Low Power Encoding for VLSI and ECC Duals

Mircea R. Stan[1]
EE Dept. University of Virginia
Charlottesville, VA 22903 USA
mircea@virginia.edu

Abstract — **Different branches of information theory are strongly related, and many classical problems are in some sense "duals" with their duality appearing in the Euclidean space (with Euclidean distance). The duality between low-power encodings and ECCs that is presented here, has the novel aspect that it works with the Hamming distance.**

I. Introduction

Low-power encodings were proposed for decreasing I/O power consumption in CMOS VLSI [1, 2]. The I/O dynamic power consumption is of the form: $P = C \cdot V_{dd}^2 \cdot f \cdot K \cdot prob(transition)$, where $K \cdot prob(transition)$ represents the number of transitions for each transfer over a K-bit wide bus.

The basic idea behind low-power encodings is to decrease the bus activity and thus decrease the I/O power consumption by *encoding* the data over the bus by adding redundancy in *space* in the form of extra bus lines [1] or in *time* in the form of extra bus cycles [2]. The resulting code is a mapping $C : U \rightarrow V$ where U has dimension 2^K (codeword length K bits) and V codewords have length N with $N > K$.

II. Limited-weight codes

An ad-hoc coding scheme for low-power I/O called Bus-Invert uses one extra bus line called *invert* (resulting in $N = K + 1$) [1]. The method computes the *Hamming distance* between the present *coded* bus value and the next uncoded data value. If the distance is $> \frac{K}{2}$ then the the next data value is complemented and $invert = 1$. Otherwise the next data value is left unchanged and $invert = 0$. The received data can be easily recovered by conditionally complementing the value on the bus according to the received *invert* line.

A more general setting for low-power I/O codes is the concept of *limited-weight codes* (LWC) [2]. The main abstraction step is to recognize that since *transitions* are to be minimized the codes should be able to have a more "direct" way of controlling transitions which can be accomplished by using *transition signaling* instead of level signaling. This enables a straightforward encoding strategy for power minimization: *in order to minimize I/O power dissipation (using transition signaling) a code with few* 1*s must be used.*

III. Low Power Encoding and ECC Duality

By definition an M-limited-weight (M-LWC) code uses codewords with the Hamming weight upper bounded by M. Because of the source entropy it follows that in order to have a sufficient number of codewords it is necessary that $\binom{N}{0} + \binom{N}{1} + \binom{N}{2} + \cdots + \binom{N}{M} \geq 2^K$ where the left-hand side represents the total number of possible codewords with weight $\leq M$ and the right-hand side represents the number of words for the uncoded source.

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Table 1: Correspondence between ECCs and LWCs

ECC	LWC
syndrome	unencoded symbol
coset leader	LW codeword
syndrome length $n - k$	unencoded length K
codeword length n	codeword length N
information bits k	extra redundancy $N - K$
perfect ECC	perfect LWC
semi-perfect ECC	semi-perfect LWC
repetition code	$\frac{m}{2}$-LWC
Hamming ECC	1-LWC

There is an unexpected relationship between LW codes and general ECCs due to the following observation: the *codewords* of a limited weight code when viewed as patterns of 1s and 0s are the same as the *error patterns* corrected by a standard block ECC. LW codewords can be viewed as the coset leaders of an ECC standard array and the ECC *syndromes* are similar to LWC *unencoded symbols*. This means that in principle we can use an arbitrary block ECC for generating the dual LWC by using a *complete* ECC decoding algorithm.

The Hamming bound $\binom{n}{0} + \binom{n}{1} + \binom{n}{2} + \cdots + \binom{n}{m} \leq 2^{n-k}$ for ECCs is similar to the LWC inequality $\binom{N}{0} + \binom{N}{1} + \binom{N}{2} + \cdots + \binom{N}{M} \geq 2^K$, except for the direction of the inequality. The LWC inequality has one more term than the dual ECC Hamming bound except for the case of *perfect* codes when the number of terms is the same. The duals of perfect or semi-perfect ECCs are desirable for efficient LWC generation [2].

Hamming codes are dual to the perfect 1-Limited Weight codes while repetition codes are dual to the $\frac{M}{2}$−LW and Bus Invert codes. The Golay code has a dual 3-LWC which is probably not appropriate for low power I/O as the Golay code decoding algorithms are too complex and iterative.

Reed Muller codes are a class of non-perfect EC codes, attractive for LW generation because they are majority decodable. Unfortunately, since they are non-perfect, the decoding algorithm will generate some LW codewords with many 1s.

The various analogies between LW and and the dual EC codes are summarized in table 1.

IV. Conclusions and future work

The duality along the Hamming distance between Limited Weight codes and linear block Error Correction codes provides a theoretical method for the algorithmic generation of low power encodings which requires finding appropriate dual ECCs with a simple and complete decoding algorithm.

References

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[2] M. R. Stan and W. P. Burleson. Low-power encodings for global communication in CMOS VLSI. *IEEE Tr. on VLSI*, Dec. 1997.