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Redbank, New Jersey, 21 – 25 May 2001

Question: 4/15

SOURCE<sup>1</sup>: IBM, Globespan

TITLE: G.gen: G.dmt.bis: G.lite.bis: Performance of LDPC coded modulation for ADSLbis under coding-latency constraints.

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### ABSTRACT

**We study the performance of LDPC coded modulation for G.dmt.bis and G.lite.bis under coding-latency constraints. DMT transmission over 100 and 200 tones is considered with a flat or linearly decreasing SNR characteristic across the tones. Latency values of 0.5 ms up to 10 ms are assumed. It is found that LDPC coding allows achieving excellent performance in terms of net coding gains with limited coding latency. The contribution also describes the architecture that we propose to use for a dual-latency path configuration.**

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<sup>1</sup> Contacts: E. Eleftheriou    ele@zurich.ibm.com  
S. Ölçer                oel@zurich.ibm.com  
IBM Zurich Research Laboratory

M. Sorbara            msorbara@globespan.net  
M. Eyvazkhani        meyvazkhani@globespan.net  
Globespan

## 1. Introduction

The performance of LDPC coded modulation for ADSL transmission has been addressed in a number of contributions [1], [2], [3], [4]. Here, we present new results that address the requirements in [5] and [6] that had not yet been considered for our LDPC coding proposal.

We first focus on system performance for LDPC coded modulation using 16-QAM (4 bits per tone) and 4096-QAM (12 bits per tone) for transmission over a channel exhibiting a flat SNR characteristic across 100 or 200 tones. We determine system performance under a coding-latency constraint of 0.5 ms up to 10 ms.

Secondly, we consider transmission over a channel exhibiting a non-flat, linearly decreasing SNR profile across 100 or 200 tones. As before, system performance is determined under a coding-latency constraint of up to 10 ms.

Due to the limited time available, we did not run simulations for outer Reed-Solomon (RS) coding. The inclusion of RS coding leads, however, to no surprise. As a general rule, for low latency values, the additional coding gain due to the RS coding is on the order of 0 dB to 0.5 dB since the RS codeword length must be short. For large latency values, additional RS coding gains of 1-1.5 dB, or more, can be obtained, see, e.g., [3].

The results presented show that significant coding gains are achieved under latency constraints. In particular, LDPC coding, when configured for “zero” additional latency, outperforms the trellis-coded modulation scheme specified in the current G.992.1 recommendation.

Finally, we also describe the architecture that we propose to use for a dual-latency path configuration.

## 2. Performance for channel with flat SNR profile

In this section, we consider 16-QAM (4 bits per tone) or 4096-QAM (12 bits per tone) transmission over a channel having a flat SNR profile across 100 or 200 tones [5], [6]. Clearly, when the number of tones and the modulation format are given, code length selection implies a specific coding latency. We consider latency values within the range of 0.5 ms to 10 ms.

The simulation results are summarized in Table 1. This table gives the net coding gain in dB at a symbol error-rate of  $10^{-7}$  without outer RS coding for different values of coding latency. We did not run simulations for codes longer than 9600 bits, hence some entries in the table are not provided.

Modulation	# of tones	Latency						
		0.5 ms	1 ms	2 ms	4ms	6 ms	8ms	10 ms
16QAM	100	4.6 dB	5.0 dB	5.8 dB	6.2 dB	6.2 dB	6.3	6.4 dB
	200	5.0 dB	5.8 dB	6.2 dB	6.3 dB	6.5 dB	--	--
4096QAM	100	4.5 dB	5.5 dB	5.8 dB	6.1 dB	--	--	--
	200	5.5 dB	5.8 dB	6.1 dB	--	--	--	--

**Table 1:** Net coding gains achieved by LDPC coding as a function of latency.

We note that, for any latency value, LDPC codes achieve net coding gains that are larger than that of the trellis-coded modulation scheme ( $\sim 3.4$  dB [7]) specified in the current G.992.1 Recommendation.

### 3. Performance for channel with nonflat SNR profile

In this section we consider transmission over an AWGN channel having a nonflat SNR profile across 200 or 100 tones given by [5], [6]

$$\text{SNR}_{\text{dB}}(k) = 50 - (50/200) \cdot k, \quad k = 0, 1, \dots, 199$$

and

$$\text{SNR}_{\text{dB}}(k) = 35 - (35/100) \cdot k, \quad k = 0, 1, \dots, 99$$

respectively. These SNR profiles are intended to approximate a twisted-pair transmission channel of medium (200 tones) and long (100 tones) reach.

We first determine the user data rate that can be achieved with each SNR profile in the absence of coding. We then compute, for each profile, the per-tone spectral efficiency of the coded scheme by ensuring that the bit allocation and gain control are used with a maximum power of 2.5 dB in each tone and no overall power boost is experienced over the active tones. The uncoded and coded schemes transmit at the same information rate. Net coding gains are determined under the latency constraints of 0.5 ms and 10 ms.

Results are presented in Figs. 1 and 2 for the medium and long reach cases, respectively. The figures show the BER as a function  $\text{SNR}_{\text{backoff}}$ , which represents the quantity in dB by which the SNR is reduced on each tone as compared to the uncoded case.

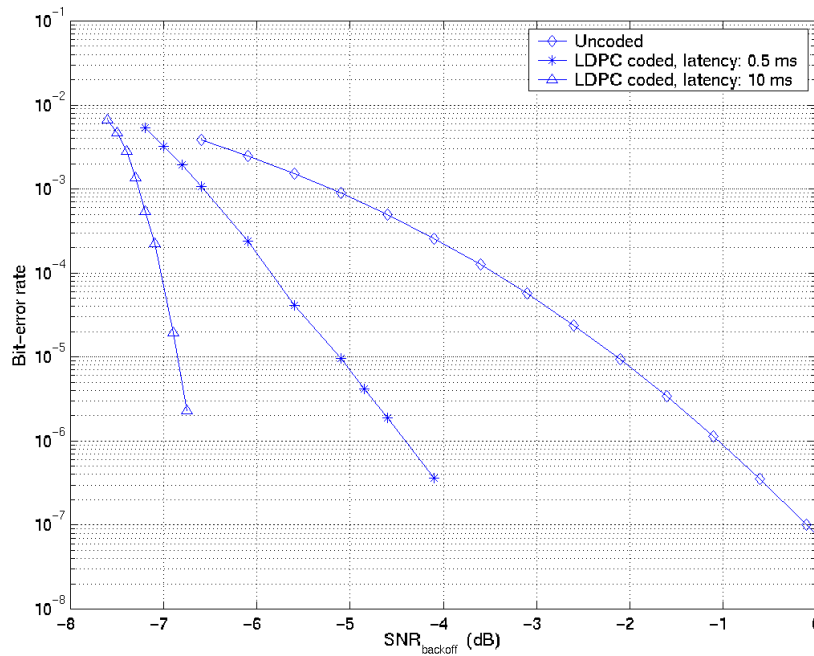
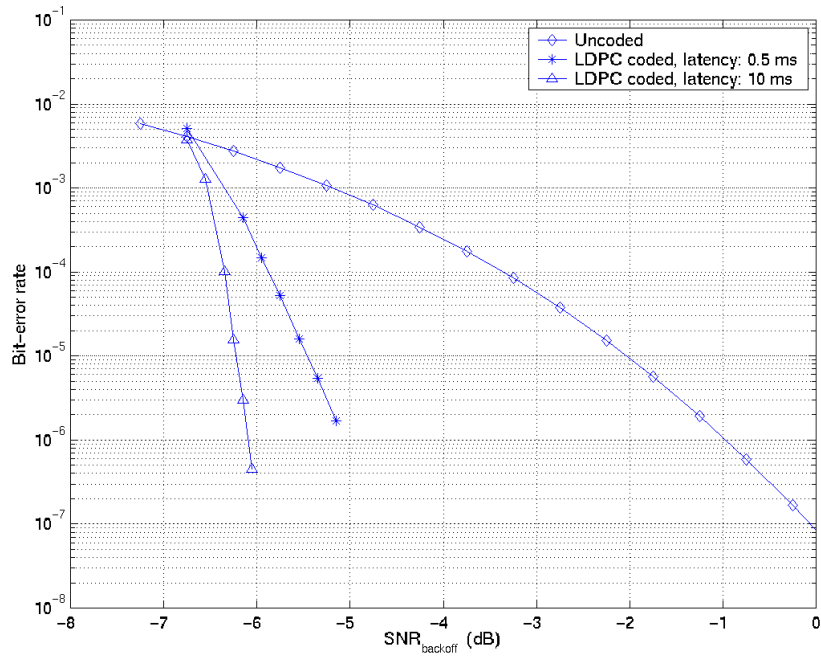


Fig. 1: Bit-error rate performance of LDPC coding for the “medium reach” case.



**Fig. 2:** Bit-error rate performance of LDPC coding for the “long reach” case.

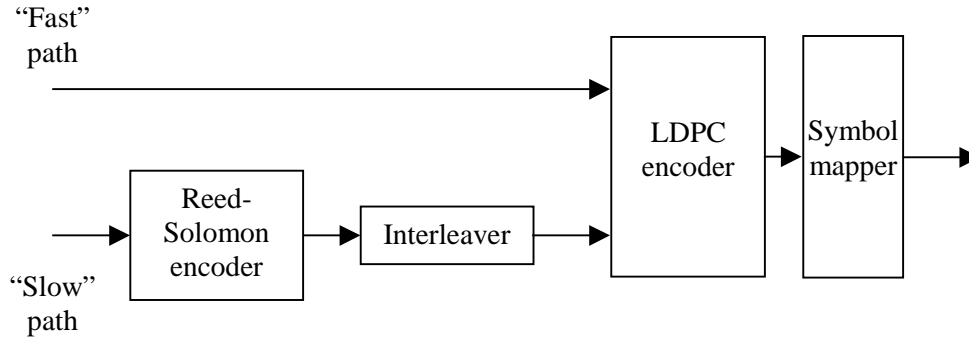
The results of Figs. 1 and 2 are summarized in Table 2 in terms of net coding gain at a BER of  $10^{-7}$  (no outer RS coding is assumed).

Reach	Latency	Net coding gain at BER = $10^{-7}$
Medium	0.5 ms	4.7 dB
	10 ms	6.0 dB
Long	0.5 ms	3.7 dB
	10 ms	6.4 dB

**Table 2:** Net coding gains achieved by LDPC coding for the nonflat SNR cases.

## **4. Dual-latency path configuration**

The dual-latency path configuration that we recommend to use in conjunction with LDPC coding is depicted in Fig. 3.



**Fig. 3:** Dual-latency path configuration for LDPC encoding.

LDPC encoding of both fast-path and slow-path binary streams is performed. The fast path offers good error-correction capability due to the LDPC code but avoids the use of an outer RS code with interleaving. It is used for low-latency connections that do not require full protection against impulse noise. The slow path offers both good error-correction capability and increased robustness to impulse noise due to the presence of an outer RS code with interleaving.

Clearly, this structure is similar to the one specified in the current ADSL Recommendation, where the LDPC encoder is replaced with a trellis-code encoder.

It is important to note that for the configuration of Fig. 3 to operate in a satisfactory fashion over the fast path, the "inner" code must be capable of providing "full performance" without relying on the presence of an outer Reed-Solomon code. For example, inner coding schemes that rely on an outer RS code to mitigate the effects of error floors are not suited to the above architecture. On the contrary, LDPC codes are well-suited as they avoid the error-floor problem, as shown, e.g., in [1]-[4].

## **5. Summary and conclusions**

We have shown that LDPC coding achieves good coding gains under latency constraints assuming flat as well as nonflat, linearly decreasing SNR profiles. We have also described the architecture that we propose to use for a dual-latency path configuration.

The results presented in this contribution, together with the results given in the earlier contributions referenced at the end of this text, fully address the set of requirements set forth for proposals on advanced coding.

This contribution pertains to G.gen, G.dmt.bis, and G.lite.bis. It is provided for information only.

## References

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