Bit Loading Algorithms for Adaptive OFDM Wireless Systems

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1 Introduction

The main goal of next generation wireless systems is to provide multimedia communication with spectrally efficient communication. Most of the up-to-date systems have been standardised to use OFDM modulation which prevents inter-symbol interference and make use of parallel subcarriers. The large number of subcarriers helps to avoid the effects of fast fading by distributing channel coded information over different subcarriers. However, if the transmitter is informed about the channel state (CSI – Channel State Information), more sophisticated adaptive transmission techniques might be applied [4].

CSI can provide information about the channel state (e. g. attenuation on each subcarrier) which can help the transmitter to choose the right constellation size, amplification factor and the state (should we use it or not) of each subcarrier. The method is called adaptive, since transmission parameters are adapted to the channel conditions.

In wired communication systems, where OFDM is applied (e. g. on xDSL lines), the adaptive transmission has been widely applied already [1]. However, in a wired environment the conditions are almost constant, thus the transmitter adapts to the channel conditions during the initialisation phase; no adaptation is needed during the communication phase. Wireless communication differs that here continous adaptation is needed to maintain effective links between the mobile node and the access point. Moreover CSI traffic should be as minimal as possible, to avoid the waste of resources.

On the other hand multimedia streams consist of different types of flows. Some of them is sensitive to packet losses, others do care of delays. Even if only video frames are transmitted, some information should be protected as much as possible (e. g. intra frames consisting of the complete description of the whole picture), and others might be lost (e. g. frames describing temporal motion information) without noticeable performance degradation. Usually bitstreams with different performance requirements are grouped into traffic classes. Our task is to support different protection mechanisms for different traffic classes. In the literature it is usually referred to as Unequal Error Protection (UEP). UEP is traditionally performed at channel coding level.

In this article UEP at the modulation level is considered when OFDM modulation is applied (separate, non-overlapping subcarriers). Basically bit loading is considered (which bit to put to which subcarrier). Only some basic CSI information is assumed to be available at the transmitter. This paper focuses on the method of bit loading, the intelligence behind that. Other parts of the system are beyond the scope. The aim of this paper is to derive clear mathematical equations that define the goal of the bit loading methods.

In Section 2 the physical model is illustrated. In Section 3 the mathematical formalisation of the bit loading algorithm is given. Finally, in Section 4 a conclusion closes the document.

2 Physical model

The transmission system considered basically consists of a channel encoder followed by the bit loading algorithm. As usual in OFDM, Inverse Fast Fourier Transform (IFFT) is applied with a parallel to serial conversion (the guard interval is also inserted here), and the result is modulated on the carrier frequency (around 5GHz in most of today wireless OFDM systems). The channel is modelled as a noisy attenuator at each subcarrier. The receiver does the reverse process: first the guard interval is removed, then serial to parallel conversion takes place. The Fast Fourier Transform (FFT) produces the estimate of the sequence, thus after the decision the channel decoder is the last block, where the stream must pass through.

To simplify the investigation, channel coding and decoding is not taken into account in this paper. Let us assume that $A_1, A_2, \ldots, A_N$ arrives at the input of the IFFT block. It has been proven [2] that the output of the FFT block ($Z_1, Z_2, \ldots, Z_N$) will be

$$Z_n = H_n \cdot w_n \cdot A_n + x_n, \tag{1}$$

where H_n is the channel attenuation in the nth subcarrier, W_n denotes the weigth coefficient related to the nth subcarrier which allows non-uniform power level allocation at the receiver side. Finally x_n is the noise which is a zero mean independent complex Gaussian variable with common deviation for all n. The simple linear model of (1) is the basis for investigation.

3 Mathematical Formalisation

We assume F traffic classes. The input parameters are the following: $\{\boldsymbol{e}, \boldsymbol{b}, \boldsymbol{h}, N\}$, where N denotes the number of subcarriers (number of subchannels used by the bit loading algorithm), vector $\boldsymbol{e} = [P_e[\ell]]$ stores the pre-defined minimal bit error probabilities corresponding to each traffic class (how much error is tolerated by the related flow). Vector $\boldsymbol{b} = [b[\ell]]$ contains the bit rates of different traffic classes. The length of vector $\boldsymbol{e}$ and $\boldsymbol{b}$ equals F. Since the number of subcarriers are usually much larger than the number of traffic classes we assume in the sequel that $F < N$. Finally, vector $\boldsymbol{h} = [H_n]$ contains the channel attenuation values. We assume that it is perfectly known by the transmitter.

The output parameters are the following: $\{\boldsymbol{m}, \boldsymbol{w}, \boldsymbol{C}\}$, where $\boldsymbol{m} = [M_n]$ contains the constellation sizes of each subcarrier. That is, $M_1 = 2$ refers to simple BPSK modulation on the first subcarrier, M_n tells M_n-QAM modulation on the nth subcarrier and $M_{20} = 1$ shows no communication on the 20th subcarrier (with one value in the constellation diagram it is impossible to communicate). Thus vector $\boldsymbol{m}$ is a discrete one (each component can get integer values). Vector $\boldsymbol{w}$ stores the amplifying gains on each subcarrier. Obviously each subcarrier can be amplified continously. Finally, matrix $\boldsymbol{C} = C_{ij}$ is also a discrete matrix, where $C_{ij} = 1$, if the ith subcarrier is applied for transmitting information of the jth traffic class, and 0 otherwise. The dimension of matrix $\boldsymbol{C}$ is $N \times F$. In every row there must be at least $(F-1)$ zeros (one subcarrier can carry only one traffic class), thus this matrix is filled with at most N ones.

The optimisation is taken care of by a proper optimisation technique. To save battery, the emitted power should be minimised during the optimisation, the total of which is given as:

$$P_T = \frac{2}{3}(\boldsymbol{m} - \boldsymbol{1})^{\mathsf{T}} \cdot \mathbf{diag}\left[\boldsymbol{w}\boldsymbol{w}^{\mathsf{T}}\right] \cdot \boldsymbol{1}, \tag{2}$$

where $\boldsymbol{1}$ is a column vector full of ones.

The following constraints must be satisfied:

$$\boldsymbol{b} \leq \boldsymbol{C}^{\mathsf{T}} \cdot \log_2(\boldsymbol{m}), \tag{3}$$

where the $\log_2$ function for vectors is interpreted the same way as for real numbers: it computes one output for each components of the vector argument. This constraint tells that the available bit rate should be sufficient for all traffic classes.

The other constraint assures sufficiently small bit error probability for all classes:

$$\boldsymbol{e} \geq \boldsymbol{C}^{\mathsf{T}} \cdot \boldsymbol{y}, \tag{4}$$

where $\boldsymbol{y} = [y_n]$ is defined as the bit error ratio on the nth subcarrier (it is a corollary of M-QAM modulation [5]):

$$y_n = \frac{2(\sqrt{M_n} - 1)}{\sqrt{M_n} \cdot \log_2 M_n} \operatorname{erfc}\left\{\sqrt{\frac{w_n^2 \cdot |H_n|^2}{\sigma_x^2}}\right\}, \tag{5}$$

where H_n is the channel transfer function gain related to the nth subcarrier, and σ_x^2 is the power of Gaussian thermal noise at every subcarrier.

Note that, however (2) is a linear function of the parameters, both constraints are non-linear functions. Some possible methods which can solve the above formalism are to be demonstrated in the seminar.

4 Conclusions

In this paper the problem of adaptive bit loading is mathematically formalised. The effect of channel encoding and decoding was not taken into account, thus a possible enhancement of the derivation would be to describe the system with the channel encoder/decoder. However, without them the problem is still very complicated and difficult to solve. Possible soltutions to the described system will be given in the seminar.

References

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