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Thorén, Karl; Öwall, Viktor; Anderson, John B

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LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

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Precision Issues in the Implementation of BCJR Decoders

Karl Thorén
Dept. of Electroscience
Lund University
SE-221 00 Lund, Sweden
karl.thoren@es.lth.se

Viktor Öwall
Dept. of Electroscience
Lund University
SE-221 00 Lund, Sweden
viktor.owall@es.lth.se

John B. Anderson
Dept. of Information Technology
Lund University
SE-221 00 Lund, Sweden
anderson@it.lth.se

Abstract — **The BCJR algorithm is a symbol-by-symbol soft-output MAP decoder for trellis codes. This paper studies the effect of wordlength variations on the BCJR performance and looks at two strategies for reducing the wordlength.**

The BCJR algorithm exists in at least two basic versions, the original algorithm for terminated codes and a version for tailbiting codes [1]. We focus on the tailbiting algorithm applied to convolutional codes, although the conclusions here apply to the terminating BCJR and to other trellis codes as well. Both BCJR algorithms are based on two linear vector recursions, one forward through the trellis and one backward. Each recursion has the form of a vector with probabilities that are calculated by a matrix multiplication between the previous vector and a sparse matrix containing transition probabilities of the information channel. Successive vectors decrease in magnitude; in addition, channel errors cause sudden drops in values. This decrease of vector elements is especially critical in the presence of significant noise bursts in the channel.

I. Precision Problems

Several implementations of the BCJR algorithm have been proposed, including a log-MAP approximate scheme[2] and an analog processor[3]. In a fixed-point hardware implementation of the BCJR decoder, one needs to use a very high precision in the decoder to represent small vector elements. There is a need to scale the numbers to higher values when they get too small.

In a digital design, scaling with powers of 2 is hardware-efficient, since it only applies a bit-shift to the digital word. We have investigated how bit-shifts can be used to reduce the wordlength in the tailbiting BCJR decoder. Some results for the (7,5) rate 1/2 convolutional code are shown in the Table. The entries are the BERs for a channel with $E_b/N_o = 1$, with a variety of wordlengths and allowed bit shifts after the vector computation. The shaded areas indicates an almost constant BER. It is clear that scaling via bit shifts greatly reduces the required wordlength needed for a near-optimal BER.

	No shift	1 bit-shift	2 bit-shifts	3 bit-shifts	No limit
4-bit	.49997	.49566	.36748	.32732	.32551
8-bit	.49997	.35510	.16341	.13683	.13277
12-bit	.48595	.20024	.12630	.12111	.12058
16-bit	.36166	.13975	.12088	.12001	.11995
32-bit	.12090	.11993	.11992	.11992	.11992

Table: BERs for bit shift/wordlength combinations

II. Using Robustness to Reduce Wordlength

We also find that a decoder optimized for a less noisy channel has higher requirements for precision in the decoder. The noise-bursts in a good channel that make the decoder fail will be so unlikely that the wordlength in the decoder must be huge to represent these probabilities. In its calculations, the algorithm should use a different, poorer E_b/N_o than the true one, if it can do so without loss of error performance. An issue related to wordlength is thus how sensitive the decoder is to incorrect information about the channel SNR. We have tested several decoders for both the Gaussian channel and the BSC to see how the BER is affected by an incorrect channel E_b/N_o. The common outcome for all studied cases has been that the decoder has a stable BER across a wide variation of E_b/N_o.

Since the tailbiting BCJR decoder is robust to incorrect SNR information, we can make a tradeoff between performance and hardware by misrepresenting the channel's SNR to the decoder. Giving the decoder a poorer SNR than is actually the case will reduce its wordlength requirement with only a minor change in error correcting performance. The Figure shows how much the wordlength can be reduced when the true E_b/N_o is 6 dB but the decoder has been misled to believe the channel has another SNR. Thus, a large precision reduction is possible.

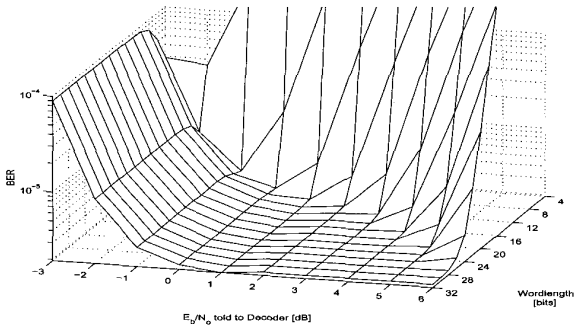

Figure: BERs for wordlength/assumed E_b/N_o combinations.

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