



Before convergence early stopping criterion for inner LDPC code in DVB standards

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► To cite this version:

Cédric Marchand, E Boutillon. Before convergence early stopping criterion for inner LDPC code in DVB standards. Electronics Letters, 2015, 51 (1), pp.114 - 116. 10.1049/el.2014.3468 . hal-01174847

HAL Id: hal-01174847

<https://hal.science/hal-01174847>

Submitted on 10 Jul 2015

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of $S_l(c)$. From $S_l(c)$ and $S_a(c)$, it is also possible to compute $\tau_l = \sum_{c=0}^{m-1} S_l(c)$ and $\tau_a = \sum_{c=0}^{m-1} S_a(c)$. Comparing τ_l with a threshold T_l and τ_a with a threshold T_a gives two new BC-ESC.

Simulation results: Bit true C simulation has been performed using the architecture presented in [7]. For each code rate, the signal to noise ratio (SNR) is set to the value required by the standard for a Quasi Error Free (QEF) transmission. For each code rate, $N = 5 \times 10^6$ frames are simulated with it_{max} iterations. A BC-ESC is assumed to be "standard compliant" if, among the N tested frames, it never stops the decoding process with more than t remaining errors. In the sequel, subscript x will denote one of the three BC-ESC methods ($x = o, l$ or a), the average number of decoding iterations for a given BC-ESC method is noted as A_x .

Let $\tau_x(k, i)$ (respectively $e(k, i)$) be the number of non-verified syndromes (respectively remaining errors) for the k^{th} simulated codeword at iteration i ($i \leq it_{max}$). Let T_x be the set of integers so that $T \in T_x$ implies that, for all $k = 1 \dots N - 1, i = 1 \dots it_{max}$,

$$\{\tau_x(k, i) \leq T_x\} \Rightarrow \{e(k, i) \leq t\}. \quad (9)$$

The threshold T_x is thus determined as $T_x = \max\{T_x\}$. A two dimensional BC-ESC implying both τ_l and τ_a can be defined by extending (9) to the two dimensional case with a dual-criteria BC-ESC. Let $T_{l,a}$ be the set of couples $(\hat{T}_l, \hat{T}_a) \in \mathbb{N}^2$ so that, for all $k = 1 \dots N - 1, i = 1 \dots it_{max}$:

$$\{\tau_l(k, i) \leq \hat{T}_l, \tau_a(k, i) \leq \hat{T}_a\} \Rightarrow \{e(k, i) \leq t\}. \quad (10)$$

At a given iteration, if $(\hat{T}_l = \tau_l(k, i), \hat{T}_a = \tau_a(k, i))$ belongs to $T_{l,a}$, then, according to (10), the number of residual errors is below t , thus the LDPC decoder can stop the iterative process and outputs the current hard decision to the outer BCH code. Fig. 2 represents the set $T_{l,a}^{4.68}$ for a code rate $r = 4/5$ and a SNR of 4.68 dB (SNR given by the DVB-S2 standard specification for QEF decoding). $T_{l,a}^{4.68}$ is defined as the set of points below the curve $\hat{T}_a^{4.68}$. Testing whether a point belongs to this set or not is straightforward: for a given value of τ_l the maximum admissible value $\hat{T}_a^{4.68}(\tau_l)$ is retrieved from a memory and τ_a is compared with $\hat{T}_a^{4.68}(\tau_l)$. For example, if $\tau_l = 3$ then $\hat{T}_a^{4.68}(3) = 100$, thus if $\tau_l = 3$ and $\tau_a \leq 100$ then the decoding process stops. Fig. 2 also shows the sets $T_{l,a}^{4.80}$ and $T_{l,a}^{4.90}$ (for SNR 4.80 dB and 4.90 dB respectively). One can note that $T_{l,a}^{4.68} \subset T_{l,a}^{4.80} \subset T_{l,a}^{4.90}$, thus, using the set $T_{l,a}^{4.68}$ for the BC-ESC, no errors are introduced for SNR 4.8 dB and 4.9 dB. This property can be generalized for all SNR above 4.68 dB and all code rates.

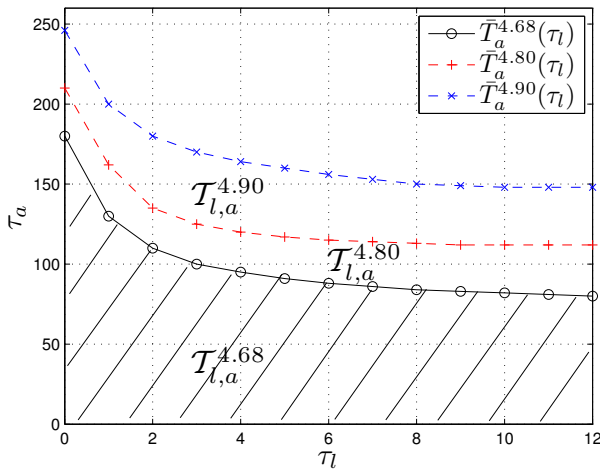


Fig. 2 Sets $T_{l,a}^{4.68}$, $T_{l,a}^{4.80}$ and $T_{l,a}^{4.90}$ for code rate $r = 4/5$. The limits of these sets are defined by the x-axis, the y-axis and the corresponding curve \hat{T}_a . $T_{l,a}^{4.68}$ is represented in dashed lines.

Table 1 shows T_x and A_x for different rates. By convention $A_x(T_x)$ indicates the average number of iterations when the BC-ESC $\tau_x \leq T_x$ is used. A_g is the minimum average number of iterations obtainable when a genius BC-ESC stops the decoding process as soon as $e \leq t$. Considering the state of the art ESC A_o , one iteration is added to take into account the latency for the syndrome computation processing in a layered architecture.

Note that, in [6], convergence is detected when all $HDA_l(c) = 0$ (no change of SO sign during two consecutive iterations, see Fig. 1) and when $\tau_a = 0$ (all check nodes are fulfilled). This ESC also requires an extra decoding iteration after convergence, again leading to an average number of decoding iterations equal to $A_o + 1$.

For all code rates, A_l , A_a and $A_{l,a}$ are below $A_o + 1$, except for code rates $r = 2/3, 3/4$ and $4/5$ where $A_l(T_l) = it_{max}$. For these code rates, $T_l = -1$, which implies that condition (9) is never fulfilled. In fact, as shown on Fig. 2, when $\tau_l = 0$, if $\tau_a > 180$ then e can be greater than t , i.e. $\tau_l = 0$ is not a sufficient criterion to ensure that $e \leq t$. The last line of Table 1 shows the reduction gain between the classical ESC ($A_o + 1$) and the proposed BC-ESC when the dual-criteria $A_{l,a}$ is used. The gain varies from 8 % (high code rates) up to 26% for code rate $1/4$. Performance of the genius BC-ESC shows that there is still a significant potential reduction in the average number of decoding iterations for low code rates (for code rate $r = 1/4$, $A_g = 15.7$ while $A_{l,a} = 20.1$).

Combined with an input buffer, the BC-ESC can be used to increase the decoding throughput [8]. It can also be used to reduce the average energy required to decode a codeword.

Table 1: Average number of iterations for several ESC methods

code rate r	1/4	1/3	2/5	1/2	3/5	2/3	3/4	4/5
it_{max}	45	40	35	35	30	30	30	30
SNR (dB)	-2.35	-1.24	-0.3	1	2.35	3.1	4.03	4.68
A_g	15.7	17.3	15	13.5	8.8	11.7	11.1	9.5
$A_o + 1$	27.2	25.5	20.5	18.2	12.1	15.4	13.6	11.9
T_l	0	0	0	0	0	-1	-1	-1
$A_l(T_l)$	26.1	24.5	19.6	17.4	11.2	30	30	30
T_a	309	281	384	274	274	79	141	108
$A_a(T_a)$	23	22.6	18.5	16.1	11	14.3	12.6	11.2
$A_{l,a}$	20.1	20.6	17.5	15.3	10	13.5	12.5	10.9
gain (in %)	26.1	19.2	14.6	15.9	17.	12.3	8.1	8.4

Conclusion: This letter shows that stopping the decoding process of an inner LDPC code can significantly reduce the average number of decoding iterations without any performance degradation, when the estimated number of remaining errors is below the maximum capacity correction of the outer decoder. A low complexity dual-criteria BC-ESC has also been proposed for DVB-S2, T2 and C2 standards. Compared to ESC, BC-ESC can reduce the average number of iterations of a few percents up to 26 %, depending on the code rate. The proposed BC-ESC can be used for energy saving or for increasing the average decoding throughput.

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