A CONTENT-BASED PRECODING SOLUTION DESIGNED FOR JPWL TRANSMISSION

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ABSTRACT

This paper presents a content-based precoding solution for the transmission of a Wireless JPEG 2000 (JPWL ISO/IEC 15444-11) image. To ensure the Quality of Service (QoS), we exploit the channel diversity with a Closed-Loop MIMO scheme. It relies on the Channel State Information (CSI) knowledge at the transmitter side that diagonalizes a MIMO channel into several hierarchical SISO subchannels. In the proposed scheme, the JPWL codestream is divided into hierarchical quality layers passing through the SISO subchannels. According to this strategy, we propose a new content-based precoding algorithm to maximize the visual quality in reception. This algorithm is compared with the Water Filling (WF) precoder that maximizes the channel capacity. Indeed, we show that WF power allocation is not adapted to ensure QoS of a hierarchical content. We compare precoders' performances on a statistical channel and a realistic time-varying MIMO channel provided by a 3D-ray tracer propagation model. Results show that the proposed approach improves the visual quality.

***Index Terms*—**Image transmission, JPWL, QoS, realistic MIMO channel, Unequal Power Allocation.

1. INTRODUCTION

During the last decade, wireless communications are widely developed. The emergence of several new wireless communications standards such as 4G, Long Term Evolution (LTE) or Wifi has increased the potential of wireless networks. Image transmissions are one of the many possibilities allowed by these networks. However, the well-known constraints of the transmission environment such as limited bandwidth, frequency fading and Doppler effect can affect the QoS required by end users. Multiple Input Multiple Output (MIMO) with Orthogonal Frequency-Division Multiplexing (OFDM) technologies have shown their efficiency to improve the QoS using the maximum diversity of wireless channel [1]. This diversity is even better exploited when system has CSI knowledge. In addition, the CSI knowledge allows decomposing the MIMO channel into independent and hierarchical SISO subchannels [2]. Unequal Power Allocation (UPA) algorithms split the power among the different subchannels in order to optimize a transmission criterion. These algorithms, called precoders [3], are generally based on optimization problem under constraint. They are then referred to the Lagrange multipliers theory to solve the problem. Several works [4-6] had shown the interest of UPA techniques in a content transmission. However, these techniques do not totally take into account the content and the systems parameters (subchannel SNRs, power, modulation and channel coding) which have an effect on the rate-distortion trade-off. So, this paper presents the following contributions. We propose a new Closed-Loop MIMO scheme that includes a CSI feedback from the receiver to the transmitter, maximizing the visual quality in reception. It is based on a successive allocation on the SISO subchannels with QoS constraint on each of them. This QoS constraint is defined by a target Bit Error Rate (BER). We use JPWL [7] because it provides robustness tools to overcome the transmission errors. In addition, it codes an image into hierarchical quality layers that is particularly adapted to the transmission on a MIMO channel decomposed into SISO subchannels. A robust JPWL decoder [6] is also used to overcome residual errors. Then we compare our algorithm with the WF precoder [3] according to the BER and the PSNR. This precoder maximizes the channel capacity by a Lagrangian optimization under power constraint. In addition, we show that not taking into account the content in the transmission of a hierarchical image penalizes the visual quality in reception. To do this, we study the algorithms performances in two cases. Firstly, we compare precoders on a statistical channel with a pseudo-random sequence and without channel coding. Secondly, we study the effect of precoding solutions on the transmission of a JPWL image over a realistic time-varying MIMO channel provided by a 3D-ray tracer propagation model [8].

The paper is organized as follow. Section II describes the global scheme and presents the proposed content-based precoding algorithm. Section III presents the simulation results. Finally, we finish by a conclusion and the future works.

2. CONTENT-BASED PRECODING SOLUTION

Fig. 1 illustrates the transmission strategy. The main objective is to maximize the visual quality of a JPWL image at reception. The robustness of the scheme is strengthened by matching the JPWL quality layers hierarchy and the SISO subchannel hierarchy this giving a content-based allocation. The visual quality is ensured by an UPA algorithm which connects the variables of the transmission chain. These variables are the SNR of each SISO subchannel (CSI), the modulation orders and the correction capacity of the used Error Correcting Codes (ECC).

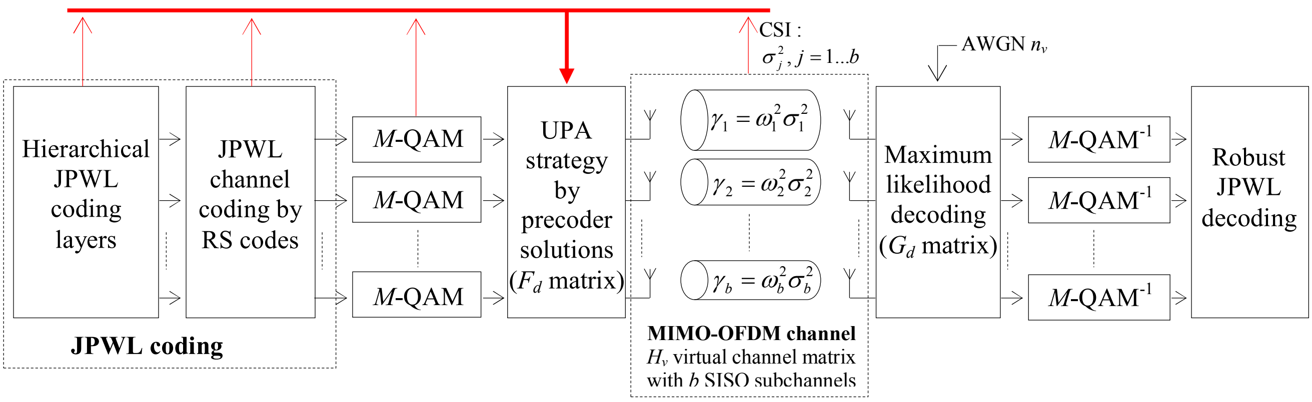


Fig. 1. Synopsys of the global scheme

2.1. Precoding on a MIMO channel

A precoder solution is used in order to decompose the MIMO channel into several uncorrelated SISO subchannels. Precoder designs allow a high flexibility in power allocation with respect to the SISO subchannels. The next step is to define a MIMO system with n_T transmitters and n_R receiver antennae ie. an ($n_T \times n_R$) MIMO system with $b = \min(n_R; n_T)$. The system equation of the MIMO system using precoder designs is given as:

$$y = GHFx + Gn \tag{1}$$

where x and y are the ($b \times 1$) transmitted and received symbol vectors, respectively. H is the ($n_R \times n_T$) MIMO channel matrix, F is the ($n_T \times b$) linear precoder matrix. G is the ($b \times n_R$) linear decoder matrix and n is the ($n_R \times 1$) zero-mean additive noise vector. The common step for all linear precoders is called the virtual transformation. This operation uses the singular value decomposition method to decompose a MIMO channel into uncorrelated SISO subchannels. After applying the virtual transformation, the diagonal MIMO channel is obtained and is expressed as follows:

$$y = G_d H_v F_d x + G_d n_v \tag{2}$$

where $H_v = G_v H F_v$ is the eigen-channel matrix ($\sigma_j, j = 1...b$), G_v and F_v are unitary matrices and $n_v = G_v n$ is the transformed white additive noise vector with covariance matrix $R_{n_v} = I_b$, I_b is b size identity matrix. The F_d and G_d are, respectively, the precoding and decoding matrices. In this paper, the Maximum Likelihood (ML) criterion is used to detect the received symbols. Without any loss of generality, the decoding matrix G_d is viewed as a unitary matrix. The diagonal precoder solutions are therefore defined only by the diagonal precoding matrix F_d. One of the purposes of this work is to compute the precoding parameters (coefficients of F_d diagonal matrix), denoted $\omega_j^2, j = 1...L$, in accordance with the other system variables (CSI, modulation order, ECC capacity), under the constraint of the total transmitted power (E_T): $\sum_{j=1}^{L} \omega_j^2 \le E_T$. This allows the computation of the SNR after a precoding step such as:

$$\gamma_j = \omega_j^2 \sigma_j^2 \quad \text{with} \quad j = 1...L \tag{3}$$

where $\gamma_j, j = 1...L$, is the Signal to Noise Ratio on subchannel j weighted by the precoding coefficient $\omega_j^2, j = 1...L$. The precoding coefficients computed for the L used SISO subchannels and provide an insignificant BER in reception. Finally, the quality of the ($n_T \times n_R$) MIMO channel is assessed by its total gain σ, computed as follows:

$$\sigma = \sqrt{\sum_{j=1}^{b} \sigma_j^2} \tag{4}$$

2.2. Unequal Power Allocation algorithm

The current investigation proposes a power allocation model under a BER constraint. This algorithm connects the parameters of the transmission chain i.e. the SNR value of each SISO subchannel, the modulation orders and ECC correction capacity. These parameters are jointly considered to compute the precoding coefficients $\omega_j^2, j = 1...L$. It is assumed that the noise on the SISO subchannels is Gaussian [2]. Thus, the binary error probability $P_{eb,j}$ on subchannel j for the M_j-QAM modulation can be formulated using the following expression [9]:

$$P_{eb,j} = \frac{2\left(\sqrt{M_j} - 1\right)}{\sqrt{M_j}\log_2 M_j} \, erfc\left(\sqrt{\frac{3\gamma_j}{2(M_j - 1)}}\right) \tag{5}$$

The aim of the model is to formulate the precoding coefficient ω_j^2 on a subchannel j and thus to provide a target BER denoted BER_{Tj}. Accordingly, $P_{eb,j}$ is identified with BER_{Tj} under asymptotic assumption. This leads to:

$$BER_{T,j} = \frac{2\left(\sqrt{M_j}-1\right)}{\sqrt{M_j}\log_2 M_j} erfc\left(\sqrt{\frac{3\omega_j^2\sigma_j^2}{2(M_j-1)}}\right) \quad (6)$$

The precoding coefficient ω_j^2 is derived from (6) to provide $BER_{T,j}$ this being a function of the eigen value σ_j^2 of the subchannel j and of the order of the QAM modulation M_j. The following equation is generated:

$$\omega_j^2 = \frac{2(M_j-1)}{3\sigma_j^2}\left[erf^{-1}\left(1-\frac{BER_{T,j}\sqrt{M_j}\log_2 M_j}{2\left(\sqrt{M_j}-1\right)}\right)\right]^2 \quad (7)$$

According to (7), we can compute the needed power to reach a target BER_{Tj} for a given SNR and modulation order on the subchannel j. We can note that for a lower target BER with the same modulation, the algorithm will provide more power (higher precoding coefficient). Moreover, if the spectral efficiency of the modulation is increased so as to reach the same BER_T, the algorithm must also provide more power.

2.3. Using RS codes rate for BER_T definition

At this demonstration step, the proposed algorithm does not yet consider the ECC correction capacity. Thus RS codes are considered because they are already implemented in the JPWL standard. An RS code is defined by the input number and the output number expressed using the symbols K and N respectively. s_j is the number of bits per symbol on the subchannel j such as $s_j = \log_2(M_j)$ with j = 1...L. So, the binary error probability $P_{RS,j}$ after channel decoding by a given RS(N_j,K_j) code on s_j-bits symbols, is [9]:

$$P_{RS,j} = \frac{1}{s_j}\sum_{i=t_j+1}^{N_j}\frac{i}{N_j}\binom{N_j}{i}{P_{S,j}}^i\left(1-P_{S,j}\right)^{N_j-i} \quad (8)$$

where $P_{S,j} = s_j P_{eb,j}$ is the symbol error probability on a s_j-bits symbol and $t_j = \lfloor (N_j - K_j)/2 \rfloor$ is the correction capacity for the given RS(N_j,K_j) code. According to (5) and (6), $P_{eb,j}$ depends on the precoding coefficient ω_j^2 and is identified with BER_{Tj}. Thus:

$$P_{S,j} = s_j P_{eb,j} = s_j BER_{T,j} \quad (9)$$

Let us define B, the target BER after channel decoding such that $P_{RS,j} \le B$, then [see. (8)]:

$$\frac{1}{s_j}\sum_{i=t_j+1}^{N_j}\frac{i}{N_j}\binom{N_j}{i}\left(s_j BER_{T,j}\right)^i\left(1-s_j BER_{T,j}\right)^{N_j-i} \le B \quad (10)$$

An approximation of the BER_T values is computed using an iterative algorithm. This allows to reach the B boundary according to a given RS(N,K) code. The decrease of the B boundary leads to a decrease in the BER_T parameter and an increase in the precoding coefficient. Thus, the proposed UPA solution, allowing high flexibility in the process of power allocation, can be jointly adapted to the channel status and the magnitude of the JPWL quality layer transmitted over the b SISO subchannels. To finely adjust the power allocation, the ECC capacity and the order of modulation are taken into account.

3. EXPERIMENAL RESULTS

In this section, the proposed UPA algorithm called Content-Based Precoder (CBP), is compared with the WF precoder. First, we study the results of these algorithms on a statistical channel for the transmission of a pseudo-random sequence. Second, we compare the results of a JPWL image transmission on a realistic channel.

3.1. Simulation on a statistical channel

3.1.1. System description

We use a 4×4 MIMO system that leads to consider 4 SISO subchannels with 4-QAM on each of them. Symbols resulting of the 4-QAM constellation are randomly generated. For each symbols vector, we generate a new Rayleigh channel matrix H and a new noise correlation matrix $R = TT^*$. H and T elements are complex Gaussian random variable, independent and identically distributed, centered with unit variance. R matrices are normalized according to the SNR. For each SNR level, we transmit 10^5 symbols vectors without ECC. For these tests, BER_T parameter is set to 10^{-9} this corresponding to a quasi-error free transmission.

3.1.2. Results on statistical channel

The figure below presents the BER variation on the MIMO channel according to the power allocation strategy:

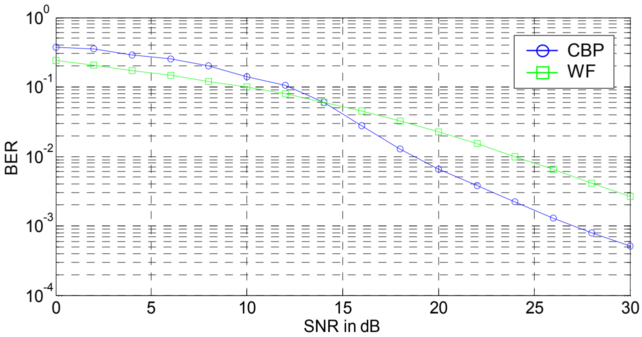


Fig. 2. Global BER variation on MIMO channel

Considering the global BER on the MIMO channel, WF precoder provides better results than CBP solution until SNR of 14dB (fig. 2). However, QoS evaluation during the transmission of hierarchical content need to consider the precoder behavior on each SISO subchannel.

Fig. 3 presents the BER variation on each SISO subchannel according to the precoding solution. WF precoder maximizes the channel capacity. His power allocation strategy corresponds to the solution of an optimization problem by Lagrange multiplier under

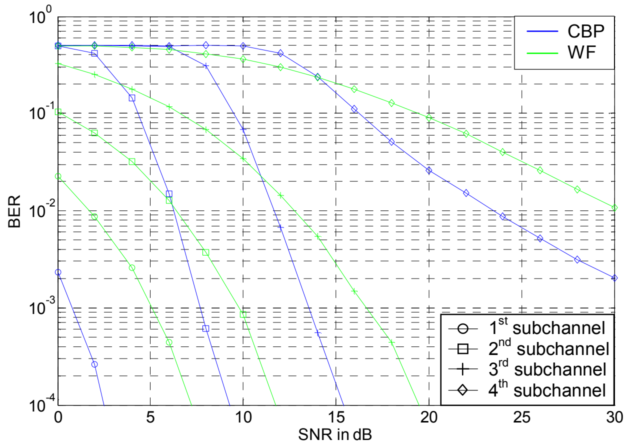


Fig. 3. BER variation on each SISO subchannel

power constraint. Thus, WF splits the power among the subchannels and those with low SNR may be unused. The CBP solution is designed to maximize the visual quality of an image in reception. Unlike the WF power allocation strategy, the CBP solution makes sure the correct transmission (defined by BER_T) of the quality base layer on the first subchannel. Then, it successively allocates power on the other subchannels (corresponding to the improvements layers). This successive distribution of power jointly considering the scheme parameters (modulation and ECC) and under QoS constraint is an enhancement factor of visual quality in reception. On the contrary, maximization of channel capacity on the subchannels is made independently both of the content and the system settings (modulation and ECC). In the case of a pseudo-random sequence without channel coding, WF performances may be overall better than our proposed algorithm especially for lower SNR (cf. fig. 2). However, in the case of a hierarchical content transmission, WF makes no guarantees about the QoS.

3.2. Simulation on a realistic channel

3.2.1. System description

The transmission chain includes specific parameters of *IEEE802.11n* standard [10]. We do not use ECC provided by this standard, but we use the RS codes provided by the JPWL standard. We consider 4-QAM and the OFDM modulation included in the *IEEE802.11n* standard with OFDM symbol period equals to 4µs. The CSI is known at both the transmitter and receiver sides. It provides σ_j^2 with $j = 1\ldots4$. We perform new channel estimation every 20 OFDM symbols, which may limit the Doppler effect and given an adaptive power allocation for precoders. The system achieves an overall transmission rate of 24Mbits/s.

3.2.2. JPWL configuration

Fig. 4 represents the JPWL codestream organization. The transmitted image is coded by JPWL into 4 quality layers. Each layer passes through a SISO subchannel and contains useful and Error Protection Bloc (EPB) data. Main header and tile-part header are allocated on the first subchannel. Each of layer is coded at 0.125bpp including EPB data and headers for the first layer. We consider only one tile to code the image. To overcome

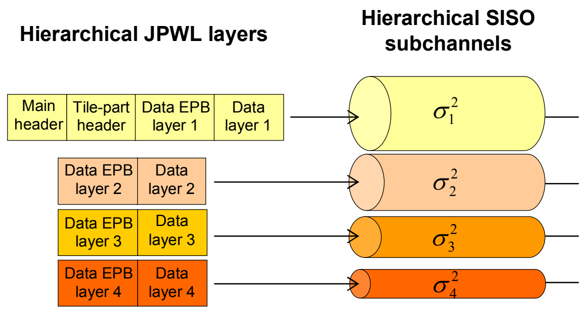
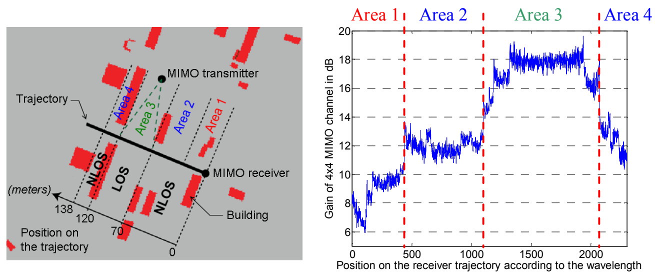


Fig. 4. JPWL quality layers and EPB data repartition on SISO subchannels

transmission errors, we use the tools of JPWL [7] such as SOP (Start Of Packet) and EPH (End of Packet Header) resynchronization markers. Main header protection and tile-part header protection predefined by the JPWL standard are also included. RS(37,32) codes are used on data layers. We choose the smallest RS code of the JPWL standard in Equal Error Protection strategy, to highlight the robustness of the global scheme. However, an Unequal Error Protection (UEP) strategy can easily be implemented but this is not the purpose of this paper. We use "Caps" colour image with resolution of 768×512 pixels for simulation. We consider a received layer is quasi-error free if the BER is limited to 10^{-9}, so $B = 10^{-9}$. According to (10), for $B = 10^{-9}$ and by using RS(37,32) codes, we consider $BER_T = 2.92{\times}10^{-5}$.

3.2.3. Realistic error-prone environment

A realistic time-varying MIMO channel in a suburban environment is used for simulations (Fig. 5).



(a) Topology of the transmission scene (b) Gain variation of the MIMO channel

Fig. 5. Realistic transmission environment

The environment used for simulation takes into account multipath and mobility in a realistic way. The complex impulse responses are provided by a channel simulator based on a 3D-ray tracer [8]. In Fig. 5(a) the buildings are in red. The MIMO transmitter is fixed and the MIMO receiver moves throughout a distance of 138m at a speed of 5 m/s. In this configuration, MIMO receiver goes through the scene alternating NLOS (Non Line Of Sight) and LOS conditions. Thus MIMO receiver successively meets bad (NLOS in area 1), average (NLOS in area 2 and 4) or good conditions (LOS in area 3). The evolution of the total MIMO channel gain σ is presented in Fig. 5(b). σ is defined by (4).

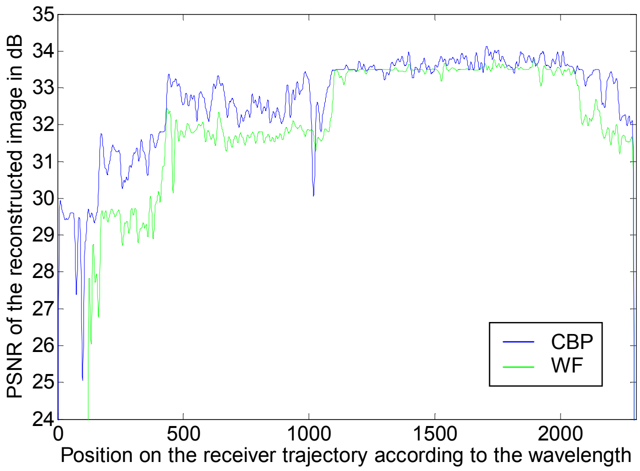


Fig. 6. PSNR variation according to the precoding solutions for "Caps" image

3.2.4. Results on realistic channel

We can see results of transmission across the environment of simulation (Fig. 6). In the case of a hierarchical image transmission on a realistic channel, we note that WF performances are lower than those presented by CBP solution. There are two main explanations. First, WF precoder does not take into account some parameters having an effect on the rate-distortion trade-off. Consequently, WF does not modify its power allocation policy whatever the correction capacity of an ECC or the modulation sensitivity. Second, WF precoder maximizes the channel capacity without taking into account the hierarchical content. The problem is considering on the set of the subchannels without QoS constraint on each of them. The result is the possibility to not allocate enough power to make a useful subchannel. In the case of a hierarchical content, a failure in the decoding of the quality layer n prevents the decoding of the layers higher than n. In practical terms, this explains the lower performances of WF in comparison with the CBP solution, in particular in the areas where the channel is disturbed. Indeed the proposed solution takes into account modulation and channel coding to provide power only for the subchannels which are considered exploitable in reception.

The computational time of UPA solutions was determined with an Intel Core 2 Duo at 2.2 GHz. An average time of 9.5µs was calculated for the WF precoder and an average time of 3.8µs for the CBP solution. Thus, the CBP solution is less complex than the WF precoder. These durations are non-prohibitive for technical implementation.

4. CONCLUSION AND PROSPECTS

In this paper, we proposed a new content-based precoding solution for the transmission of a JPWL image over MIMO channel decomposing into SISO subchannels. It relies on an allocation regarding source and channel hierarchy to improve the QoS. The proposed UPA algorithm takes into account transmission parameters affecting rate-distortion trade-off such as order of modulation and correction capacity of RS codes with QoS constraint on each SISO subchannel. We show that our solution provides a better QoS than the WF precoding solution based on Lagrangian optimization. The proposed work is not limited to the JPWL content. It may be expand to other hierarchical content like video. We plan to extend this work to adaptive scheme including UPA, UEP and adaptive modulation. We also aim to develop a CBP declension with other statistical channel assumptions such as Rayleigh or Ricean models.

ACKNOWLEDGMENT

This work has received support from the French National Research Agency through the CAIMAN project, ANR-08-TO-002. The authors would like to thank Didier Nicholson and Cyril Bergeron from THALES Communications.

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