BLIND-EQUALISED AND TURBO CODED SATELLITE BASED DIGITAL VIDEO BROADCASTING

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ABSTRACT

The Pan-European Digital Satellite Video Broadcasting (DVB-S) system's performance is characterised. Various configurations of blind equalisers and convolutional codecs operating at different code rates were investigated. The standard system's performance was improved upon replacing the conventional convolutional codec by a turbo codec. Lastly, the feasibility of employing 16-level Quadrature Amplitude Modulation (16-QAM) within the DVB-S system is demonstrated, potentially doubling the available bitrate hence improving the associated video quality at the cost of a higher Signal-to-Noise Ratio (SNR) requirement. This extra transmitted power requirement can be eliminated upon invoking a similar complexity turbo codec, which requires lower transmitted power for attaining the same performance as the standard convolutional codes.

1. BACKGROUND AND MOTIVATION

The Pan-European Digital Video Broadcasting (DVB) standards designed for terrestrial [1], cable-based [2] and satellite-oriented [3] transmission of DVB signals have been harmonised with each other, in order to maintain seamless transport of video signal. These standardisation activities were followed by a variety of system performance studies in the open literature [4, 5, 6, 7]. Against this backcloth, in this treatise we proposed turbo-coding based improvements to the satellite-based DVB system [3] and studied the performance of the proposed system under dispersive channel conditions in conjunction with a variety of blind channel equalisation algorithms. The transmitted power requirements of the standard convolutional codecs can be reduced upon invoking a similar-complexity turbo codec. More explicitly, the complexity of the constraint-length 7 convolutional code and that of the constraint-length 3 turbo code is similar, since there are two turbo decoders, which are invoked eight times during the eight iterations. Hence the number of trellis states encountered by the concolutional and turbo decoders is similar. Alternatively, the standard system's bit error rate (BER) versus signal-to-noise ratio (SNR) performance can almost be matched by a turbo-coded 16-level quadrature amplitude modulation (16QAM) based scheme, whilst doubling the achievable bit rate within the same bandwidth and hence improving the associated video quality. This is achieved at the cost of an increased system complexity.

The remainder of the paper is organised as follows. A terse overview of the turbo-coded and standard DVB satellite scheme is presented in Section 2. Following this, the performance of the improved DVB satellite system was examined over a dispersive two-path channel in Section 3, before our conclusions and future work areas were presented in Section 4.

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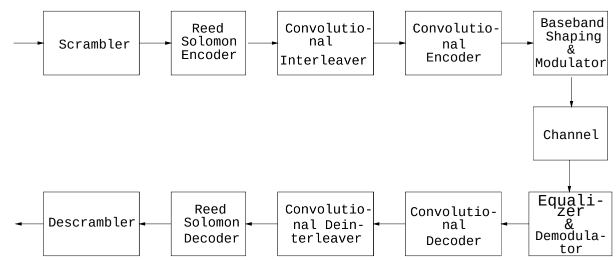

Figure 1: Schematic of the DVB satellite transmitter functions.

2. DVB SATELLITE SCHEME

The schematic of the DVB satellite (DVB-S) system [3] is portrayed in Figure 1. The MPEG-2 encoded video bit stream is channel encoded and QPSK modulated [8]. In order to protect the MPEG-2 video coded stream, powerful concatenated channel coding is invoked, constituted by a shortened Reed-Solomon RS(204,188) outer code [9], which corrects up to eight corrupted 8-bit symbols in a block of 204 bytes, and a half-rate inner convolutional encoder having a constraint length of 7 [9, 10]. A variable puncturer - not shown in the figure - can also be invoked, which supports code rates of 1/2 (no puncturing) as well as 2/3, 3/4, 5/6 and 7/8. The convolutional encoder's parameters are portrayed in Table 1.

The standard DVB-S system was invoked as a benchmarker and we have improved the standard system's performance by replacing the convolutional codec by a turbo codec [11] [12] employing the parameters summarised in Table 2. Readers interested in further details of the DVB-S

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Rate	1/2
Constraint Length	7
k	1
n	2
Polynomials (octal)	171,133

Table 1: Parameters of the CC(n,k,K) convolutional inner encoder in the DVB-S modem.

Rate	1/2
Input block length	17952 bits
Interleaver	random
Number of iterations	8
Constraint Length	3
k	1
n	2
Polynomials (octal)	7,5

Table 2: Parameters of the inner turbo encoder used to replace the DVB-S system's convolutional coder.

system are referred to the DVB-S standard [3].

The properties of the satellite channel have been characterised for example by Vogel and his colleagues [13, 14, 15, 16]. The channel model employed in this study was the two-path (nT)-symbol spaced channel impulse response (CIR), where T is the symbol-duration and in our studies we used $n = 1$ and $n = 2$. This corresponds to a stationary dispersive transmission channel. Our channel model assumed that the receiver had a direct line-of-sight with the satellite as well as a second path caused by a single reflector. In our work, we studied the ability of a range of blind equaliser algorithms to converge under various path delay conditions. The blind equalisers used in the system are as follows:

- The Modified Constant Modulus Algorithm (or Modified CMA) [17]
- The Benveniste-Goursat Algorithm (or B-G) [18]
- The Stop-and-Go algorithm [19]
- The Per-Survivor Processing (PSP) Algorithm [20]

A summary of the equalisers' parameters is given in Table 3.

	Equal. Tap Update Step–Size	No. of Equal. Taps	Initial Tap–Vector
Benveniste-Goursat	$5x10^{-4}$	10	$(1.2, 0, \cdots, 0)$
Modified-CMA	$5x10^{-4}$	10	$(1.2, 0, \cdots, 0)$
Stop-and-Go	$5x10^{-4}$	10	$(1.2, 0, \cdots, 0)$
PSP (1 sym delay)	10^{-2}	2	$(1.2, 0)$
PSP (2 sym delay)	10^{-2}	3	$(1.2, 0, 0)$

Table 3: Summary of the equaliser parameters used in the simulations. The tap–bector $(1.2, 0, \cdots, 0)$ indicates that the first equaliser coefficient is initialised to the value 1.2, while the others to 0

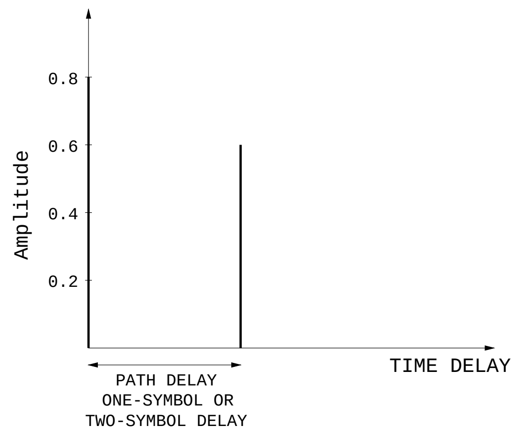

Figure 2: Two-path satellite channel model with either a one-symbol or two-symbol delay.

3. PERFORMANCE OF THE DVB SATELLITE SCHEME

In this section, the performance of the DVB-S system was evaluated by means of simulations. Two modulation types were used, i.e. QPSK and 16-QAM [8], and the channel model of Figure 2 was employed. The first channel model had a one-symbol second-path delay, while in the second one the path-delay corresponded to the period of two symbols. The average BER versus SNR per bit performance is presented after the equalisation and demodulation process, as well as after Viterbi [9] or turbo decoding [12].

The average BER curves after Viterbi or turbo decoding are shown in Figure 3 for QPSK. In this figure, the average BER over the non-dispersive AWGN channel after turbo decoding constitutes the best case performance, while the average BER of the one-symbol delay two-path unequalised channel after turbo decoding corresponds to the worst case performance. Again, in this figure only the Modified-CMA was featured for simplicity. The performance of the remaining equalisers was similar and hence it is not explicitly shown.

It is observed in Figure 3 that the combination of the Modified CMA based blind equaliser with turbo decoding exhibited the best SNR performance in conjunction with QPSK. The only comparable alternative was the PSP algorithm. Although the performance of the PSP algorithm is better at low SNRs, the associated curves cross over and the PSP algorithm's performance becomes inferior after the average BER becomes approximately 10^{-3}. Although not shown in Figure 3, the Reed-Solomon decoder, which was concatenated to either the convolutional or the turbo decoder, yielding typically an error-free output after the average BER of its input reached approximately 10^{-4}. In this case, the PSP algorithm performed worse in channel SNR terms by at least 1 dB in the area of interest, which is at an average BER of 10^{-4}. A final observation in the context of QPSK in Figure 3 is that when convolutional decoding is used, the associated E_b/N_o performance of the rate 1/2 scheme appears inferior to that of the rate 3/4 and the rate 7/8 scenarios beyond certain E_b/N_o values due to the high proportion of redundant bits.

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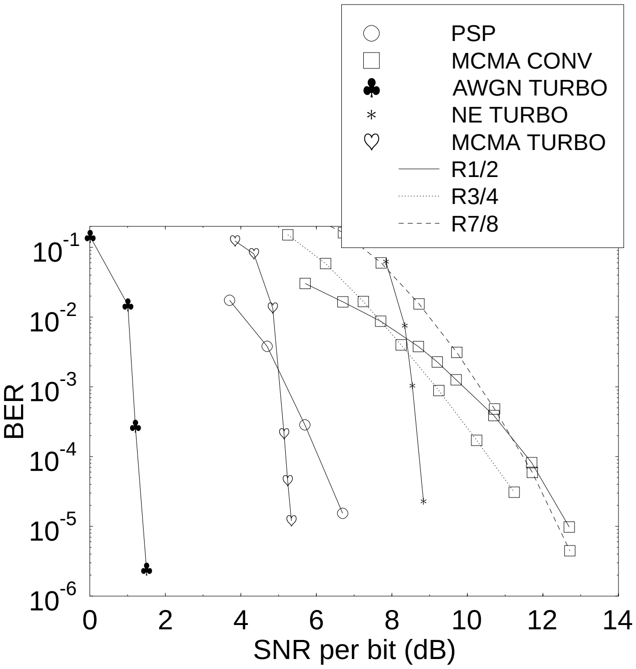

Figure 3: Average BER versus SNR per bit performance after convolutional or turbo decoding for **QPSK** modulation and **one-symbol delay CIR** (NE: Non-Equalised B-G: Benveniste-Goursat S-a-G: Stop-and-Go MCMA: Modified Constant Modulus Algorithm PSP: Per-Survivor-Processing).

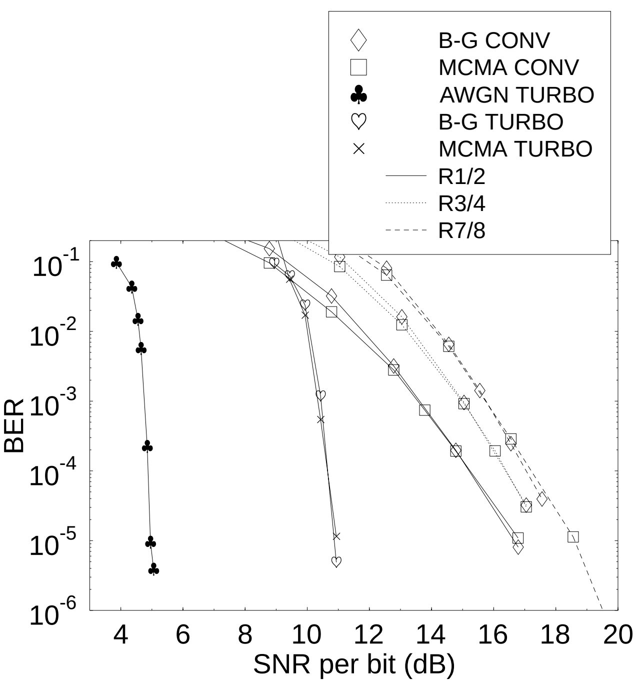

Figure 4: Average BER versus SNR per bit after Viterbi or turbo decoding for **16-QAM** and the **one-symbol delay two-path CIR** of Figure 2.

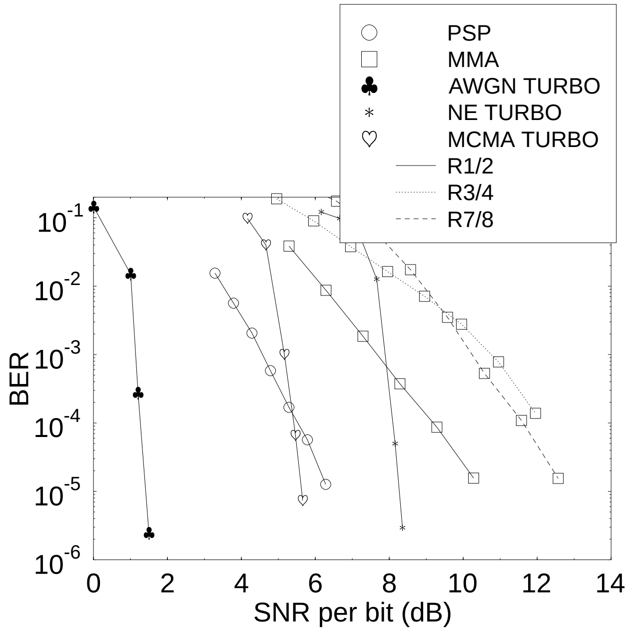

Figure 5: Average BER versus SNR per bit performance after convolutional or turbo decoding for **QPSK** modulation over the **two-symbol delay two-path CIR** of Figure 2.

In Figure 4, the corresponding BER curves are given for 16-QAM, under the same channel and equaliser conditions. The Stop-and-Go algorithm has been excluded from these experiments, since it does not converge for high SNR values. This happens because this procedure is only activated, when there is a high probability of correct equaliser coefficient update. In our case, the equaliser is initialised far from its convergence point and hence the decision–directed updates are unlikely to provide correct equaliser coefficient updates. In the absence of noise this leads to the algorithm being permanently de-activated. If noise is present though, then some random perturbations from the point of the equaliser's initialization can activate the algorithm and can lead to convergence. This was our observation at medium SNR values. But again, for high SNR values the algorithm does not converge.

It is also interesting to compare the performance of the system for the QPSK and 16-QAM schemes investigated. When the one-symbol delay two-path channel model of Figure 2 was considered, the system was capable of supporting the use of 16-QAM with the provision of an additional E_b/N_o of 5 dB. *Although the DVB-Satellite standard system only employs QPSK modulation, our simulations showed that - especially with the advent of turbo coding - 16-QAM can be employed equally well. This allows us to double the video bitrate and hence improve its quality.* The comparison of Figures 3 and 4 also reveals that the extra SNR requirement of 5 dB for 16QAM over QPSK can be eliminated by employing turbo coding at the cost of a similar implementational complexity.

In Figure 5 the corresponding BER results for the two-symbol delay two-path channel of Figure 2 are given for QPSK. This figure is similar to Figure 3 in terms of its trends. However, the "cross-over point", beyond which the

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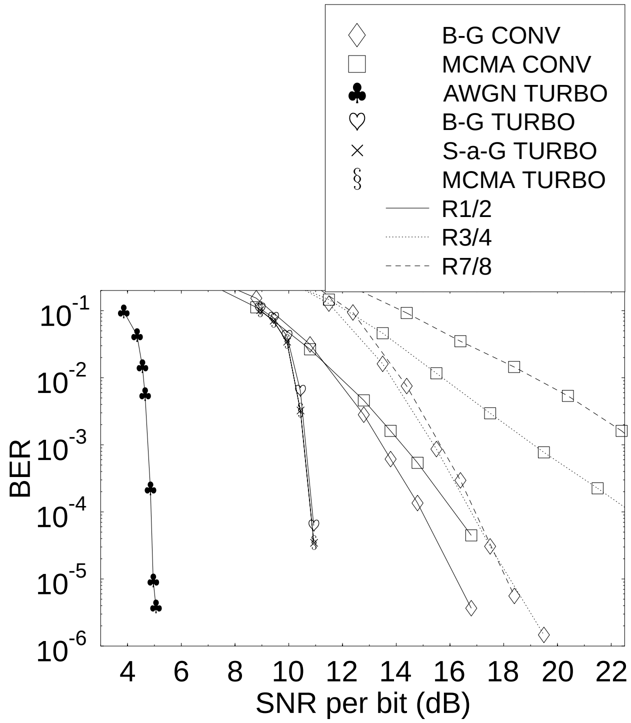


Figure 6: Average BER versus SNR per bit performance (a) after equalisation and demodulation and (b) after Viterbi or turbo decoding for **16-QAM** over the **two-symbol delay two-path CIR** of Figure 2.

performance of the PSP algorithm becomes worse, than that of the Modified CMA in conjunction with turbo decoding is now at 10^{-4}, which is in the area where the RS decoder provides an error-free output.

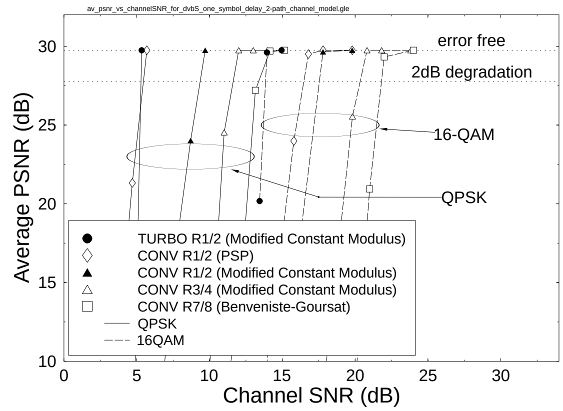
Finally, in Figure 6 the associated 16-QAM results are presented. Notice that the Stop-and-Go algorithm was again excluded from these results. We can observe the high performance difference between the B-G and the Modified CMA.

In the previous cases we did not observe such a significant difference. The difference in this case is that the channel exhibits an increased delay spread. This illustrates the capability of the equalisers to cope with more widespread multipaths, keeping their length constant. The Benveniste-Goursat equaliser is more efficient than the Modified CMA in this case.

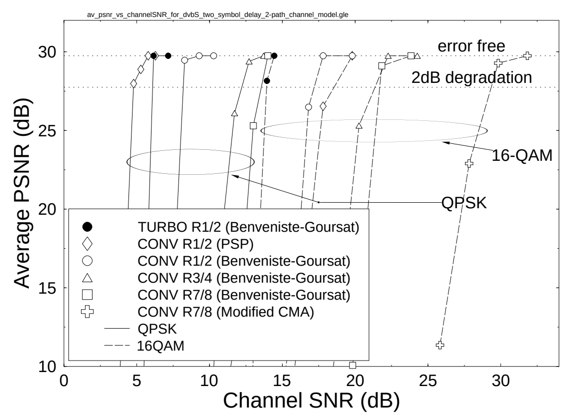
If we compare the performance of the system employing QPSK and 16-QAM under the two-symbol delay two-path channel model of Figure 2, we again observe that 16-QAM can be incorporated into the DVB system, if an extra 5 dB of SNR per bit is affordable in power budget terms. However, only the B-G algorithm is worthwhile considering here out of the three linear equalisers used in our work.

Figure 7 portrays the corresponding reconstructed video performance in terms of the average peak signal-to-noise ratio (PSNR) versus channel SNR for the one-symbol delay and two-symbol delay two-path channel model of Figure 2. The average PSNR is defined as follows:

$$\mathrm{PSNR} = 10log_{10}\frac{\sum_{n=0}^{N}\sum_{m=0}^{M}255^2}{\sum_{n=0}^{N}\sum_{m=0}^{M}\Delta^2} \qquad (1)$$



(a) One-symbol delay two-path channel model



(b) Two-symbol delay two-path channel model

Figure 7: Average PSNR versus channel SNR for (a) one-symbol delay two-path channel model and (b) two-symbol delay two-path channel model of Figure 2.

where Δ is the difference between the uncoded pixel value and the reconstructed pixel value.

Table 4 provides an approximation of the convergence speed of each algorithm for each case. It is clear that PSP exhibited the fastest convergence, followed by the Benveniste-Goursat algorithm. In our simulations the convergence was quantified by measuring the slope of the BER curve, as this curve was reaching the associated residual BER, implying that the BER has reached steady-state. The Stop-and-Go algorithm converges significantly slower, than the other algorithms, which can also be seen from Table 4. This happens because during the startup the algorithm is deactivated most of the time, an effect which becomes more severe with an increasing QAM order.

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	B-G	MCMA	S-a-G	PSP
QPSK 1 sym	$2 \cdot 10^5$	$4.4 \cdot 10^5$	$2.6 \cdot 10^5$	380
QPSK 2 sym	$2 \cdot 10^5$	$3.9 \cdot 10^5$	$2.1 \cdot 10^5$	380
16-QAM 1 sym	$5.6 \cdot 10^5$	$8.8 \cdot 10^5$	$19 \cdot 10^5$	
16-QAM 2 sym	$4.9 \cdot 10^5$	$5.6 \cdot 10^5$	$18 \cdot 10^5$	

Table 4: Equaliser convergence speed measured in the simulations, given as the number of bits required for convergence (x sym: x-symbol delay two-path channel).

4. CONCLUSIONS AND FUTURE WORK

In this contribution, we have investigated the performance of a turbo-coded DVB system in a satellite broadcast environment. A range of system performance results was presented based on the standard DVB-S scheme, as well as on a turbo-coded scheme in conjunction with blind-equalised QPSK/16QAM. The convolutional code specified in the standard system was substituted by turbo coding, which resulted in a substantial coding gain of around 4-5 dB. We have also shown that 16-QAM can be utilised instead of QPSK, if an extra 5 dB SNR per bit gain is added to the link budget. This extra transmitted power requirement can be eliminated upon invoking a similar-complexity turbo codec, which requires lower transmitted power for attaining the same performance as the standard convolutional codecs. Our future work will be focused on extending the DVB-Satellite system to supporting mobile users for the reception of satellite broadcast signals. The use of turbo equalisers will also be investigated in comparison to blind equalisers. Further work will also be dedicated to trellis coded modulation (TCM) and turbo trellis coded modulation (TTCM) based orthogonal frequency division multiplexed (OFDM) and single-carrier equalised modems. A range of further related wireless video communications aspects are treated in [21].

5. ACKNOWLEDGEMENT

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