Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**A STUDY OF THE BENEFIT OF CONCATENTATED CODING IN IEEE 802.16**
Date Submitted	**2001-7-06**
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Re:	Call for Contributions: Comments on 802.16ab-01/01
Abstract	This document presents a study of proposed concatenated code in 802.16ab-01/01. Under short code blocks and identical overall code rate, the concatenated code may not outperform convolution code by itself without byte interleaving.
Purpose	Seek discussion and suggest using concatenated code as optional at **section 8.3.6.3.3.2.2.1 (IEEE 802.16ab-01/01 page 102)**
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1. INTRODUCTION

The Draft Standard for IEEE 802.16c proposes a concatenation of a systematic Reed-Solomon outer block code with a nonsystematic convolutional inner code. There is no byte interleaving between the RS outer code and the convolutional inner code; therefore, the benefit of the concatenation is degraded. The problem with having byte interleaving is the increased transmission delay. This memo presents simulation results for the BER performance of the concatenated code, postulating an ideal BPSK/QPSK coherent channel.

The convolutional inner code is K=7 punctured rate-1/2, and uses tail biting to create a block size equal to the RS block size. (This means to start the convolutional encoder at the beginning of the block loaded with the data at the end of the data block.) To decode without knowledge of the ending state, the Viterbi decoder passes through the data block more than once to eliminate the startup transient.

The (N,K,T) RS code uses 8-bit bytes, and the block size N is a shortening of 2^8-1. The byte error correcting capability is T = (N-K)/2. It is assumed that the RS decoder removes all errors if the number of byte errors is T or less, fails to decode if the number of byte errors exceeds T, and has a negligible probability of decoding incorrectly and adding additional errors.

2. CODING MODES

The shortest code blocks proposed by IEEE 802.16 are

Shortened RS code	Punctured convolutional code	Overall code rate
(24,18,3)	Rate-2/3	Rate-1/2
(81,72,4)	Rate-3/4	Rate-2/3
(30,26,2)	Rate-5/6	Rate-0.722

The longest code blocks proposed by IEEE 802.16c are

RS code	Convolutional code	Overall code rate
(64,48,8)	Rate-2/3	Rate-1/2
(108,96,6)	Rate-3/4	Rate-2/3
(120,108,6)	Rate-5/6	Rate-3/4

SIMULATED BER PERFORMANCE OF CONCATENATED CODE WITHOUT BYTE INTERLEAVING

The concatenated code was simulated with unquantized soft-decision Viterbi decoding. The path memory of the Viterbi decoder is 64 bits. In the simulations, the Viterbi decoder starts at the beginning of each data block with all states set to the same metric value and decodes twice, outputting to the RS decoder only on the second pass. The Viterbi decoder produces a hard binary output, which is presented to the RS decoder as 8-bit bytes.

The simulation counts the number of byte errors in the code block to determine whether the errors can be corrected by the RS decoder. If the RS decoder fails to decode, the number of bit errors is the actual number in the data bytes of the systematic RS code.

Simulation results of BER for the concatenated code are plotted in Figure 1 for the shortest code blocks and in Figure 2 for the longest code blocks. As already stated, the convolutional code has tail biting over the block length. For comparison, the union bound on theoretical BER performance of the convolutional code by itself is also plotted in Figure 1[1; p 243-249]. As a check between theory and the simulation, the simulated BER performance of Viterbi decoding with tail biting is plotted in Figure 1 for two code rates and is seen to be in excellent agreement with the theoretical curves even for the shortest code blocks.

COMPUTED BER PERFORMANCE OF CONCATENATED CODE WITH IDEAL BYTE INTERLEAVING

For comparison, the BER performance of the concatenated code is obtained assuming ideal byte interleaving, so the byte errors occur independently in the code word. The simulation measures the average probability of a byte error at the output of the Viterbi decoder and computes the probability of getting more than T byte errors using the binomial distribution. For the computation, the number of bit errors in an erroneous byte is assumed to be four. The results are plotted in Figure 3.

3. CONCLUSIONS

The expected advantage of the concatenated code is a steeper behavior of the BER as a function of E_b/N_o. However, for the shortest block lengths, the concatenated code without byte interleaving is better than the convolutional code by itself at the same overall code rate only for a BER below 10^{-8}. For the longest block lengths, the concatenated code is better only for a BER below roughly 10^{-7}. With ideal byte interleaving, the concatenated code for the shortest block lengths is better only for a BER below roughly 10^{-5} or higher.

It is theoretically possible to improve the performance of the concatenated code somewhat by implementing a Viterbi decoder that outputs soft binary decisions. This flags some erroneous bytes as erasures enabling the RS decoder to do errors + erasures decoding. However, it is judged that the potential improvement is small and would be at the cost of a much greater decoding complexity.

4. REFERENCE

[1] G. C. Clark and J. B. Cain, Error-Correction Coding for Digital Communications, Plenum Press, 1981.

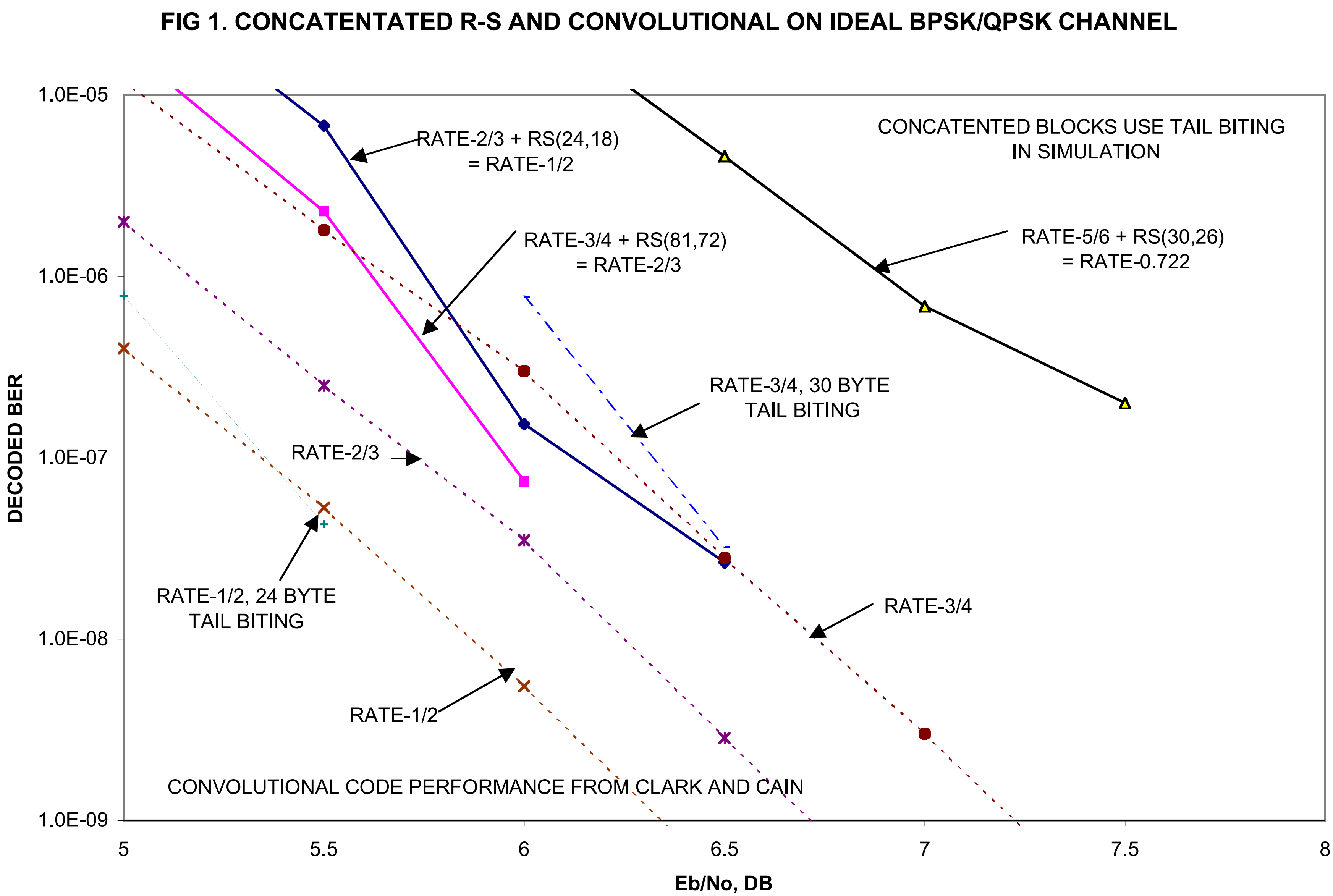
FIG 1. CONCATENTATED R-S AND CONVOLUTIONAL ON IDEAL BPSK/QPSK CHANNEL
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
DECODED BER
5
5.5
6
6.5
7
7.5
8
Eb/No, DB
RATE-2/3 + RS(24,18)
= RATE-1/2
CONCATENTED BLOCKS USE TAIL BITING
IN SIMULATION
RATE-3/4 + RS(81,72)
= RATE-2/3
RATE-5/6 + RS(30,26)
= RATE-0.722
RATE-3/4, 30 BYTE
TAIL BITING
RATE-2/3
RATE-1/2, 24 BYTE
TAIL BITING
RATE-3/4
RATE-1/2
CONVOLUTIONAL CODE PERFORMANCE FROM CLARK AND CAIN

FIG 2. CONCATENTATED R-S AND CONVOLUTIONAL ON IDEAL BPSK/QPSK CHANNEL

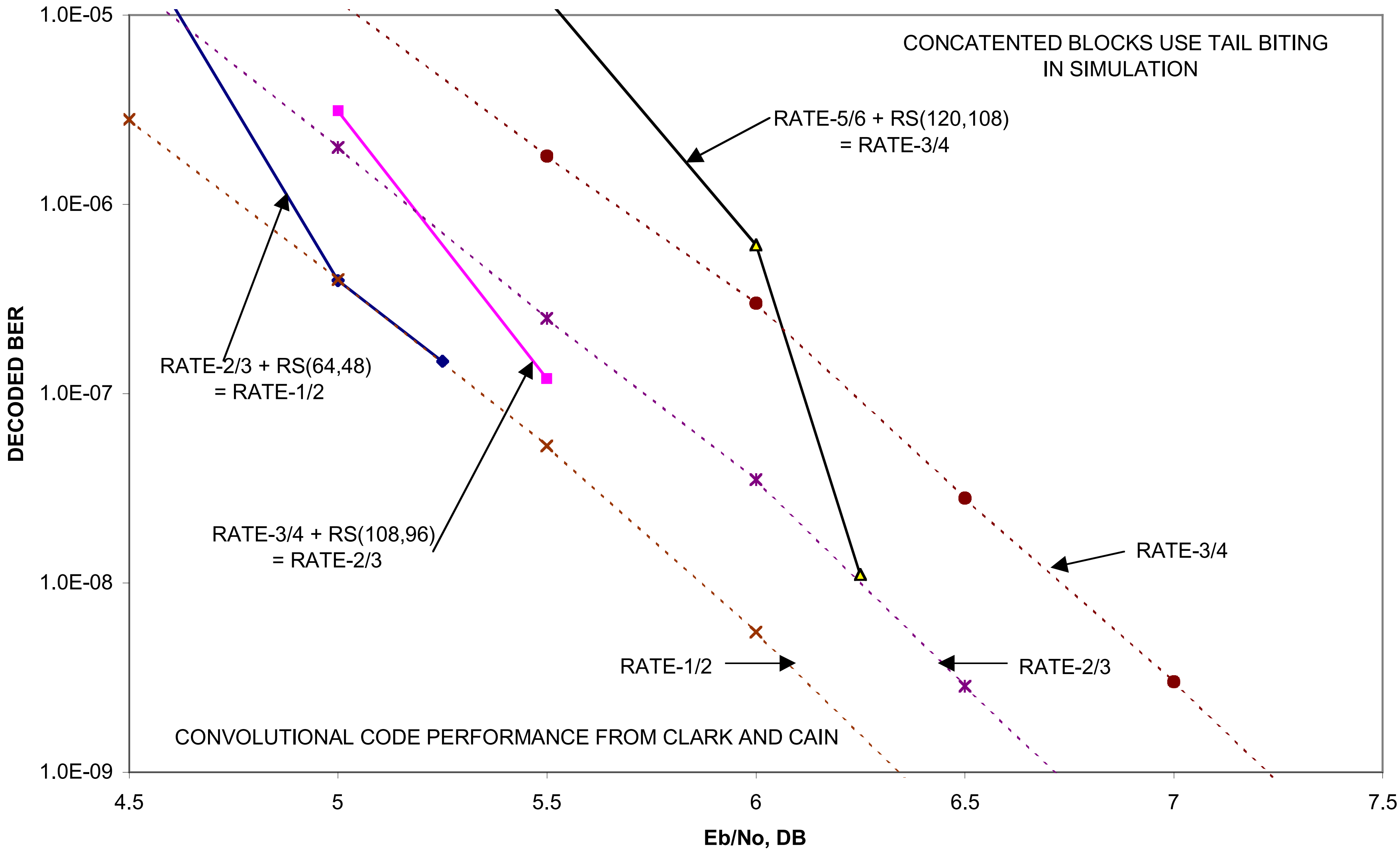

FIG 3. CONCATENTATED R-S AND CONVOLUTIONAL ON IDEAL BPSK/QPSK CHANNEL