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Area and Power Efficient
Trellis Computational Blocks in 0.13\(\mu\)m CMOS

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Abstract—Improved add-compare-select and branch metric units are presented to reduce the complexity in the implementation of trellis-based decoding architectures. These units use a complementary property of the best rate 1/2 convolutional codes to reduce both area requirements and power consumption in a silicon implementation with no loss in decoding performance. For a 0.13\(\mu\)m CMOS process, synthesized computational blocks for decoders that can process codes from memory 2 up to 7 show up to 17% savings in both cell area and power consumption.

I. INTRODUCTION

Trellis-based decoding is a popular method to recover encoded information corrupted during transmission over a noisy channel. For example, the Viterbi algorithm (VA) [1] and the BCJR algorithm [2] are two schemes that work on an underlying trellis description of the encoded sequence. Note that the BCJR in the logarithmic domain (logMAP algorithm [3]) is commonly used in turbo decoding schemes.

Basic computations in either algorithm involve branch metric (BM) calculations and add-compare-select (ACS) operations. In case of the VA, an ACS operation successively discards branches that are not part of the survivor path. In case of the logMAP, this operation corresponds to an Add-MAX operation [4] to recursively calculate forward and backward state metrics. However, this is basically an ACS operation with an added offset (ACSO) to correct for the Jacobian logarithm. Thus, the presented results for the ACS hold for the ACSO as well.

Almost all good rate 1/n convolutional codes, n an integer, have the property that the code symbol labels on the two branches into each trellis node are complementary. In an earlier paper [5], we used this property and presented architectural simplifications for these units. Here, we apply this idea to see how these arithmetic savings translate into area and power savings in a silicon implementation.

We start by briefly reviewing notation and necessary modifications in the following section. Then, architectural issues for a hardware realization are addressed in Section III. We also present a variation that trades area for speed. As a case study, a computational kernel for Viterbi decoding is synthesized. The synthesis results in Section IV confirm the benefits of these approaches compared to a traditional setup. Also, power savings are estimated at gate level.

\[\lambda(s' \rightarrow s) = \begin{cases} y_i, & c_i(s' \rightarrow s) = 0 \\ 2^q - 1 - y_i, & c_i(s' \rightarrow s) = 2^q - 1 \end{cases} \]

and the complete branch metric becomes

\[\lambda(s' \rightarrow s) = \sum_{i=0}^{n-1} \lambda_i(s' \rightarrow s).\]

The ACS operation is expressed as

\[\Gamma(s, k+1) = \min \{\Gamma(s', k) + \lambda(s' \rightarrow s), \Gamma(s'', k) + \lambda(s'' \rightarrow s)\}\]

and illustrated in Fig. 1(b). \(\Gamma(s, k+1)\) is the updated metric of state s at time k+1, based on the preceding state metrics.
The branch metric \( \lambda(s' \rightarrow s) \) can take four different values for a rate 1/2 code, namely \( \lambda[x_0 x_1] \) for every possible combination of symbols \( x_j \in \{0,1\} \). The complementary metrics to \( \lambda[00] \) and \( \lambda[10] \) that are needed in a conventional ACS unit are \( \lambda[11] \) and \( \lambda[01] \), respectively. In the improved approach only two metrics are needed since the other two can be calculated according to (4), that is, \( \lambda[11] \) is expressed by \( \lambda[00] \) and \( \lambda[01] \) by \( \lambda[10] \). The factor \( \lambda(s' \rightarrow s) \) of Fig. 2 to be added in an ACS unit is therefore either \( \lambda[00] \) or \( \lambda[10] \).

From the preceding considerations the hardware savings become apparent by looking at an example, an ACS unit setup for decoding a (7,5) code in Fig. 3. In this picture, the state metric corrections in the two ACS units on the left become obsolete since \( \lambda[00] \) was subtracted from all updated state metrics.

The correction factor to be used in the two ACS units on the right is then
\[
\Delta \lambda = \lambda[10] - \lambda[00] = (2^q - 1) - 2y_0. \tag{8}
\]

Consequently, for rate 1/2 codes that have the complementary property half the ACS units save one addition compared to a conventional setup. Therefore, the number of required additions is \( 5 \cdot 2^{m-1} \), where \( m \) is the encoder memory. Compared to a conventional ACS unit setup \( (3 \cdot 2^{m}) \) additions, the reduction in arithmetic complexity is 17%.

The necessary distance measures \( \lambda[\cdot] \) are provided by BM units. Fig. 4 shows both a conventional and the improved BM unit. The former (a) needs four additions and two inverters to calculate the four branch metrics. The latter (b) only needs two additions and three inverters to calculate two branch metrics considering that the calculation of \( \Delta \lambda \) can be simplified with \( y_0 = (2^q - 1) - \bar{y}_0 \) and therefore (8) becomes
\[
\Delta \lambda = 2\bar{y}_0 - (2^q - 1) \pmod{2^q} = 2\bar{y}_0 + 1. \tag{9}
\]

This expression is calculated by a left-shift of \( y_0 \) followed by a bit-inversion (MSB excluded).

Note that the critical path in half the ACS units is increased by the delay of an addition. However, this problem is solved...
by delaying the correction into the next computation cycle and the original critical path of the ACS unit is maintained. In this case, the additions for the correction that are after the multiplexers in Fig. 3 move into different ACS units into the comparison path instead, see the retimed ACS unit in Fig. 5. Besides storing $\Delta \lambda$ in the BM unit, two new correction factors $\lambda^*[00]+\Delta \lambda$ and $\lambda^*[10]+\Delta \lambda$ are needed for this architecture. These additions are not carried out in the ACS units since this again would increase the critical path. They are instead precalculated in the BM unit; the complexity is moved from the ACS units to the BM unit which is instantiated only once instead of $2^m$ times. Fig. 6 shows this BM unit which is the BM unit from Fig. 4(b) appended with two additions and a register. If the extra delay introduced by these additions can not be tolerated, the datapath can always be pipelined since it is purely feedforward.

IV. IMPLEMENTATION AND SYNTHESIS RESULTS

In this case study, we implemented Viterbi computational blocks for best feedforward rate 1/2 convolutional codes [6] up to memory $m = 7$. The output of an ACS unit is both the surviving path into the respective state and the updated state metric, see Fig. 7. We neglect survivor memory management since this part of the decoder does not differ between the conventional and improved architectures. The BM and ACS units are described in a VHDL model at register-transfer level based on generic parameters.

The well-known state metric normalization techniques are still valid since differences among the state metrics remain the same. A modulo normalization scheme is used and the state metrics become

$$[\log_2\left(2^{(2^q-1)(m+1)}\right)]$$

(10) bits wide. The comparison in the ACS unit is implemented with the modified comparison rule [7]. Channel symbol wordlength is $q = 3$ since this gives negligible degradation in decoding performance compared to infinite precision.

We used a design kit from Virtual Silicon for the UMC $0.13 \mu m$ CMOS process. Power figures were obtained by Synopsys Power Compiler using toggle information from a gate level simulation run with state- and path-dependent cell information, and random input stimuli. Both dynamic (switching and short-circuit power) and leakage power are included in the results. However, it turns out that the contribution from leakage power is negligible in this study. At this design stage, it is assumed that the contribution from clock tree and interconnection, which is relevant for absolute area and power numbers, is the same in both architectures since we are only interested in the relative savings between architectures.

The improved versions are compared to their respective conventional setup with regard to their application area. For applications with relaxed timing requirements, area and power comparisons are done for the architecture in Fig. 3 together with the respective BM units. Synthesis tests showed that the area-delay product curve is flat down to a delay of about 3.5 ns, which is set as a constraint to the critical path. The power simulation is carried out at a clock frequency of $f_{clk}=250MHz$. For the retimed architecture of Fig. 5 this delay reaches further down to 2 ns. Here, we only synthesized the ACS units in order to investigate the impact of the saved adder in every unit. For the power simulation $f_{clk}=400MHz$ is assumed.

Table I lists the synthesis results of the cell area for a conventional ACS setup together with the BM unit from

1 United Microelectronics Company
is commonly used in turbo decoding schemes, the encoder memory does not exceed 4 and hence cell area savings can be as high as 12% per computational unit.

V. CONCLUSIONS

We showed that both area requirements and power consumption of trellis computational kernels can be reduced by making use of the complementary code symbol property of all good rate 1/2 convolutional codes. In our case study, area savings vary between 17% and 9% and power savings from 17% to 7% are reported in a 0.13 µm CMOS process. Furthermore, iterative decoding schemes can easily employ this simplification since their logMAP decoders are principally based on the same computational kernel.

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REFERENCES