Using turbocodes on optical links

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ABSTRACT

The fast evolving telecommunication world is permanently in search for faster and better communication links. On one hand, turbo codes are like a dream come true. Due to their amazing performance, they have become the reference in the word of error detecting and correcting codes. On the other hand, broadband transmission channels like optical fibres can meet the need for higher transmission velocity.
In this paper therefore we will bring these two elements together and thus the performance of turbocodes on optical links will be studied. First the turbocode will be optimised throughout an individual analysis of each of its design parameters. Moreover it wil be shown that turbocodes have much better performance than the well known Reed-Solomon codes. Finally we will show that the 8Bit/10Bit code, which is required to comply with the Gigabit Ethernet standard, becomes superfluous when working with turbocodes.
All tests were carried out on multimode graded-index glass fibres.

Keywords: Concatenated codes, turbo codes, optical fibre, Reed-Solomon codes, 8B/10B code, Gigabit Ethernet.

1. INTRODUCTION

Turbocodes are a type of channel codes, a means of protecting information against errors on its way through the transmission channel. As on all other transmission channels, errors will be introduced on optical fibres due to the signal degradation which light pulses experience when travelling through the optical medium. The goal of the turbocode is to decrease this number of transmitted errors.
As turbocodes are forward error correcting (FEC) codes, redundant bits have to be added to the real information that one whiches to send to a certain destination. This redundant information, obtained through a mathematical treatment of the original data, will allow the correction of a certain number of transmission errors.

2. TURBOCODES

More precisely turbocodes are a refinement of concatenated codes, as constituent codes are used in parallel or in series. The refinement lies in the use of soft decisions in an iterative decoding process. For binary transmission channels (when only 0's and 1's are transmitted), a soft decision is a real number where the hard decision (the decision 0 or 1) is characterized by its sign and where the size indicates the certainty (confidence) of its hard decision.
Logically a soft decision gives more information than a hard decision. On the other hand the decoding process is very complex and needs a lot of calculations.
The turbo code that was used in this article consists of the parallel concatenation of two identical rate 1/2 Recursive Systematic Convolutional (RSC) encoders, with between them an interleaver. Hence the rate of the turbocode, which is shown in Fig. 1, is 1/3.

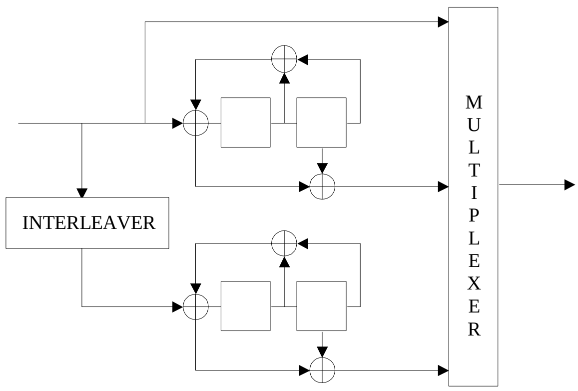

Fig. 1: Turbo code with 2 identical (5,7) RSC-codes

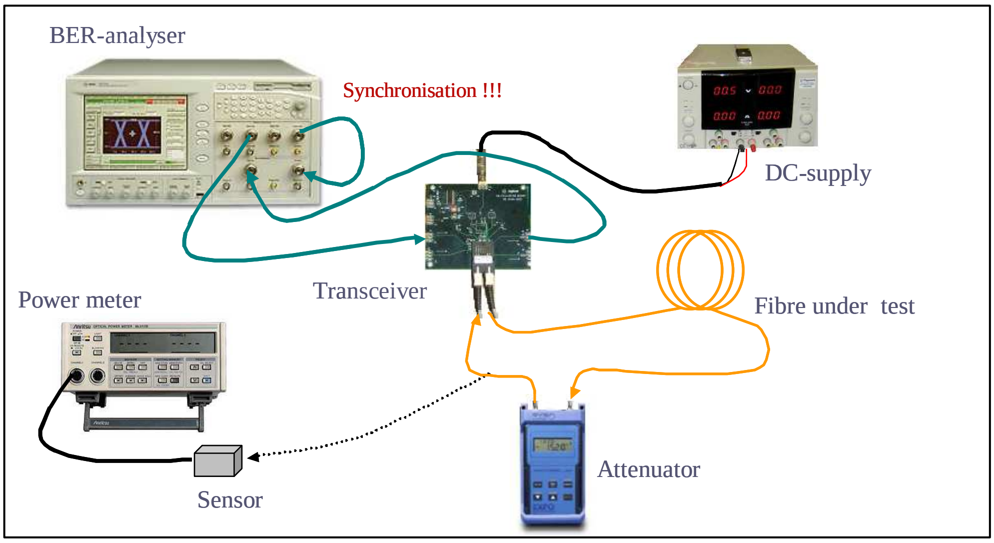

Fig. 2: Test set-up

3. TEST SET-UP

The goal of our tests is to relate the bit error rate (BER) to the power at the entrance of the optical receiver and to evaluate in what way the BER can be decreased by use of turbocodes.
The test set-up, as illustrated in Fig. 2 is conceived in such a way that for every measurement, the BER and power at the receiver side is measured.
The Error Performance analyzer measures the BER over the optical link under test. It compares the received data pattern (with errors) with the original one and calculates the bit error rate. The analyser also provides the user with some statistical information about block errors, burst errors and important for this paper, pattern sensitivity. An analysis of this pattern sensitivity allows to display pattern dependencies and to locate where errors occur. As the analyzer needs electrical data, a tranceiver is used to convert the electrical signals to optical data and vice versa at the receiver. The transceiver Evaluation Board also consists of an 850nm VCSEL and a silicon PIN photodiode.
The DUT (Device Under Test) is a graded-index multimode glass fibre that fulfils the Gigabit Ethernet standard. The attenuator was used to simulate different values of the power at the receiver side and thus different numbers of errors.
Since Coding and decoding is not one of the features provided by the Error Analyzer, a MATLAB-program was used to create and encode patterns which are uploaded into the Analyzer. As the analyzer has a limited memory, it cannot stock the entire erroneous pattern, so another MATLAB program was used to recreate a worst-case erroneous pattern for decoding.

4. PERFORMANCE MAXIMISATION

As explained, the first goal of this article is to optimise the turbocode. This was realised by submitting each building block of the turbocode to an individual analysis. As can be seen in Fig. 1, several design parameters are to be examined, such as the length and the type of interleaver, the generator vectors of the RSC-codes, a homogeneous or heterogeneous composition of the constituent codes, the decoding algorithm, etc. Of course the maximisation of the performance of turbocodes may not only consider its own design parameters, but one has to make sure that the resulting error correcting capacity is adapted to the expected number of errors on the transmission link. An over-designed error correcting code is useless and introduces great overhead and thus delays. Our tests have lead to a homogeneous use of RSC-codes with generator vector (5,7) (as in Fig. 1) and a random interleaver. Moreover all tests were carried out using the Log-MAP decoding algorithm.

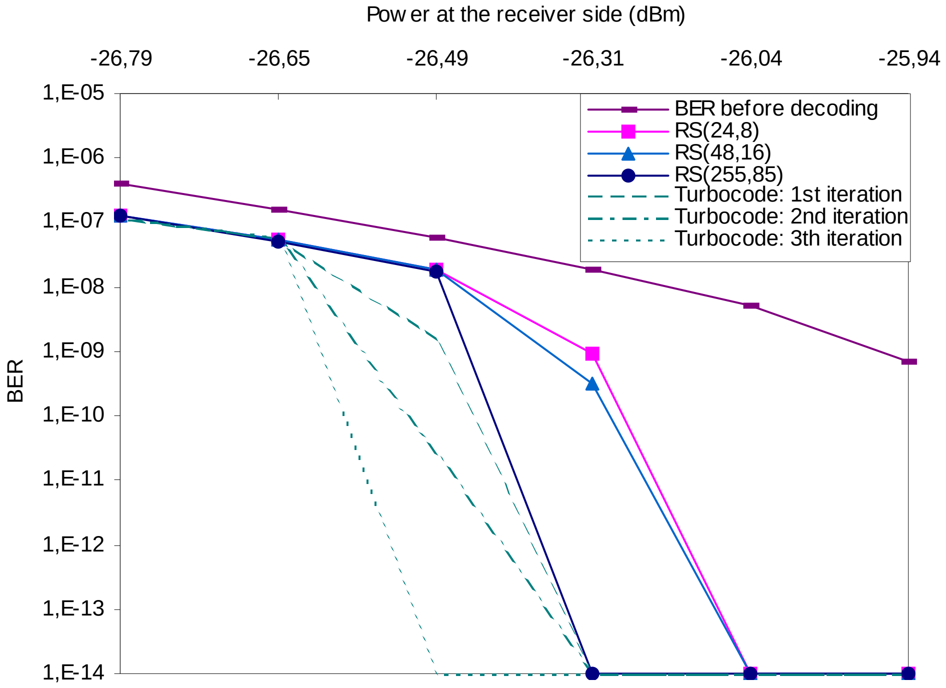

Fig. 3: Comparison between RS-codes and Turbo codes

5. COMPARISON BETWEEN REED-SOLOMON CODES AND TURBO CODES

To examine if turbo codes are competitive with the existing error correcting codes, a comparison with the well known Reed-Solomon codes is needed. To make an honest comparison between these two channel codes, one has to make sure they are provided with the same overhead to protect their data.
Hence we must choose a Reed-Solomon code with the same code rate as our turbo code. This has lead to the RS(48,16) and RS(24,8) codes. As RS(n,k) codes add n-k bytes to each block of k bytes, the coding rate of these selected codes is indeed 1/3. To compare the turbo code with a very powerfull, but scarsely used RS-code, the performance of the RS(255,85) is also plotted. In Fig. 3 one can see clearly that the performance of the turbocode exceeds that of all RS-codes with shining colours, and this already after a single iteration. For the same power obtained at the receiver side, the BER of the turbocode is much lower than that of each of the RS-codes.

6. ARE TURBOCODES TO BE USED IN COMBINATION WITH GIGABIT ETHERNET ?

As Gigbit Ethernet has become the most popular network technology, we studied the performance of turbocodes on a Gigabit Ethernet link. As stated earlier, to comply with this standard a supplementary encoding is needed, i.e. the 8Bit/10Bit code. This code, which is integrated in Gigabit Ethernet for its favourable DC-balancing characteristic, converts each 8-bit information block into a code word of 10 bits. The resulting coded sequence must be DC-balanced. Hence the number of ones and zeros transmitted through the fibre will be equal, so the overall DC-component will be nearly zero. Moreover each codeword has to exhibit a certain number of transitions (from 0 to 1 and vice versa), which improves synchronisation.
We now have to examine if the 8B/10B code helps the turbocode accomplish even better error-correcting performances than without the use of this code. The study of the influence of this 8B/10B code on the performance of turbocodes was divided into two steps. First the influence of (the DC-balancing characteristic of the) 8B/10B coding on the error introduction was examined. In Fig. 4 one can clearly see that the optical receiver can make a better decision with than without the 8B/10B code. The error level is clearly much lower when the 8B/10B code is used together with the turbocode.

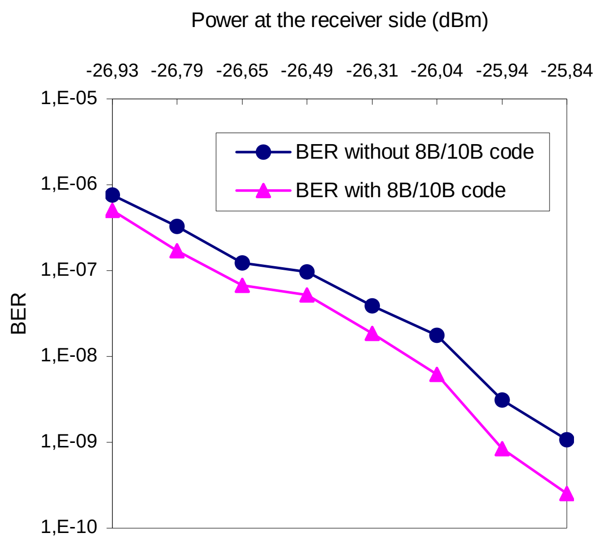

Fig. 4: Influence of the 8B/10B coding on the error introduction

Now the influence of the 8B/10B decoding process on the error level must be considered. Logically much more code words can be created with 10 bits than with 8 bits. Hence, if a 10-bit word is received that is not a codeword (does not appear in the lookup table), we will probably decode incorrectly and supplementary errors will be introduced.

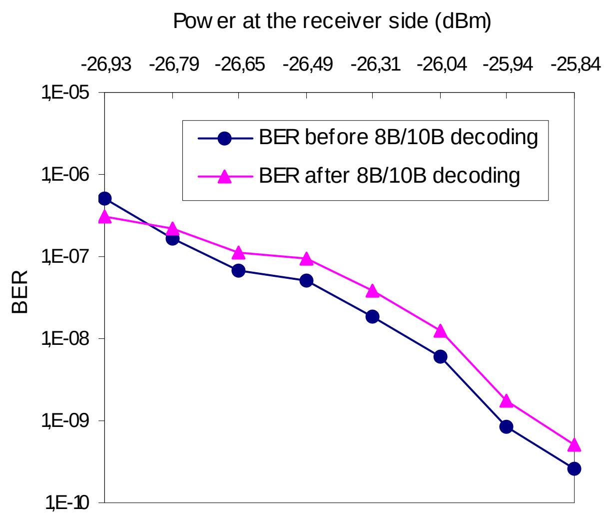

Fig. 5: Influence of 8B/10B decoding on the error level

In Fig. 5 this reasoning is clearly confirmed as the error level after decoding is much higher than that before decoding.
The question is wheter this negative effect of decoding will undo the positive effect built up by DC-balancing. Fig. 6 shows that is not the case, especially for very high and very low error quantities.

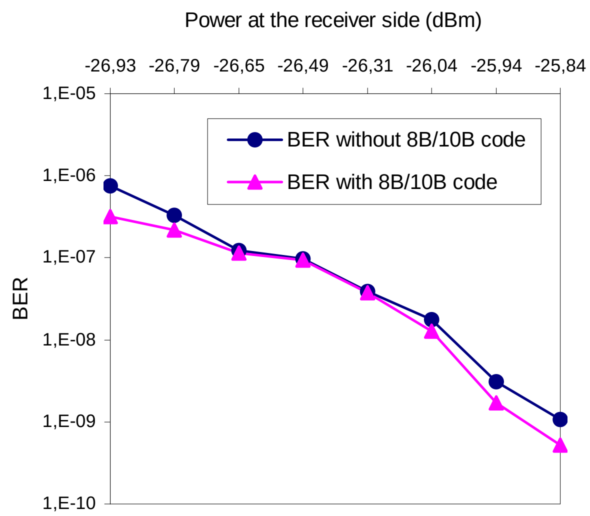

Fig. 6: Influence of 8B/10B code on error level

Moreover the errors introduced by the 8B/10B decoding process are mainly block errors, while the errors in the turbocoded stream are randomly distributed. These block errors are also caused by the 'univocal' relation between the 8-bit words and the 10-bit codewords in the lookup table. Indeed, if a 10-bit word with one error is received, in the worst case the decoded word wil be entirely wrong and hence contain 8 errors. To limit the length of this block errors, the 8B/10B code has been split up in a 3B/4B code for the most significant bits and a 5B/6B code for the least significant ones. This solution limits the worst-case blok error length to 5 bits.
Nevertheless these block errors will have a bad influence on the performance of the turbocode. Moreover this bad influence is larger as the original number of errors is lower. The chance that the random distributed errors in this case result in a block error is as well as non-existent.
Conclusions can only be drawn after application of the turbodecoding. Then only we can decide wheter the 8B/10B code and the turbocode are to be used together.
The performance difference due to the 8B/10B code is shown in Fig. 7.
One can see that the 8B/10B code ony has a positive influence in case the number of errors is high. For a small number of errors, the positive effect of DC-balancing is nearly completely annulated by the combined negative influence of 8B/10B decoding itself and the block errors introduced by it.

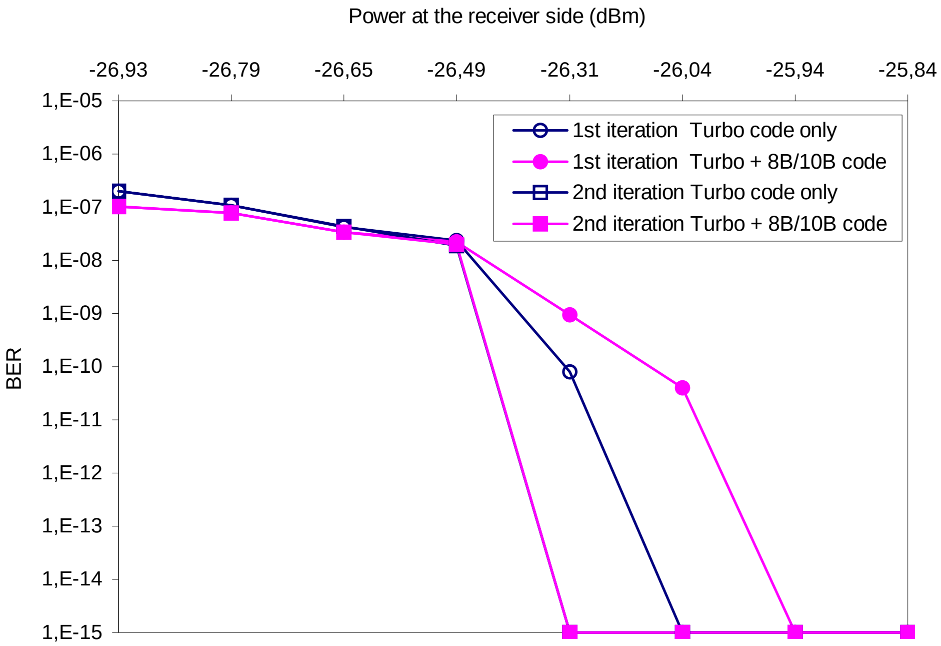

Fig. 7: Influence of 8B/10B code on the performance of the Turbo code

7. CONCLUSIONS

We can conclude that a well-considered choice of the design parameters of the turbo code is essential, since it brings a great improvement of its performance. Moreover turbocodes exceed clearly the performance of the well known Reed-Solomon codes, even if the turbocode is not optimised. Finally we can conclude that the combined use of the 8B/10B code and turbocodes is only positive when a great number of errors is introduced on the optical link. Therefore a combined use of turbocodes and the 8B/10B code is only advisable for bad communication links, which is however very improbable for optical fibres (and hence for local area networks). Nevertheless if one whishes to use turbocodes on a Gigabit Ethernet LAN, we advise not to apply the 8B/10B code. However this implies a violation/modification the of Gigabit Ethernet standard.

8. REFERENCES

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