Channel Equalization for OFDM

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***Abstract*—This paper proposes a specific approach to channel equalization for Orthogonal Frequency Division Multiplex (OFDM) systems. Inserting an equalizer realized as an adaptive system before the FFT processing, the influence of variable delay and multipath could be mitigated in order to remove or reduce considerably the guard interval and to gain some spectral efficiency. The adaptive algorithm is based on adaptive filtering with averaging (AFA) for parameter update. Based on the development of a model of the OFDM system, through extensive computer simulations, we investigate the performance of the channel equalized system. The results show much higher convergence and adaptation rate compared to one of the most frequently used algorithms - Least Mean Squares (LMS).**

***Index Terms*—Adaptive algorithms and filters, channel equalization, orthogonal frequency division multiplexing.**

I. BACKGROUND

OFDM is widely accepted as an attractive transmission technique for different types of broadband transmission systems. It is also a very promising technique for delivering high data rate multimedia services over the mobile radio channel. The performance of such systems is limited by the severe effects of multiple delay spread. In order to overcome this problem a guard interval (cyclic prefix/suffix) is added to each OFDM symbol, to efficiently combat the multi-path effect, at the price of some loss in spectral efficiency, depending on the ratio of unextended and extended symbol periods. Other techniques are also used to combat impairments in time and frequency varying radio channels to obtain high spectral efficiencies in cellular systems, such as channel coding and interleaving, adaptive modulation, equalization, spectrum spreading, dynamic channel allocation etc.

For channel equalization in OFDM there are two general approaches. First one is to apply an equalizer after the FFT block [1]. Second option is to make equalization before the FFT processing [2]. Our design uses the second approach.

II. METHOD

Channel estimation in coherent OFDM can be performed by inserting pilots into the two-dimensional time-frequency lattice, since the mobile channel can be viewed as a two-dimensional stochastic signal sampled at scattered pilot positions, where a noisy sample is obtained. To be able to interpolate channel estimates both in time and frequency, the pilot spacing has to fulfill the Nyquist sampling theorem. In the design of channel estimators for OFDM, pilot information must be distributed optimally in the time-frequency grid. For the 2D pilot patterns a trade-off has to be found; pilots have to be placed close enough to guarantee reliable estimation of the channel frequency response and at the same time, pilot density must be kept as low as possible to avoid reduction of the data rate. For our case the minimum pilot spacing in time and frequency is determined, having in mind some expected bandwidth of the channel variation in time and frequency. We use a cyclic pilot pattern to ensure reliable estimation of the channel in time and frequency. To shorten the delay before the first channel estimates can be calculated, which is undesirable in packet transmission, we use a preamble of symbols for initial training. Then the inserted pilots within the data symbols, besides channel estimation, are used for tracking the remaining offset after the initial training [3,4].

The main processing blocks are presented in Fig. 1. Concerning channel equalization, we use the approach of equalization before the FFT processing. Using this arrangement it is possible to realize the equalizer as an adaptive system with relatively simple structure. Concerning the adaptive algorithm, we employ a recently developed in [5] method based on adaptive filtering with averaging for parameter update. Comparison with one of the most frequently used algorithms – Least Mean Squares (LMS) [6,7] shows that the present design has three very attractive features: high adaptation rate, relatively low computational complexity and robustness in fixed-point implementations. The equalizer works in two modes. First, in training mode for channel estimation. Estimation error is defined as the difference between the estimate and the original signal available through the pilot signals. Second, in decision direction fashion, when the estimation error is determined as the difference between the estimate and the detected data symbols at the decision device output.

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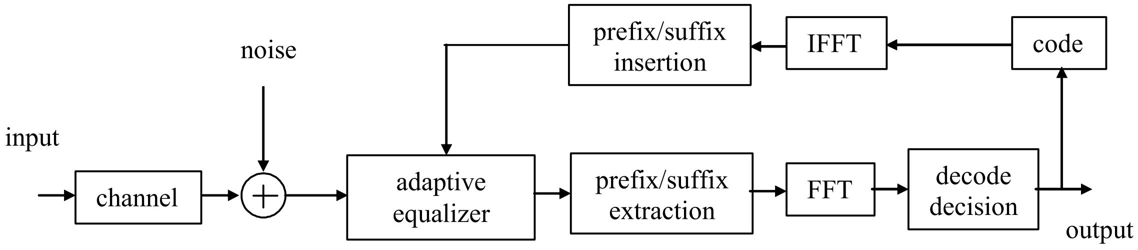

Fig. 1. Channel equalization.

III. ADAPTIVE FILTERING WITH AVERAGING (AFA)

In this section a recently developed algorithm [5] for adaptive equalization is applied for the OFDM system described in the previous section, where s(n) – original signal; x(n) – signal after the channel (see Fig. 1); y(n) – output signal for the adaptive equalizer; d(n) – output signal for the decision device; W(n) – coefficients vector; e(n) – error signal.

Then the needed steps for the AFA equalizer can be presented as

signal estimation:

$$y(n) = W(n)X(n) \tag{1}$$

signal detection:

$$d(n) = f[y(n)] \tag{2}$$

estimation error:

$$e(n) = s(n) - y(n) \quad \text{training mode} \tag{3}$$

$$e(n) = d(n) - y(n) \quad \text{tracking mode} \tag{4}$$

coefficients update:

$$\overline{W}(n) = \frac{1}{n}\sum_{k=1}^{n} W(k) \tag{5}$$

$$W(n+1) = \overline{W}(n) + \frac{1}{n^{\gamma}}\sum_{k=1}^{n} X(k)e(k) \tag{6}$$

$1/2<\gamma<1$, γ - forgetting factor.

The general structure of the equalizer is given in Fig. 2.

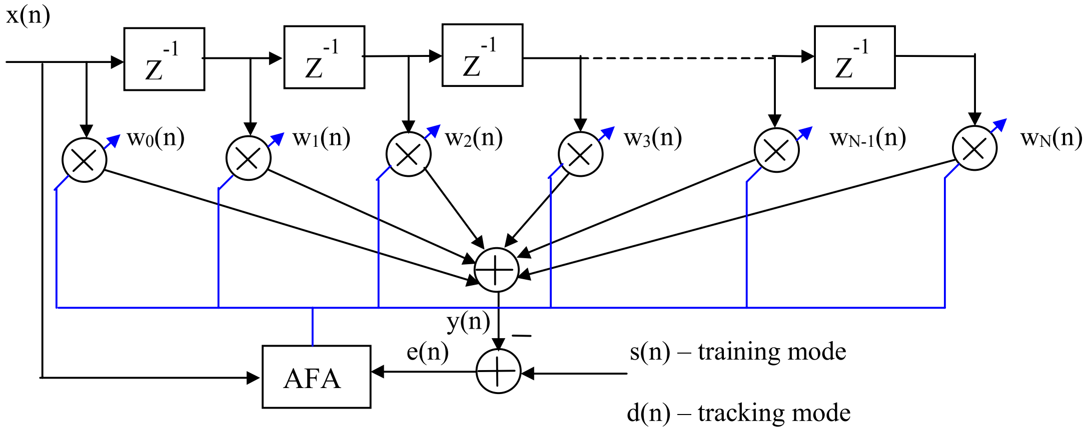

Fig. 2. Adaptive equalizer.

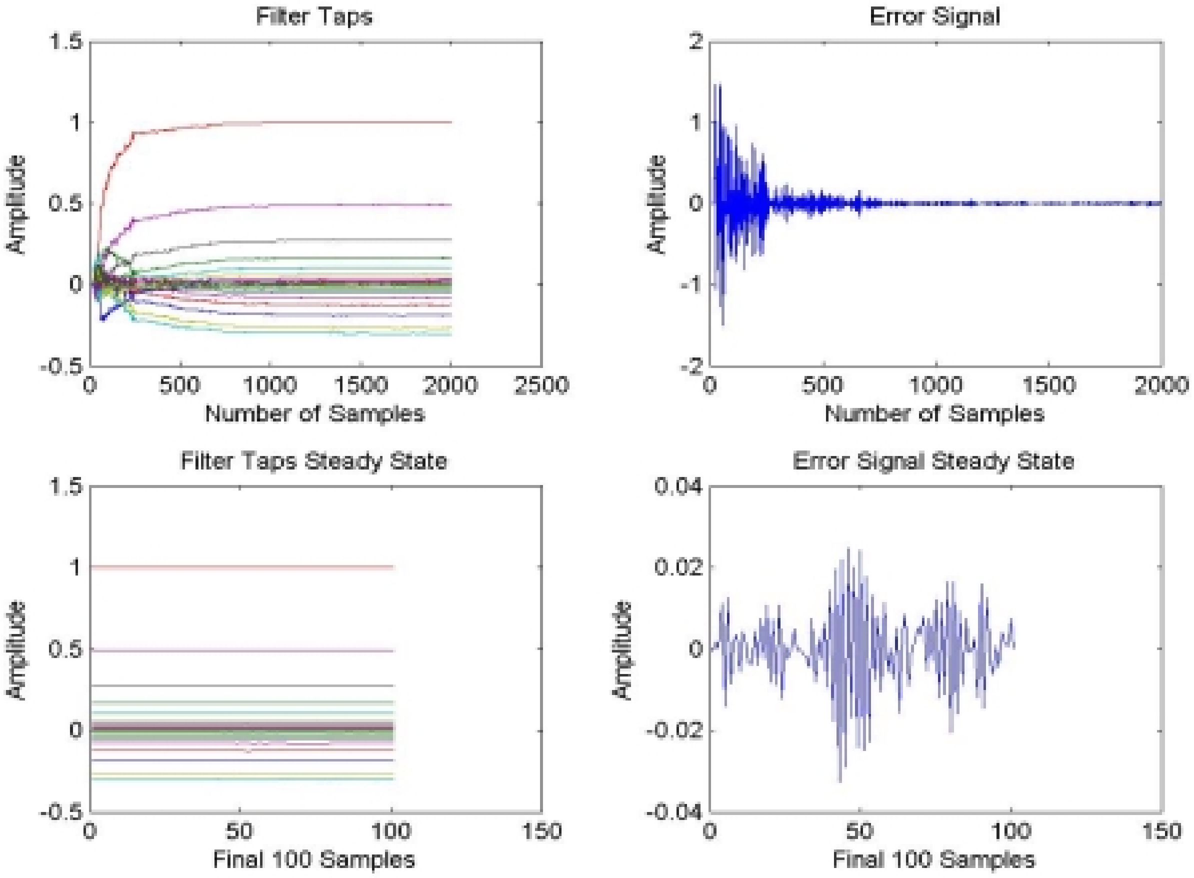

Fig. 3. LMS algorithm.

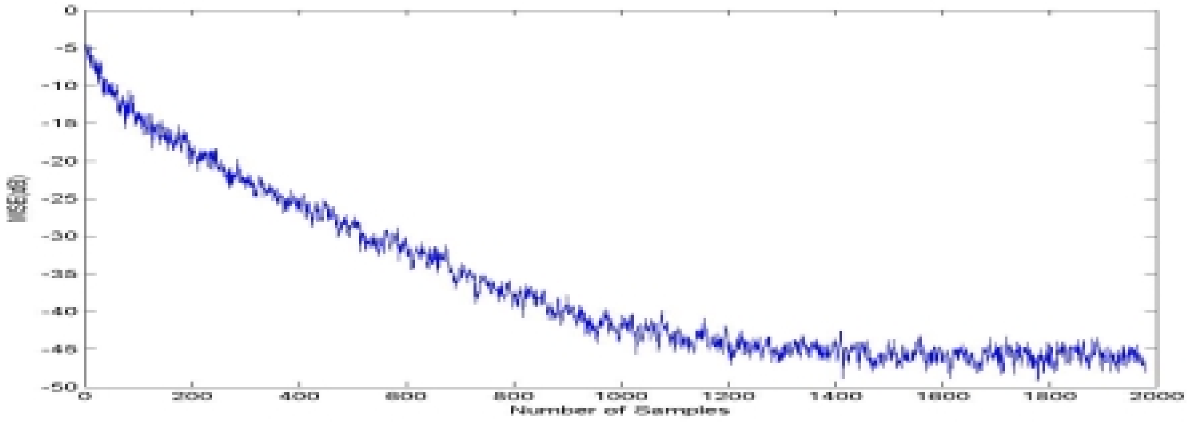

Fig. 4. LMS algorithm.

IV. SIMULATION

For the computer simulation the following approach is adopted. At the transmitter side, a 16 or 64 QAM input data signal is mapped into complex symbols. Cylic pattern of pilots for channel estimation are inserted. OFDM is realized using an inverse fast Fourier transform (IFFT). Possibility for introduction of variable cyclic extension and windowing is included in the model. The complex baseband channel model used to evaluate the transmission system consists of a number of paths, each affected by Rayleigh fading. The tap weights of the channel are chosen to give a flat delay profile. The total delay spread can be adjusted to represent different mobile environments. At the receiver side the opposite operations are performed including the channel estimation and equalization as presented in Fig. 1.

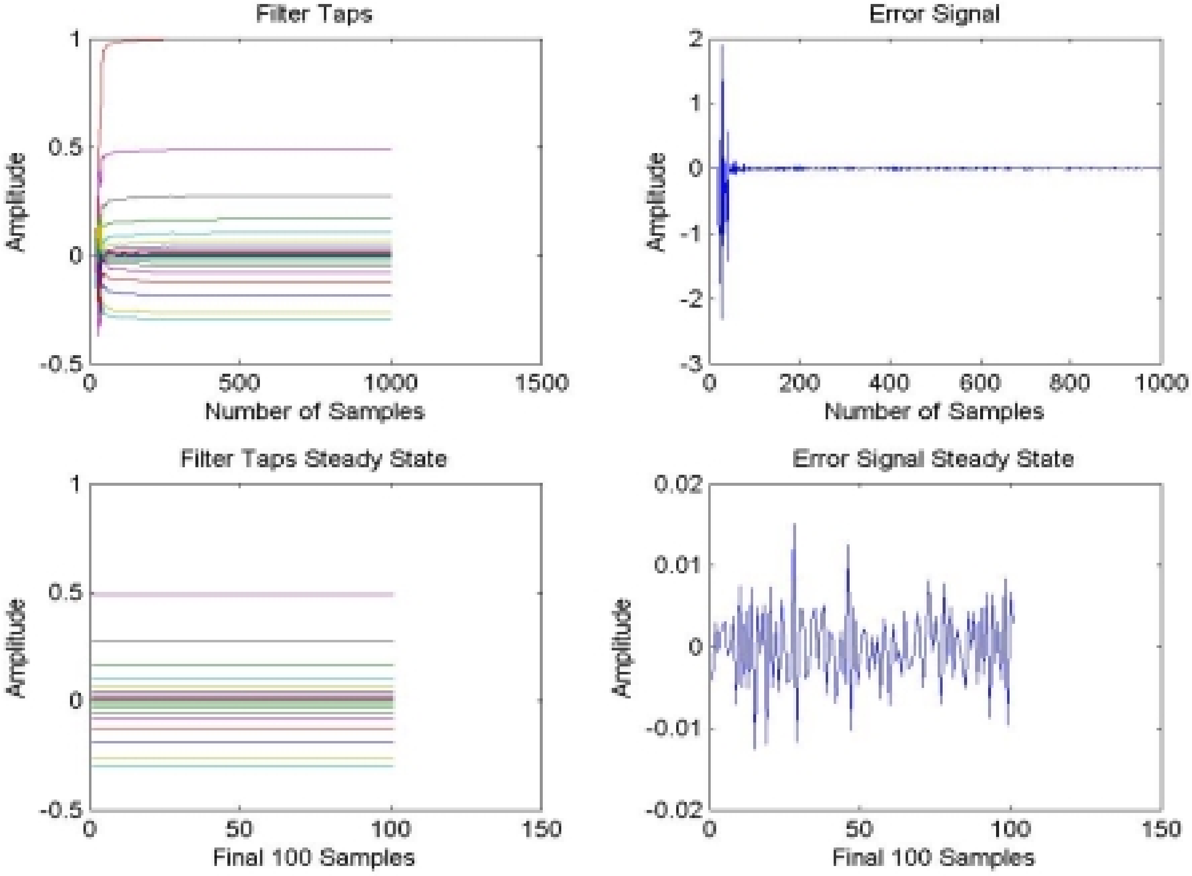

Fig. 5. AFA algorithm.

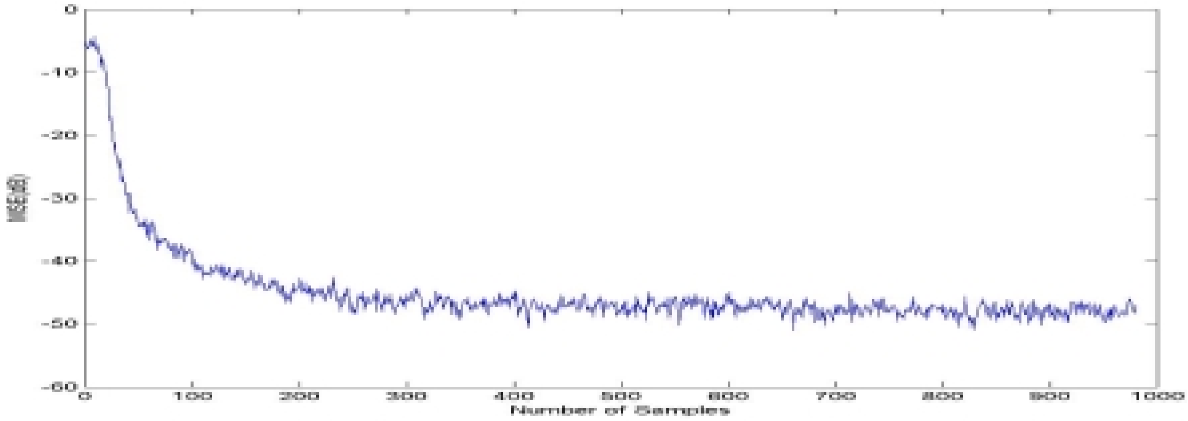

Fig. 6. AFA algorithm.

V. EXPERIMENTAL RESULTS

A comparison of AFA algorithm with LMS algorithm is implemented and the results are presented in Fig. 3-6. Here the channel is modeled as FIR filter of second order and the equalizer is realized as a FIR adaptive filter of 20th order, SNR=20 dB. The LMS and AFA equalizers have the following parameters: $\mu = 0.02$; $\gamma = 0.55$.

Under these conditions the trajectories of the equalizer coefficients and the error signal are shown in Fig. 3 and Fig. 5. While in Fig. 4 and Fig. 6 the results for MSE after 100 independent trials are presented. The main advantage of AFA equalizer compared to LMS equalizer is his much higher convergence rate. A 40 dB reduction for MSE is achieved after 200 iterations for AFA and after 1200 iterations for LMS which means about 6 times faster convergence.

VI. CONCLUSIONS

The main results of the present contribution could be summarized as follows:

- employing pattern of pilots for channel estimation together with adaptive equalization we can improve performance and/or considerably reduce the guard time;
- the adaptation rate is high and the equalizer is able to track the channel fluctuations.
- the overall computational complexity of the process of estimation and equalization is relatively low, which implies low power consumption.

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