International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 10 (2015) pp. 26339-26345

http://www.ripublication.com

Water-Filling for Cyclic Prefixed Multi-Carrier Transmission over an ADSL Channel using a TEQ Equalizer

F. Bouasria [1] and M.chetioui[2]

[1]Laboratory of Knowledge Management and Complex Data, University of Saïda (20000), Algeria
[2] University of Saida, B.P138 En-nasr (20000), Algeria
E-mail: valencfaty@yahoo.fr, chetioui.mohammed@yahoo.fr

Abstract

The multipath nature of the wireless channel can be described as a Finite Impulse Response (FIR) filter, which easily results in the hostile InterSymbol Interference (ISI). Usually, Orthogonal Frequency Division Multiplexing (OFDM) systems combat the hostile ISI with the aide of the Cyclic Prefix (CP).In this work, we consider a cyclic prefixed multi-carrier. Based on this scheme, we propose a power allocation method (like water-filling for OFDM) for a Time Equalizer (TEQ) equalizer. This power allocation is computed in order to maximize the decision Signal-to-Noise Ratio (SNR) at the receiver and the solution is the optimum transmit waveform for a given channel and a given transmit power. Water-filling bit-load method, we us, is discussed and compared to other simpler methods.

Keywords: Cyclic Prefix, Multi-Carrier, Multipath fading channels, watter-filling, Power Allocation

1. Introduction

The rest of this paper is organized as follows. Section 2 presents the system model and Multicarrier Equalization by Restoration of RedundancY (MERRY) algorithm. The Water-Filling (WF) optimization is presented in Section 3. The proposed solution applied on OFDM (WF. OFDM) with TEQ equalizer is compared with the classical OFDM using a TEQ in Section 4 by means of numerical simulations. Finally, some conclusions are drawn in Section 5.

2. System Model and MERRY algorithm

This section derives the basic MERRY algorithm. What come later will discuss various generalizations and performance-enhancing extensions. At the beginning, consider a OFDM system in Figure 1.

After the CP is added, the last v samples are identical to the first v samples in the symbol [7, 9],
i.e.

$$x(M.n+i) = x(M.n+i+N)\quad i \in \{1,2,\cdots,v\} \quad (1)$$

Where $M=N+v$ is the total symbol duration, and n is the symbol index. To simplify the notation, henceforth we assume n=0 (without loss of generality). The received data r is obtained from x by

$$r(k) = \sum_{l=0}^{L-1} h(l)\, x(k-l) + n(k) \qquad (2)$$

and the equalizer data y is similarly obtained from r by

$$y(k) = \sum_{j=0}^{T-1} w(j)\, r(k-j) \qquad (3)$$

where T is the length of the equalizer **w.** The ombined channel is denoted by $c = h * w$,

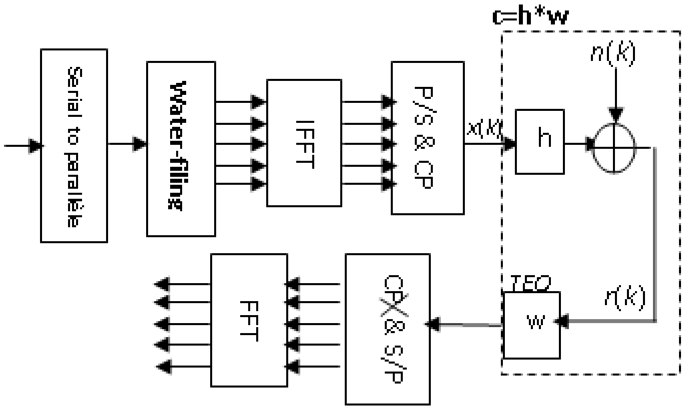
Where $x(n)$ with dimensions $Q\times 1$ is defined as

$$x(n) = \left[x(n,0) \quad x(n,1) \quad \cdots \quad x(n,Q-1)\right]^T \qquad (4)$$

and is composed of samples during the n^{th} OFDM symbol transmitted by the k^{th} user. The CP can convert the time-domain linear convolution of the FIR channel to a cyclic convolution; the ISI is eliminated with the aid of CP. The transmitted sequence with CP is

$$\underline{\mathbf{x}}_k(n) = \begin{bmatrix} x_k(n,Q-v) \\ \vdots \\ x_k(n,Q-2) \\ x_k(n,Q-1) \\ x_k(n,0) \\ x_k(n,1) \\ \vdots \\ x_k(n,Q-v) \\ \vdots \\ x_k(n,Q-2) \\ x_k(n,Q-1) \end{bmatrix} \qquad (5)$$

For clarity, the time-domain CIR (Channel Impulse Response) vector for the k^{th} user is described as



$$\mathbf{h}_k = \left[h_k(0) \quad h_k(1) \quad \cdots \quad h_k(L_{ch}) \right]^T \tag{6}$$

The channel destroys the relationship in (1), because the ICI and ISI that affect the CP are different from the ICI and ISI that affect the last v samples in the symbol. The astute reader will also note that we have shortened the channel to v taps, yet a multicarrier system only requires shortening to $v+1$ taps. However, when v is large (32 in Asymmetric Digital Subscriber Loops (ADSL)), shortening the channel by an extra tap should have a minimal effect on the performance.

If the channel order $L_{ch} \leq v$, then the last sample in the CP should match the last sample in the symbol. One cost function that reflects this is [10]:

$$J_{merry}(\delta) = E\left[\left| y(v+\delta) - y(v+N+\delta) \right|^2 \right], \delta \in \{0, \ldots, M-1\} \tag{7}$$

Where δ is the symbol synchronization parameter, which represents the desired delay of the channel–TEQ combination.

The MERRY algorithm [1, 9], performs a stochastic gradient descent of (7), with a constraint to avoid the trivial solution $\mathbf{w}=0$. The MERRY algorithm is:

Given δ ,
For symbol n=0,1,…,

$$\tilde{\mathbf{r}}(n) = \mathbf{r}(n+\nu+\delta) - \mathbf{r}(n+\nu+N+\delta)$$

$$y(n) = \mathbf{w}^T(n)\tilde{\mathbf{r}}(n)$$

$$\hat{\mathbf{w}}(n+1) = \mathbf{w}(n) - \mu y(n)\tilde{\mathbf{r}}^*(n)$$

$$\mathbf{w}(n+1) = \frac{\hat{\mathbf{w}}(n+1)}{\|\mathbf{w}(n+1)\|} \qquad (8)$$

where $\mathbf{r}(n) = [r(n), r(n-1), \ldots, r(n-L_w)]^T$,and * denotes complex conjugation, and μ is the TEQ adaptation step size, it's taken at: 0,75.

3. Water-Filling Optimization

Within initialization of ADSL connection, channel partitioning (bit-loading) is done. Water-filling algorithm examines per-tone SNR and result in per-tone number of bits and energy levels that should be optimally used.

To maximize the data rate, $R = b/T$, for a set of parallel subchannels when the symbol rate $1/T$ is fixed, requires maximization of the achievable $b = \sum_n b_n$ over b under a given total input energy and a target probability of error. Specifically, the number of bits allocated to the nth subchannel is

$$b_n = \log_2\left(1 + \frac{\varepsilon_n g_n}{\Gamma}\right) \qquad (9)$$

where $g_n = |H_n|^2 / 2\sigma_n^2$ represents the subchannel signal-to-noise ratio when the transmitter applies a unit energy to that subchannel. The ratio g_n is a fixed function of the channel, but ε_n , which denotes the 2-D subsymbol energy allotted to the nth subchannel, can be optimized to maximized b, subject to a total transmit energy constraint of

$$\sum_{n=1}^{N} \varepsilon_n \le \varepsilon_x \qquad (10)$$

Since $\log(1+x)$ is a strictly increasing function of x, the total energy constraint of (10) will be binding, i.e., equality is met. Using Lagrange multipliers, the cost function becomes

$$\frac{1}{In2}\sum_{n} In\left(1+\frac{\varepsilon_n g_n}{\Gamma}\right)+\lambda\left(\varepsilon_x-\sum_{n=1}^{N}\varepsilon_n\right) \qquad (11)$$

differentiating with respect to ε_n produces

$$\frac{1}{In2}\frac{1}{\varepsilon_n+\frac{\Gamma}{g_n}}=\frac{\lambda\Gamma}{g_n} \qquad (12)$$

Thus, the aggregate bit rate in b is maximized when the optimum subchannel transmit energies satisfy

$$\varepsilon_n+\frac{\Gamma}{g_n}=K=\text{constant} \qquad (13)$$

and K is chosen such that the total energy constraint given by (10) is met.

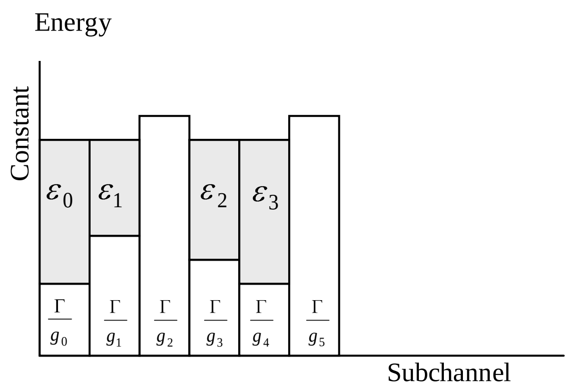


Fig.2: 1llustratio.n of discrete water-filling for 6 subchannels

4. Simulation Results

Figure 3 shows a plot of the ISI vs. Number of iteration. It shows simulation results using Water-filling a standard ADSL test channel. The FFT size was 512, the CP length was 32, the TEQ had 16 taps, and signal to noise rapport was 40 dB. Figure 3 shows that Water-filling can converge rapidly provide a perfect result .

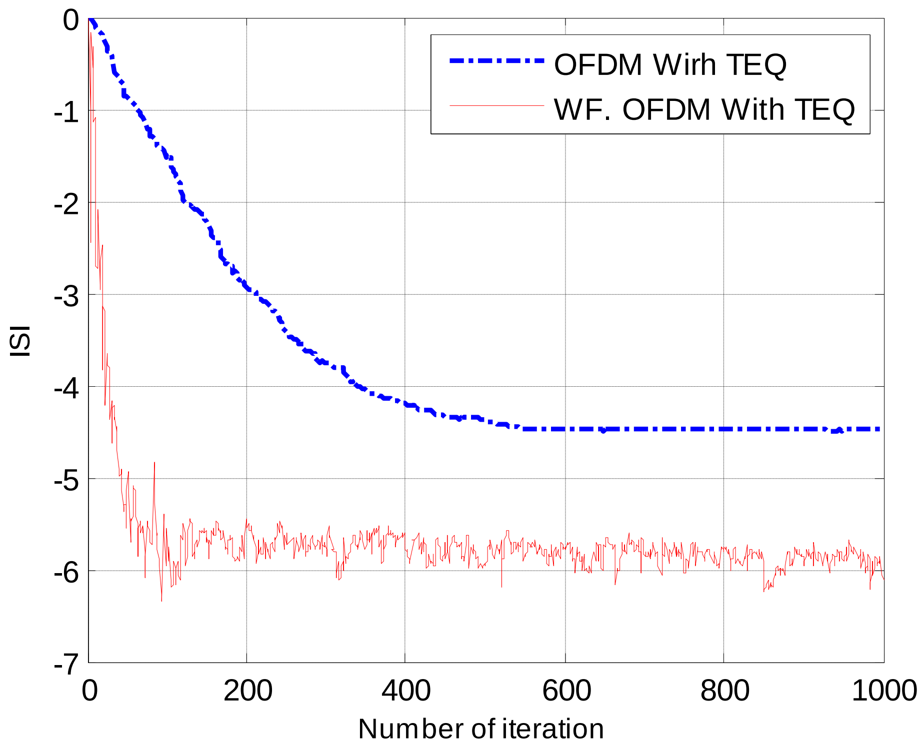


Fig. 3: Performance of OFDM system in term of ISI, using the water-filling

5. Conclusion

In this paper, we introduce a water-filling solution technique for OFDM system .We prove that the proposed method leads to the desired optimum energy distribution . Simulation results and comparison with and without water-filling algorithms confirm the effectiveness of the channel OFDM method.

The water-filling solution is unique because the rate function being maximized is concave. Therefore, there is a unique optimum energy distribution and a corresponding rate distribution among the sub-channels with multichannel or multicarrier modulation.

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