On the robustness of a joint source-channel coding scheme for image transmission over non frequency selective Rayleigh fading channels

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Abstract

The aim of this paper is to present a joint source channel coding scheme for image transmission over a non frequency selective Rayleigh fading channel. Because of the very high BER, a JPEG or JPEG2000 compressed image cannot be transmitted without major visual degradation quality. On the one hand we use a compression algorithm based on Wavelet Transform and Vector Quantization called WTSOM (Wavelet Transform Self Organized Map), and on the other hand we combine differential modulation, symbol interleaving, unequal error protection and antenna diversity to improve the performance of the transmission. The results show a relation between the received images PSNR and the normalized Doppler frequency of the Rayleigh channel. The performance of this joint source channel scheme allows us to obtain a good visual quality of the images even with very bad transmissions conditions

1. Introduction

In this paper we study the behaviour of a joint source channel coding scheme for images transmission, initially designed for AWGN channel, over a Rayleigh fading channel with very high BER (1%). In section 2 we briefly describe this coding scheme called WTSOM (Wavelet Transform Self Organize Map) and present its good performances on the AWGN channel. The Rayleigh channel constraints are presented in section 3, and methods based on differential modulation used to circumvent them are implemented in section 4. The complete transmission chain is studied in section 5 and we derive a relation between the received images PSNR and the normalized Doppler frequency of the channel in subsection 5.1. These results depend on a Reed-Solomon error correcting code which may be linked to an interleaver. A simple antenna diversity scheme is presented in subsection 5.2 which permits a transmission with a much lower signal to noise ratio with the same visual quality, and finally, a discussion and conclusions section appears as section 6.

2. WTSOM source channel coding

In order to achieve a robust joint source-channel coding scheme for image transmission, several authors have proposed an association between a Vector Quantization (VQ) and a square QAM modulation [1,2,3]. The visual quality of the images depends on the size and the number of vectors in the codebook. We have recently proposed an original joint source channel code which applies the VQ on different sub images of wavelet decomposition. A practical way of decomposing a signal into its wavelet coefficients is to apply a filter bank, which in our 2-D case can be represented by Fig. 1. I(x, y) is the original image, G is a high-pass filter (applied along x then along y), H is a low-pass filter (applied along x then along y). H and G can be built so that they permit a perfect reconstruction of the original image. This first level of decomposition leads to:

- HH_1: sub image of the diagonal details at scale 1
- HL_1: sub image of the vertical details at scale 1
- LH_1: sub image of the horizontal details at scale 1
- LL_1: low-resolution sub image at scale 1.

This filter bank can be re-applied n times starting from LL_1, to produce the detail and low-resolution sub images at scale *n* as shown in Fig. 1.

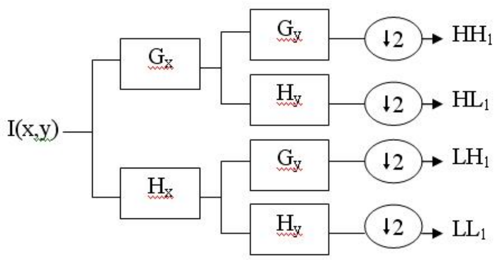

Fig. 1: Filter bank for wavelet decomposition of an image at the first scale (↓ 2 =decimation by 2).

In our application, we use the Daubechies (9/7) biorthogonal wavelets such as in the JPEG 2000 case [4]. The coordinates in the wavelet series are computed with a different dual set of basis functions. Such wavelet decomposition at scale 2 is shown in Fig. 2.

Fig. 2: Wavelet decomposition of an image at scale 2.

From wavelet decomposition at scale three, we preserve the five most significant sub images on which we apply a specific VQ with five codebooks. The corresponding transmission chain is represented in Fig. 3, each codebook contains 256 vectors and only the vectors indices are transmitted.

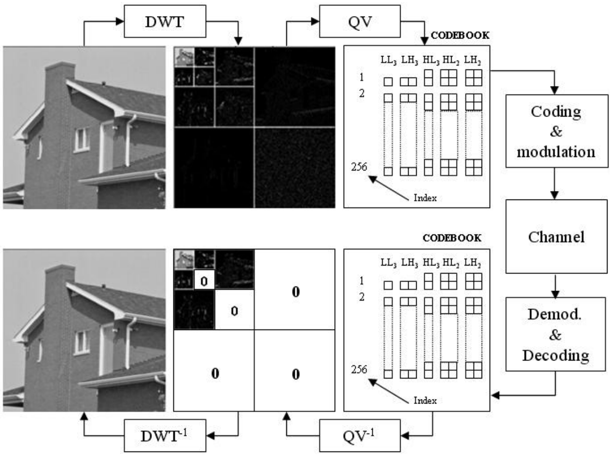

Fig. 3 : WTSOM transmission chain.

Thanks to the WT part, we obtain a high compression rate (in the order of 25) whereas the SOM algorithm yields good transmission performances even with high BER due to the induced neighbourhood relations among indices [5]. Fig. 4 shows the result of an image transmission for JPEG (a) and JPEG2000 (b) with a low bit error rate (BER=10^{-4}) where the file headers are not corrupted and for WTSOM (c) for a high BER of 10^{-2}.

(a) PSNR = 9.96 dB

(b) PSNR = 13.81 dB

(c) PSNR = 26.83 dB

Fig. 4: Image transmission through AWGN channel

(a) JPEG, BER = $1x10^{-4}$, PSNR = 9.96 dB
(b) JPEG2000, BER = $1x10^{-4}$, PSNR = 13.8 dB
(c) WTSOM, BER = $1.2x10^{-2}$, PSNR = 26.83 dB

In the case of an AWGN channel, the robustness of this method is clearly shown: the gain in PSNR is greater than 13 dB in comparison with JPEG and JPEG2000 for the same compression rate and for a higher BER. It is well known that the Rayleigh fading channel is much more challenging than the AWGN channel. We therefore propose solutions for mobile communications using the WTSOM scheme in the next sections.

3. Rayleigh channel transmission model

The results shown in the next sections were obtained by computer simulations of a wide sense uncorrelated scattering (WSSUS) Rayleigh fading channel. The received signal in the complex baseband is given by:

$$z_k(t) = a_k(t) \cdot e^{j\theta_k(t)} \cdot s_k(t) + n_k(t)$$

where $a_k(t) \cdot e^{j\theta_k(t)}$ with $\left|a_k^2(t)\right| = 1$ is a Rayleigh faded complex envelope, $n_k(t)$ represents the filtered additive white Gaussian noise (AWGN) and $s_k(t)$ is the transmitted signal. In the following sections we evaluate the robustness of the WTSOM algorithm when transmitted on this channel for the following normalised Doppler frequency $f_D T_s$ range:

$$0.0001 < f_D T_s < 0.04$$

We will focus on situations where neither channel state information nor reliable estimation of the carrier phase is available at the receiver side. In these situations, coherent QAM modulation schemes are not appropriate as Fig. 5 suggests.

a) AWGN BER = 1.2%

b) Rayleigh $f_D T_s = 0.001$ BER = 46%

Fig. 5: WTSOM transmission using 16QAM

The disastrous effect shown on Fig. 5 b) is mainly due to the random phase added by the Rayleigh channel to the 16QAM transmitted signal.

4. Rayleigh channel and differential modulations

Differential modulation/demodulation techniques have prooved to be very robust due to the fact that they can mitigate the phase distortions caused by fading. Moreover, as no channel estimation is needed, the system complexity is reduced significantly.

In order to have a bandwidth efficiency comparable to the AWGN channel case, we consider the use of a 16 points constellation that may be differentially encoded and decoded. This scheme is known as 16 Star QAM [6] or 16DAPSK (Differential Amplitude and Phase Shift Keying)[7]. 16DAPSK uses a combination of independent 2DASK and 8DPSK. Three of the four bits are modulated by a Gray encoded 8DPSK. The remaining bit is amplitude modulated by a 2DASK scheme: a “0” doesn’t change the amplitude while a “1” changes it. The following figure shows the signal constellation of the 16DASPK modulation:

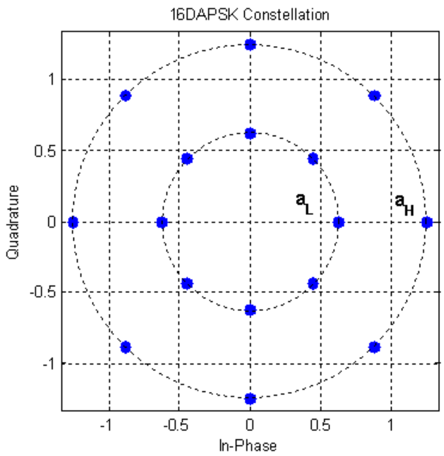

Fig. 6: 16DAPSK signal constellation

As can be seen in Fig. 6, the constellation is made up of two concentric rings having radius a_L for the inner ring and a_H for the outer ring. An important caracteristic of 16DAPSK is its ring ratio rr = a_H/a_L which has to be optimized for each Eb/N_0. However our simulations have shown that a value of 2 is optimum for quite a wide range of signal to noise ratios on a Rayleigh fading channel. This value is in perfect agreement with the one used in [6].

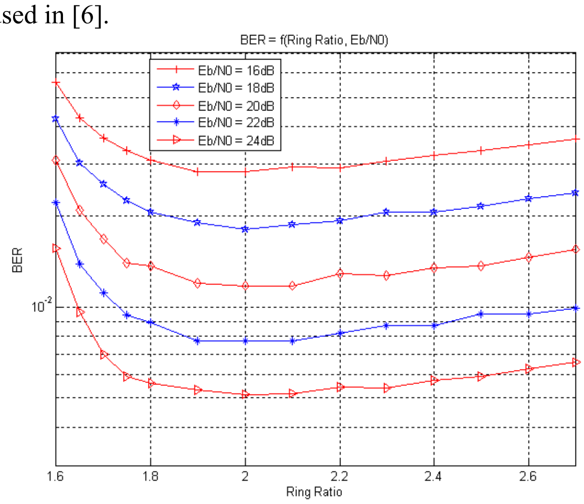

Fig. 7: 16DAPSK BER versus ring ratio

The 8DPSK bits are decoded using the following decision variable:

$$v_k = \arg\left(z_k z_{k-1}^*\right)$$

where z_k and z_{k-1} represent respectively the present and previous DPSK symbols. The decision rule for the 2DASK bit is given by:

$$\begin{cases} 0 & \mathit{if} \qquad \beta_L < \left|\dfrac{z_k}{z_{k-1}}\right| < \beta_H \\ 1 & \mathit{elsewhere} \end{cases}$$

The values of β_L and β_H have been optimised by simulation to give 0.68 and 1.47 respectively.

5. Joint source channel coding with Rayleigh Channel.

As mentioned in [6] the four 16-DAPSK bits have different bit error probabilities (BEP). For example, the 2DASK amplitude bit BEP is four times larger than the 8DPSK msb BEP (see Fig. 8).

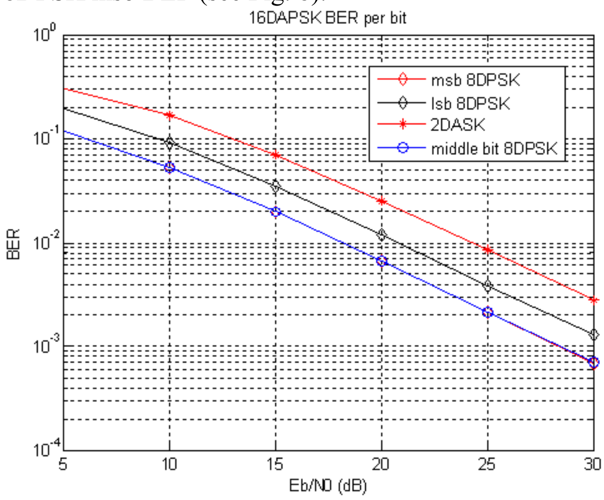

Fig. 8: 16DAPSK BER per bit versus mean SNR

From the first part, we recall that in the WTSOM scheme, the vector indices have a neighbourhood relation with each other. Because of that, a small error on an indice should lead to another indice near to the original one and thus, to a small degradation of the visual quality [5]. Therefore, having the joint source-channel coding strategy in mind, we have to achieve a better protection for the msb of a 16-DASPK symbol. This results in the mapping in Table 1.

Table 1: WTSOM mapping on 16DAPSK

WTSOM	MSB	Third bit	2^{nd} bit	LSB
16DAPSK	MSB 8DPSK	Middle bit 8DPSK	LSB 8DPSK	2DASK

Moreover, in the WTSOM scheme, the LL_3 subband contains the most important information about the image. Therefore, it needs a higher level of protection. In the AWGN case, this is achieved by a (255,205) RS code. On slow Rayleigh fading channels, errors appear in bursts whose durations are inversely proportional to the normalised Doppler frequency f_DT_s. RS codes have good burst error correction capabilities and are thus appropriate for Rayleigh fading channels. However, one must take care of the average duration of fades which should not be too long so as not to exceed the RS code correction capability. To avoid the disastrous effects of bursts, one can use an interleaver which spreads out burst errors over a large number of symbols.

5.1. Without antenna diversity

The system has been optimised for a normalized Doppler frequency $f_DT_s = 0.001$ (see Fig. 9). In this case, a (510,4) symbol block interleaver [9] has shown to yield an average 0.9dB gain over the non interleaved case. As expected, the RS code doesn't work well for $f_DT_s < 0.0007$ (long fades) and thus needs deeper interleaving.

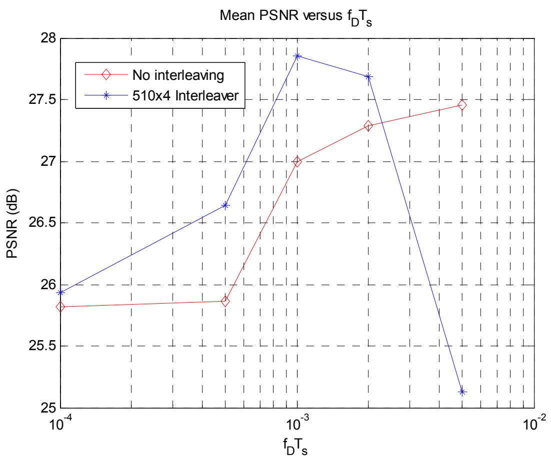

Fig. 9: Image mean PSNR versus normalised Doppler frequency f_DT_s

On the other hand, our simulations have shown that the interleaver degrades the performance of the system when $f_DT_s > 0.002$. In this case, the RS code performs quite well without the need of an interleaver. Fig. 10 presents some significant results for different values of f_DT_s (from relatively fast fading to quite slow fading).

a) f_DT_s=0.015 BER=1.8%
no ECC, no interleaving
PSNR = 25.5dB

b) f_DT_s =0.015, BER=1.8%
RS code, no interleaving
PSNR = 26.7dB

c) f_DT_s=0.001 BER =1.2%
no ECC, interleaving
PSNR = 26.8dB

d) f_DT_s=0.001, BER =1.2%
RS code, interleaving
PSNR = 28.8dB

e) f_DT_s=10^{-4}, BER =1.3%
no ECC, interleaving
PSNR = 23.8dB

f) f_DT_s =10^{-4}, BER=1.3%
RS code, interleaving
PSNR = 24dB

Fig. 10: WTSOM image transmission

These results have been obtained using a value of 20dB for $(E_B/N_0)_{dB}$. This value can be reduced significantly by using a low complexity diversity scheme presented in the next section.

5.2. With antenna diversity

In order to increase the working range of the system a simple diversity combiner based on received signal strength (RSS) of order 2 has been implemented. This scheme is similar to those used in [6] [8] and [10].

5.2.1. 8DPSK decisions

With a diversity of order 2, the decision variable is a simple vectorial addition of the decision variables coming from the two branches:

$$V_k = \arg(v_{1,k} + v_{2,k})$$

where $v_{l,k}$ is defined by $v_{l,k} = z_{l,k} z^*_{l,k-1} \quad l = 1,2$.

5.2.2. 2DASK decisions

The decision variable is given by:

$$\frac{|z_{1,k}|^2 + |z_{2,k}|^2}{|z_{1,k-1}|^2 + |z_{2,k-1}|^2}$$

The lower and upper decision thresholds are now egal to $\beta_L{}^2$ and $\beta_H{}^2$. This simple diversity stategy allows the WTSOM scheme to work quite well, down to a signal to noise ratio of 12dB (8dB gain; see Fig. 11) and permits to extend the normalised Doppler frequency up to $f_D T_s$ = 0.04 (0.02 with diversity order 1) as shown in Fig. 12.

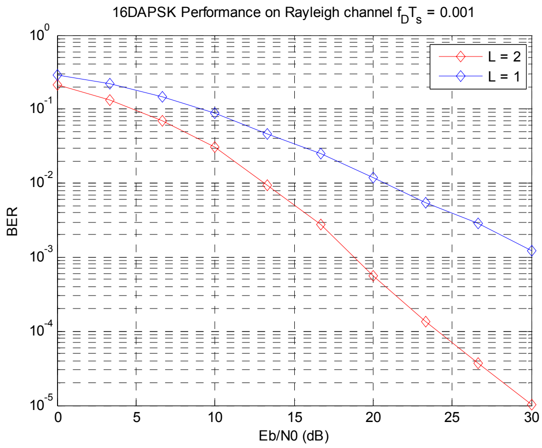

Fig. 11: 16DAPSK BER versus mean SNR

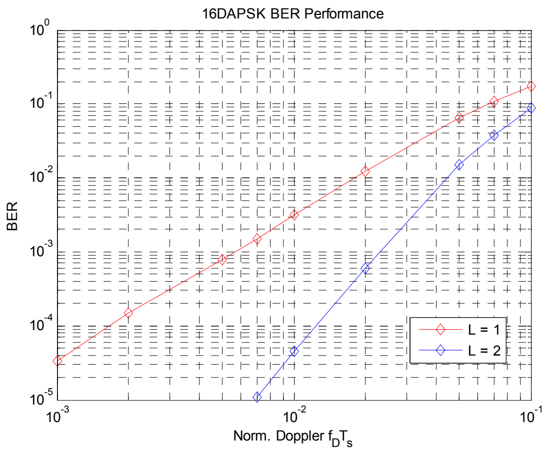

Fig. 12: 16DAPSK irreducible noise floor versus normalised Doppler frequency $f_D T_s$

a) $f_D T_s = 10^{-3}$ BER=1.3% no ECC, no interleaving PSNR = 26.4dB

b) $f_D T_s = 10^{-3}$ BER=1.3% RS code, interleaving PSNR = 27.7dB

Fig. 13: WTSOM image transmission with antenna diversity

The visual quality of the images in Fig. 13 shows clearly the robustness of our joint source channel coding scheme.

6. Conclusion

In this paper, a robust joint source-channel coding scheme for image transmission over a non frequency selective Rayleigh fading channel was presented. Using relatively low complexity techniques allowed by the joint source channel strategy we obtained a good visual quality of the received image even with relatively poor transmission conditions (e.g.: $f_D T_S$=10-3; E_b/N_0=12dB, BER=1.3%; PSNR=27.7 dB). Although this work has been limited to non frequency selective channels, our future work will deal with the frequency selective case.

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