left(Pi + S\left(i \bmod Q\right)\right) \bmod K \qquad (1.1)$$

where i denotes the address of the data symbol after interleaving and $\pi(i)$ represents its corresponding address before interleaving.

The same ARP parameters are used for all coding rates of a particular frame size *K*. Therefore, incrementally moving from any high coding rate to any lower rate is possible by transmitting only corresponding parity bits from the puncturing mask. These puncturing masks apply for all of the different frame sizes.

3 URLLC scenario

3.1 Simulation assumptions: URLLC and mMTC

The agreements for simulation conditions:

- Evaluate BLER performance versus SNR.
- BLER simulations down to 10^{-4} are recommended (to observe the error floor) for URLLC.

Channel	AWGN			
Modulation	QPSK, 16 QAM			
Coding Scheme	Convolutional codes	LDPC	Polar	Turbo
Code rate	1/12, 1/6, 1/3			
Decoding algorithm	List-X Viterbi	min-sum	List-Y	Max-log-MAP
Info. block length (bits w/o CRC)	20, 40, 200, 600, 1000			

The interleaver parameters designed for block sizes of eMBB (*K*= 96, *K*=208, *K*=400 and *K*=992 bits) provided in R1-1613029 proposed at RAN1#87 can be reused for the URLLC scenario down to coding rate R = 1/5 with puncturing masks provided for eMBB. Then, for coding rates R < 1/5, puncturing masks and polynomials used for URLLC provided next are applied.

3.2 Puncturing masks

3.2.1 Puncturing masks for Rates R ≥ 1/3

These masks apply only for sizes specific for URLLC (*K*=20, *K*=32, *K*=40, *K*=48, *K*=80 bits, *K*=600 bits). For R=1/3 the considered constituent code is RSC$(1, 15/13)_8$ there is no puncturing.

R	**Parity puncturing mask for systematic = 1111**
1/2	1010
2/3	1000

Note : "1" means "non-punctured (transmitted) symbol" and "0" means "punctured (non-transmitted) symbol".

3.2.2 Puncturing mask *R*=1/6

Considered constituent code RSC(1, 15/13, 17/13, 11/13)$_8$ the puncturing mask is:

Systematic	0000
Parity (FF=15)	1111
Parity (FF=17)	1111
Parity (FF=11)	1111

Note : "1" means "non-punctured (transmitted) symbol" and "0" means "punctured (non-transmitted) symbol".

3.2.3 Puncturing mask *R*=1/8

Considered constituent code RSC(1, 15/13, 17/13, 11/13, 16/13)$_8$ the puncturing mask is:

Systematic	0000
Parity (FF=15)	1111
Parity (FF=17)	1111
Parity (FF=11)	1111
Parity (FF=16)	1111

Note : "1" means "non-punctured (transmitted) symbol" and "0" means "punctured (non-transmitted) symbol".

3.2.4 Puncturing mask *R*=1/10

Considered constituent code RSC(1, 15/13, 17/13, 11/13, 16/13, 12/13)$_8$ the puncturing mask is:

Systematic	0000
Parity (FF=15)	1111
Parity (FF=17)	1111
Parity (FF=11)	1111
Parity (FF=16)	1111
Parity (FF=12)	1111

Note : "1" means "non-punctured (transmitted) symbol" and "0" means "punctured (non-transmitted) symbol".

3.2.5 Puncturing mask *R*=1/12

Considered constituent code RSC(1, 15/13, 17/13, 11/13, 16/13, 12/13, 17/13)$_8$ the puncturing mask is:

Systematic	0000

Parity (FF=15)	1111
Parity (FF=17)	1111
Parity (FF=11)	1111
Parity (FF=16)	1111
Parity (FF=12)	1111
Parity (FF=17)	1111

Note : "1" means "non-punctured (transmitted) symbol" and "0" means "punctured (non-transmitted) symbol".

3.3 Interleaver parameters

3.3.1 ARP interleaver parameters for *K*=20 bits

ARP interleaver parameters (*K*=20)		
Q	***P***	$\left(S(0)...S(Q-1)\right)$
4	7	(3, 3, 11, 15)

3.3.2 ARP interleaver parameters for *K*=32 bits

ARP interleaver parameters (*K*=32)		
Q	***P***	$\left(S(0)...S(Q-1)\right)$
4	9	(3, 5, 3, 5)

3.3.3 ARP interleaver parameters for *K*=40 bits

ARP interleaver parameters (*K*=40)		
Q	***P***	$\left(S(0)...S(Q-1)\right)$
4	11	(3, 19, 31, 7)

3.3.4 ARP interleaver parameters for *K*=48 bits

ARP interleaver parameters (*K*=48)		
Q	***P***	$\left(S(0)...S(Q-1)\right)$
4	11	(3, 27, 47, 23)

3.3.5 ARP interleaver parameters for *K*=80 bits

ARP interleaver parameters (*K*=80)		
Q	***P***	$(S(0)....S(Q-1))$
4	11	(3, 63, 3, 63)

3.3.6 ARP interleaver parameters for *K*=600 bits

ARP interleaver parameters (*K*=600)		
Q	***P***	$(S(0)....S(Q-1))$
4	31	(3, 63, 475, 299)

The same ARP parameters are used for coding rates 2/3, 1/2, 1/3, 1/6, 1/8, 1/10 and 1/12 of a particular frame size *K*.

4 Performance results

The performance results presented in section 4 were obtained using the puncturing patterns and the interleaving parameters described in the previous sections. We start by QPSK constellation. Then 16QAM simulations are provided over an AWGN channel.

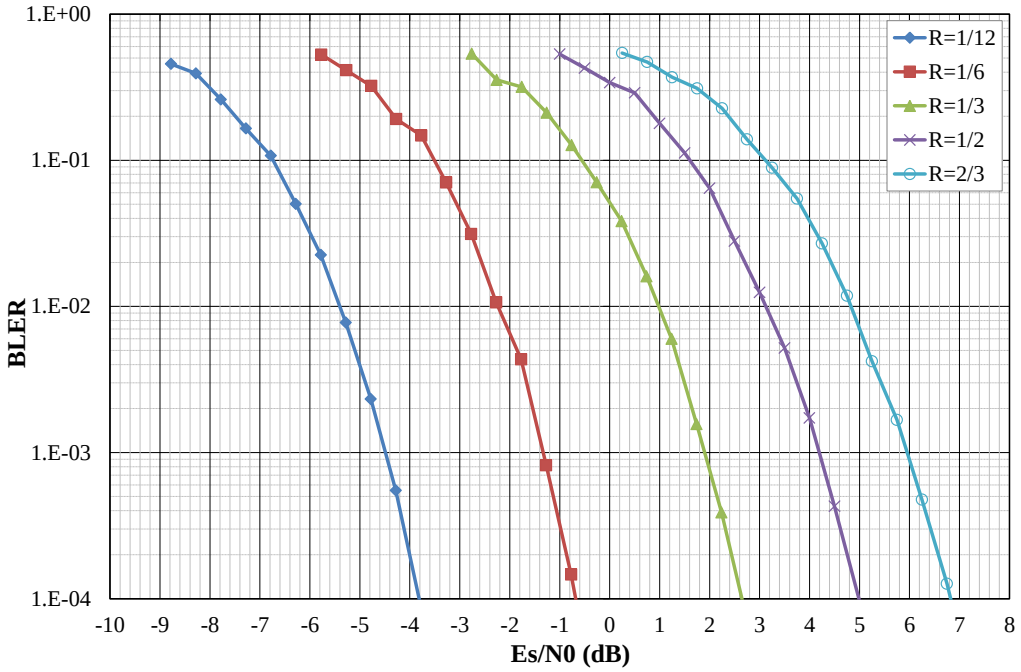

Figure 1: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **QPSK modulation**, information block size ***K* = 20 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

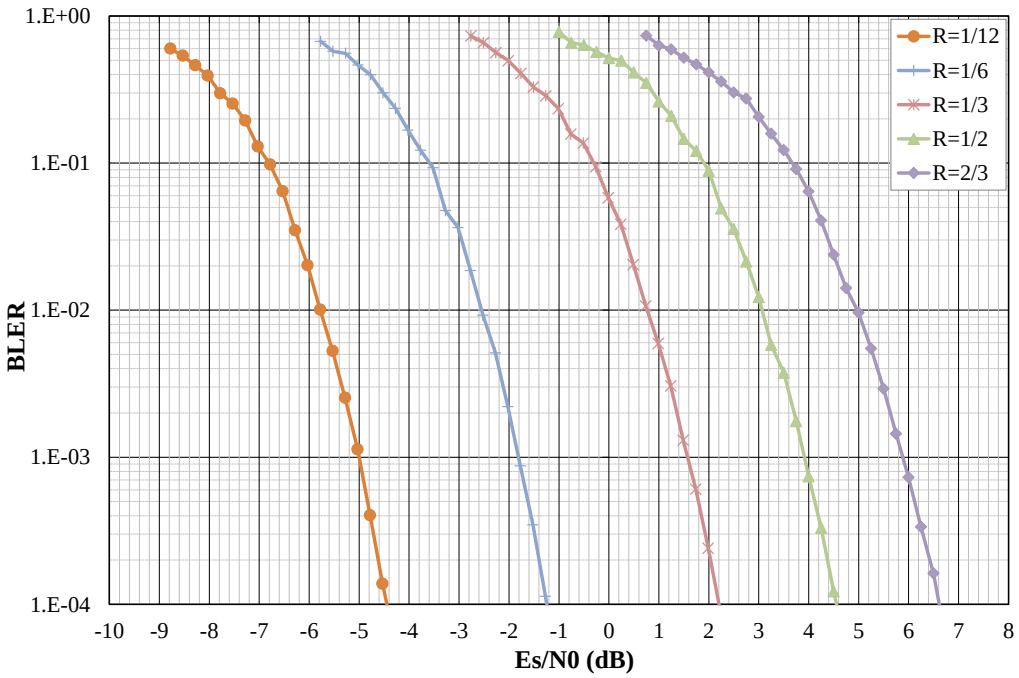

Figure 2: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **QPSK modulation**, information block size ***K* = 32 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

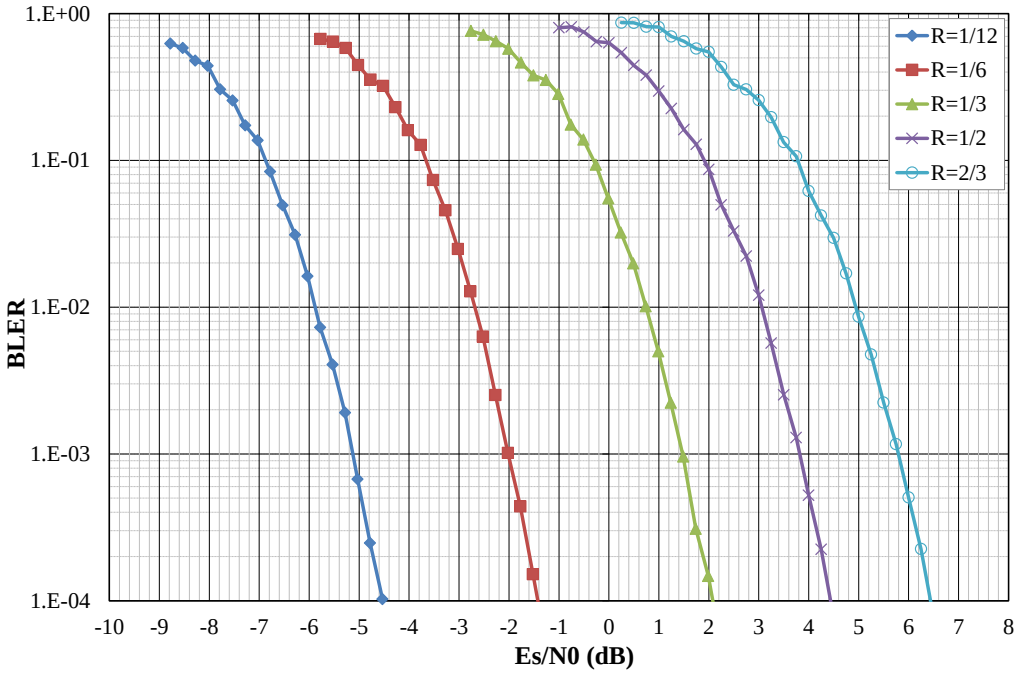

Figure 3: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **QPSK modulation**, information block size ***K* = 40 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

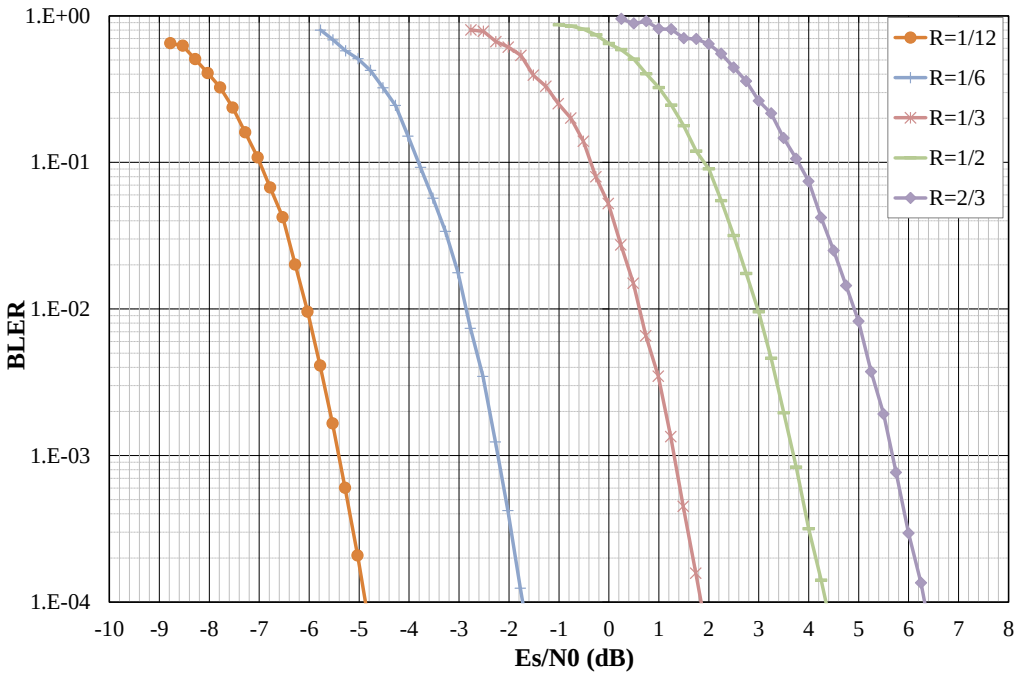

Figure 4: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **QPSK modulation**, information block size ***K* = 48 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

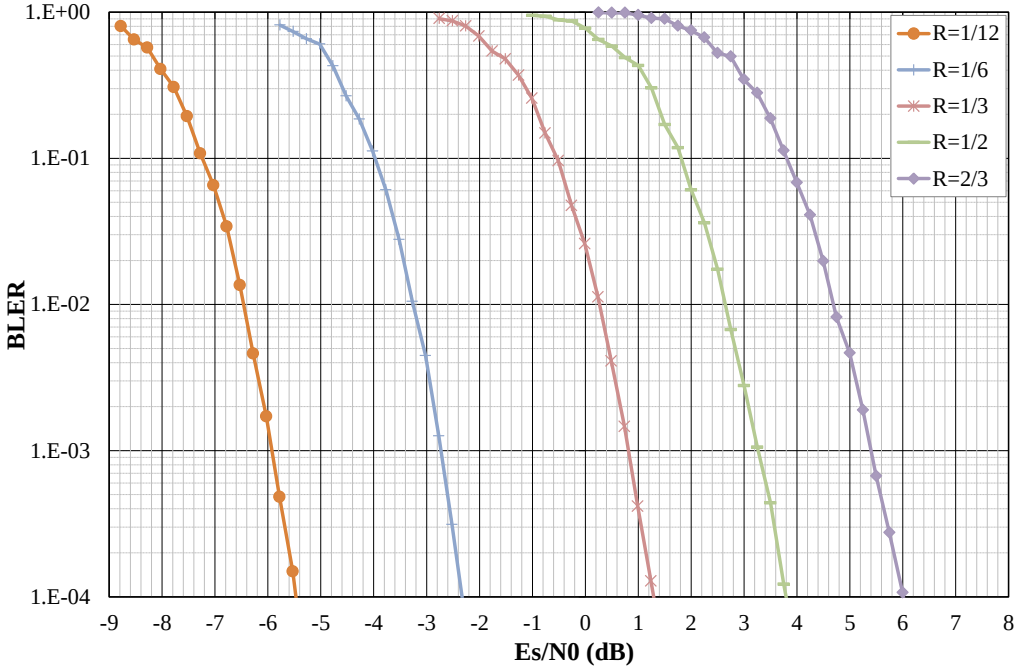

Figure 5: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **QPSK modulation**, information block size ***K* = 80 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

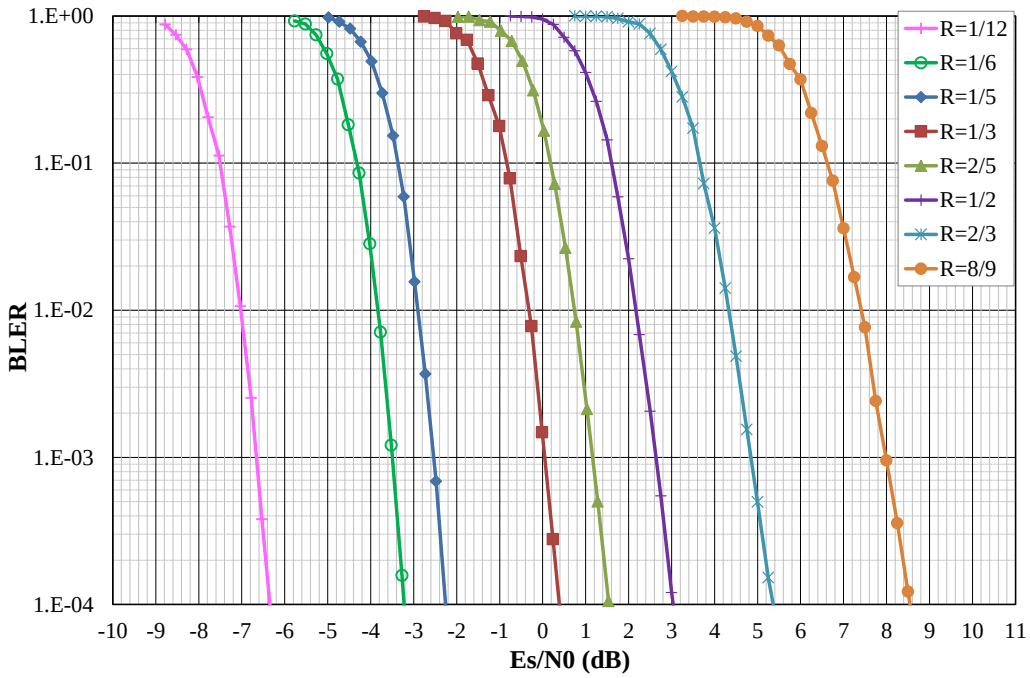

Figure 6: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **QPSK modulation**, information block size ***K* = 208 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination. **eMBB and URLLC channel Scenarios**.

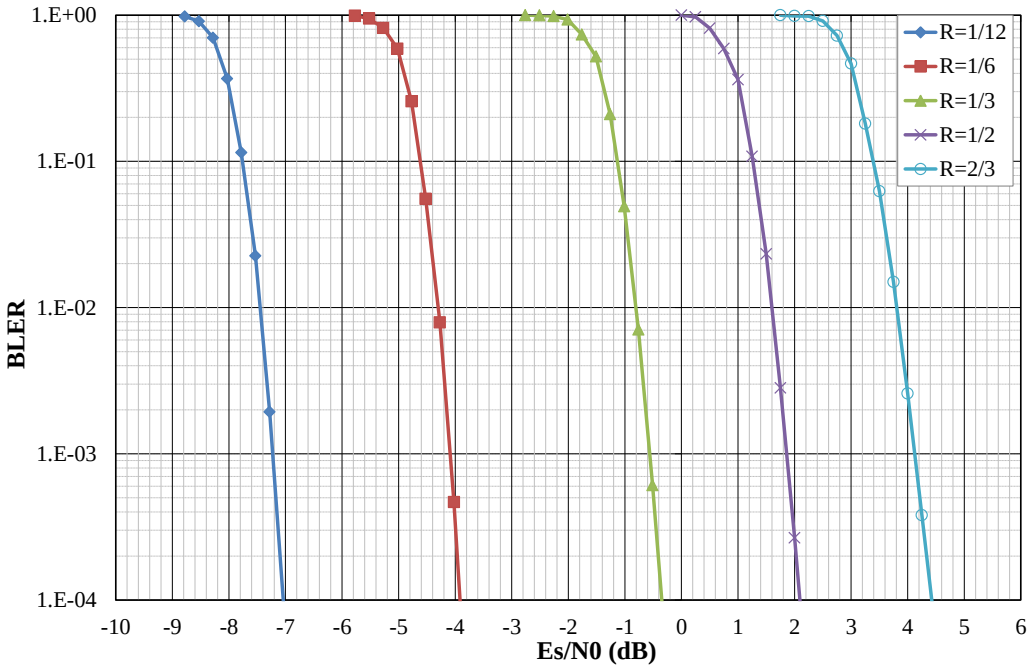

Figure 7: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **QPSK modulation**, information block size ***K* = 600 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

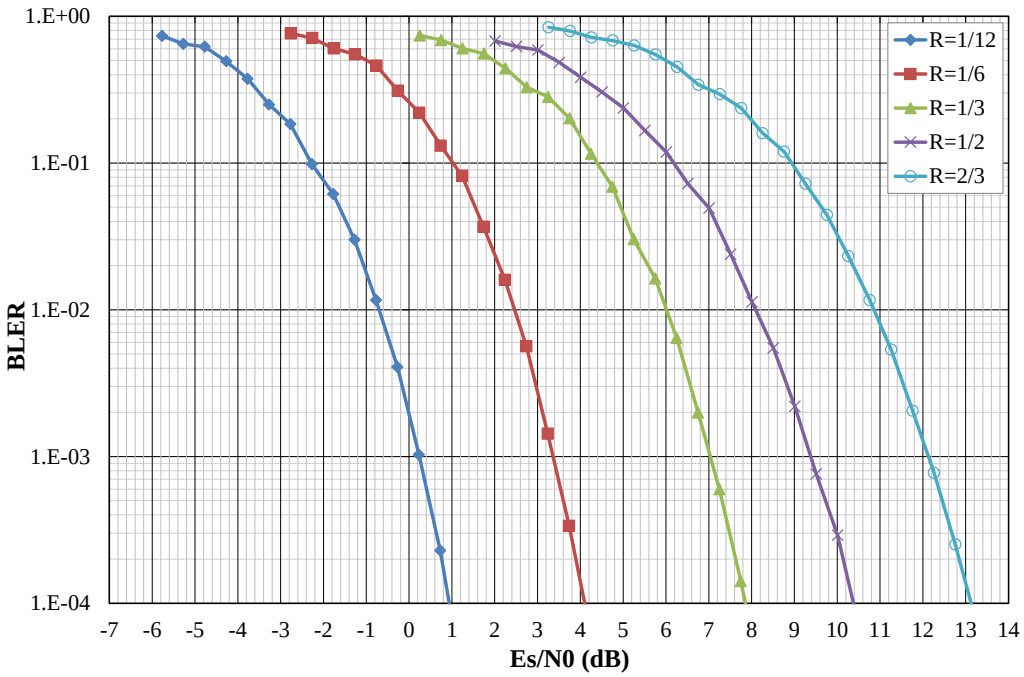

Figure 8: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **16QAM modulation**, information block size ***K* = 20 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

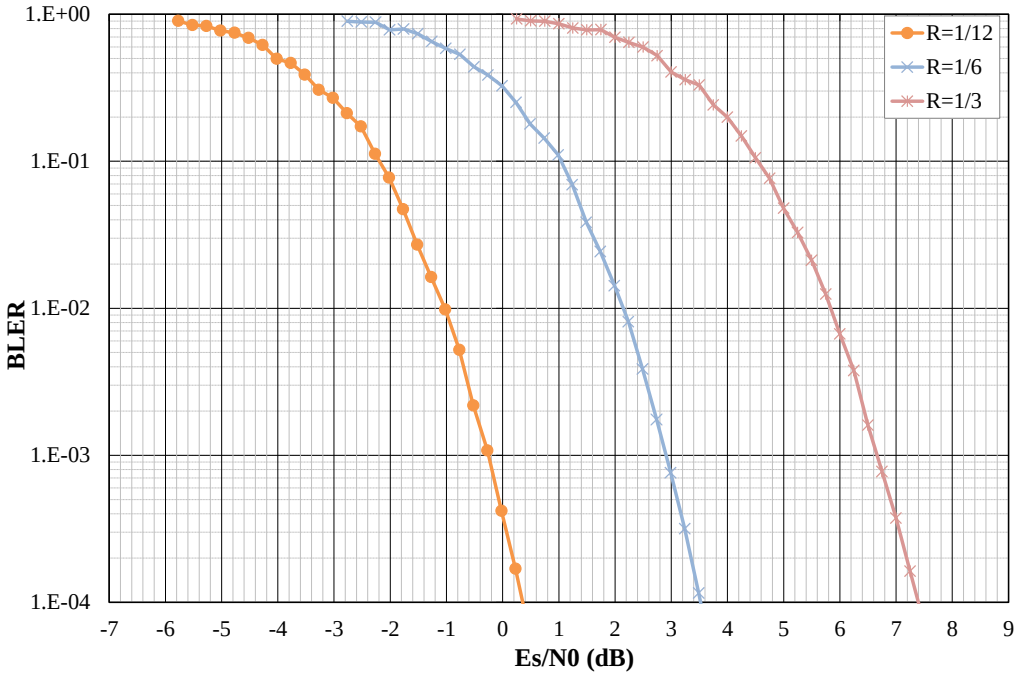

Figure 9: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **16QAM modulation**, information block size ***K* = 32 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

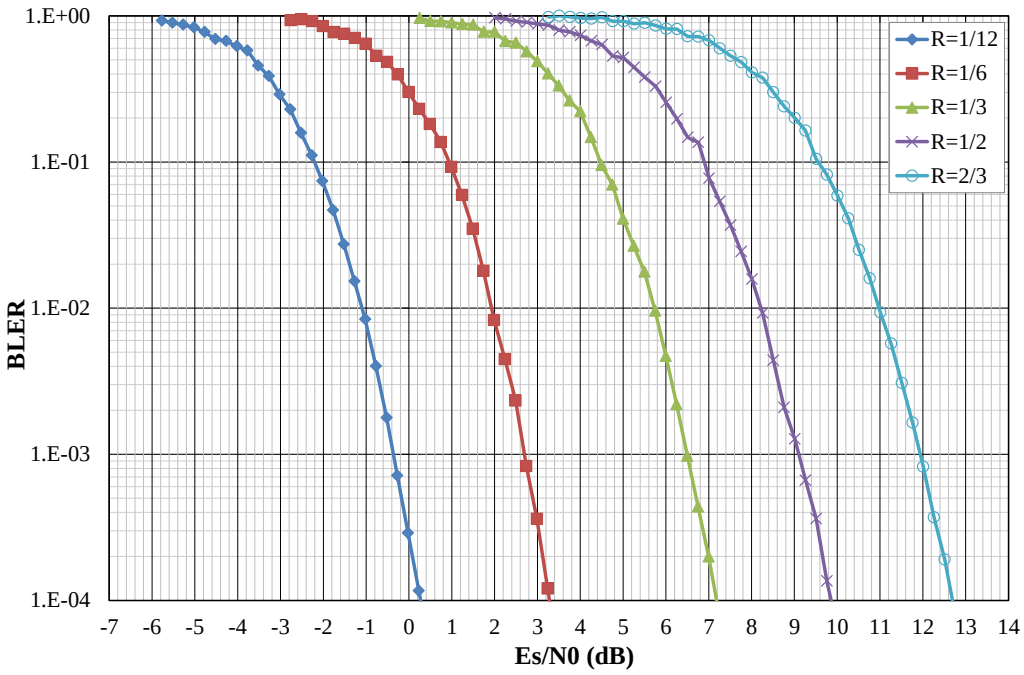

Figure 10: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **16QAM modulation**, information block size ***K* = 40 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

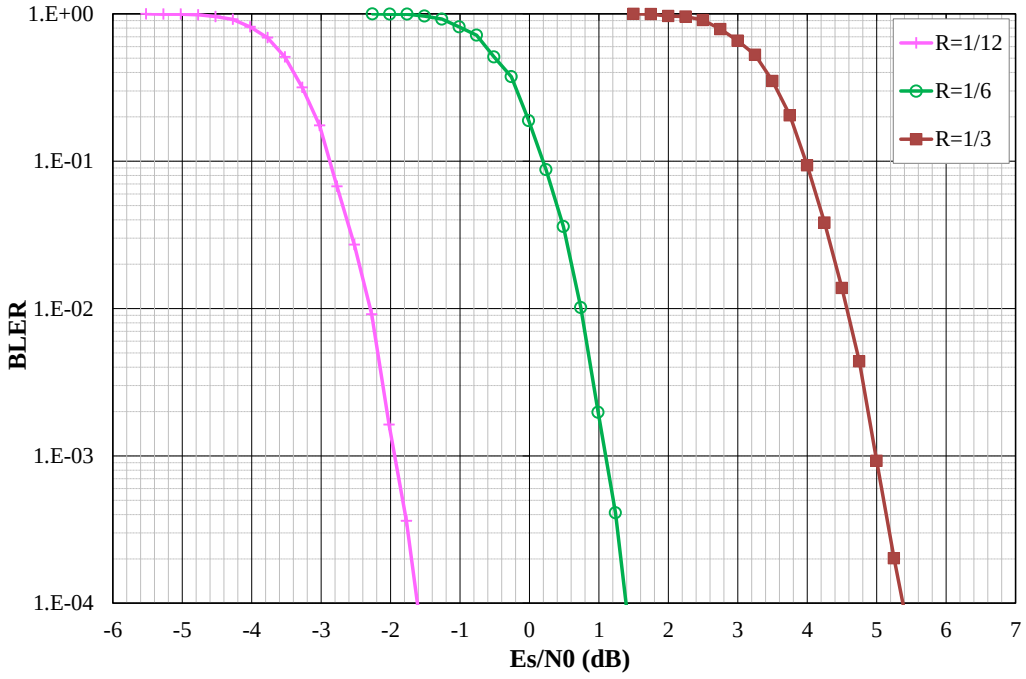

Figure 11: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **16QAM modulation**, information block size ***K* = 208 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

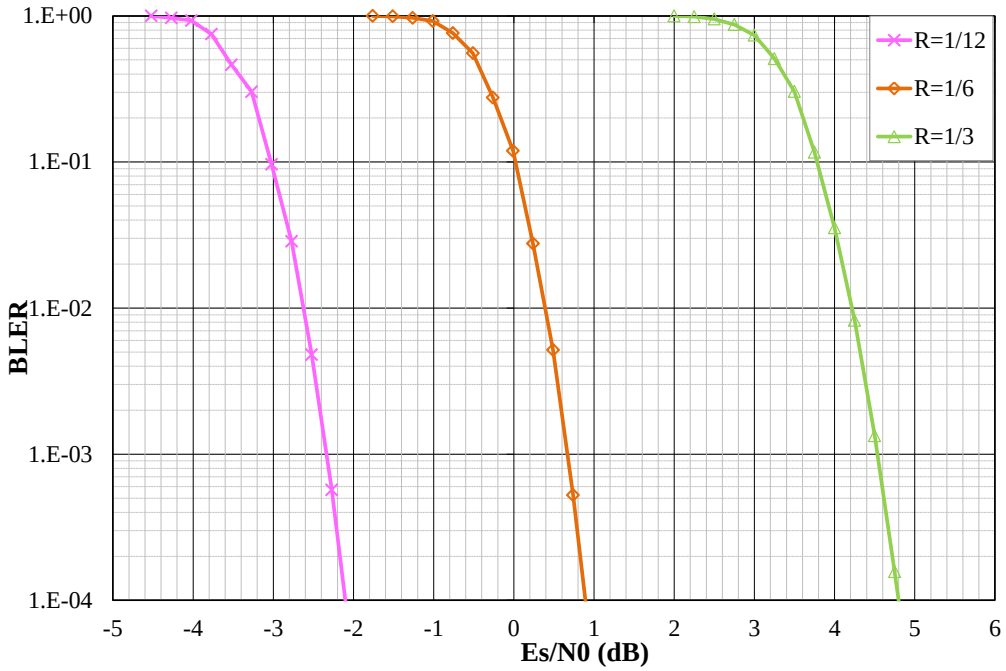

Figure 12: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **16QAM modulation**, information block size ***K* = 400 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

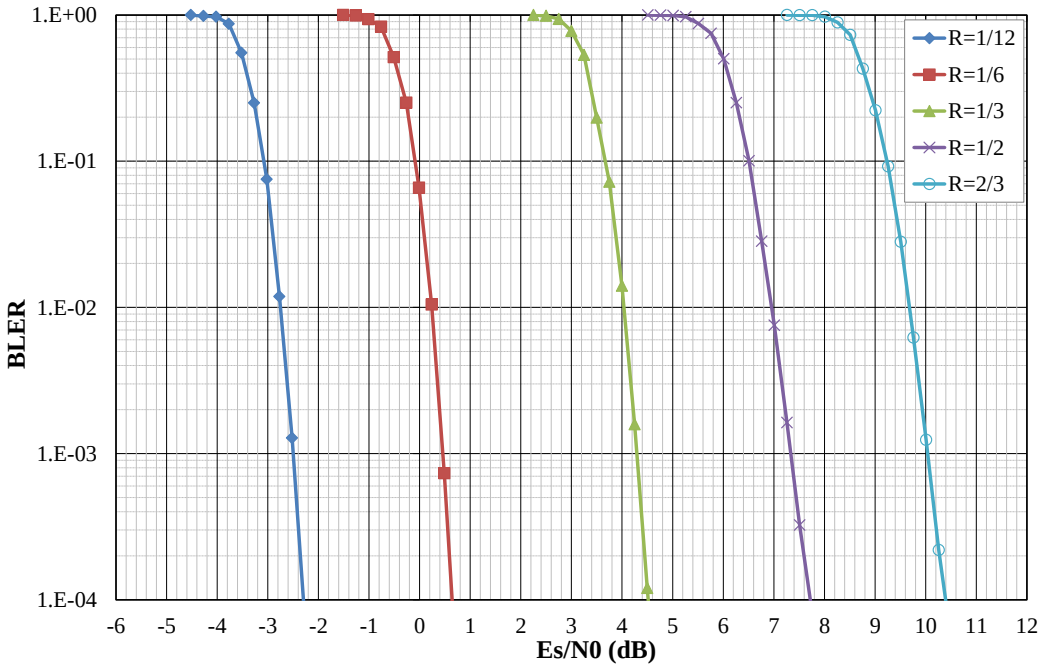

Figure 13: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **16QAM modulation**, information block size ***K* = 600 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

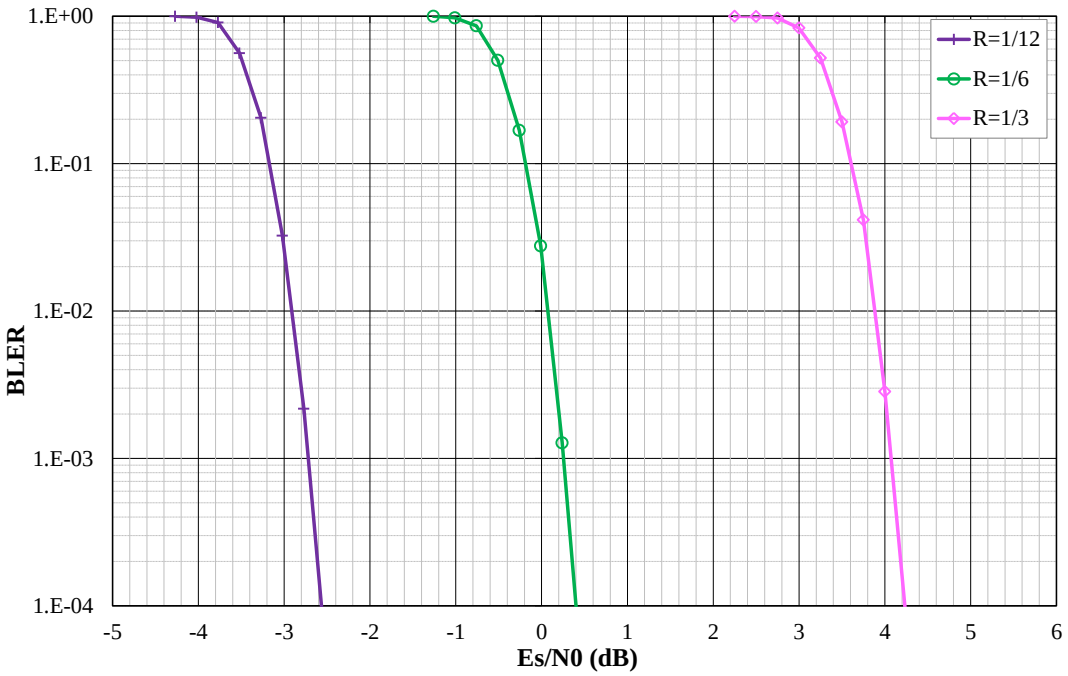

Figure 14: Performance evaluation of the enhanced turbo code in AWGN channel in terms of BLock Error Rate vs Es/N0. **16QAM modulation**, information block size ***K* = 992 bits**, 8 decoding iterations of the Max-log-MAP algorithm, tail-biting termination.

5 Conclusion

Observation 1: Enhanced Turbo codes can greatly improve the performance of LTE turbo codes especially for the URLLC scenario.

Observation 2: Proposed ARP interleaver is maximum contention free eliminating memory access conflicts for all possible sub-block parallelism.