Project	**IEEE 802.16 Broadband Wireless Access Working Group**
Title	Decision-feedback Equalizer for FWA PHY
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Re:	This contribution is submitted in response to call for contributions from the IEEE 802.16 chair on Sep. 22, 1999 for submission of PHY proposals for BWA
Abstract	The PHY proposal for calculation-efficient equalizer is submitted for consideration by the group to be accepted as PHY standards for BWA.
Purpose	The proposal should be accepted as part of PHY standard for BWA.
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Table of Contents

IEEE 802.16 Broadband Wireless Access Working Group

Decision-feedback Equalizer for FWA PHY

1 Introduction

We propose a method for decision feedback equalizers used in high speed digital receiver demodulators for fixed wireless access system standard IEEE 802.16. The proposed modualtion is QPSK or QAM modulation, the frequency band to be used is 10 to 50 GHz. The proposed upstream data rate is upto 20 Msymbols/sec. At such high speeds, the reception will be hampered by multipaths with long delays. The new algorithm uses the sparse channel characteristics of the wireless terrestrial channel. A variation of the decision feedback equalizer, namely the partial feedback equalizer, is introduced. The sparseness of the channel is combined with the partial feedback equalizer to develop the new algorithm. Similarity with subspace based filtering is noted, which results in robust performance in the presence of noise. The new algorithm has a superior convergence speed and lower steady state mean squared error, as compared to conventional approaches.

2 Reference Model

We propose new decision feedback equalizers, at the receiver, for multipath mitigation.

Frequency Bands

The proposed frequency band (carrier frequency) is between 10 GHz and 50 GHz.

Channel Spacing

The channel spacing is proposed to be about 10 MHz.

Modulation Formats

The proposed up-stream modulation format is QPSK, or QAM modulation, or 8PSK modulation. The system will be able to handle multi-modulation format, i.e. switch from QPSK to QAM.

Modulation Rates

The upstream modulator should provide symbol rate upto 20 Msymbols/sec.

Equalizer

The equalizer may have more than 200 taps.

- For the upstream data, i.e from the fixed user to the base-station, the data rate of 20Msymbols/sec, for QPSK modulation, translates to 40Mbits/sec. Our equalizer algorithms will handle upstream data, i.e. it is at the base station that we propose to use the equalizer algorithms. The algorithms also work on downstream data.

A base station service area is called a cell, with a cell radius typically less than 15 km, depending on rain regions and availability requirement. In fixed wireless access systems, static and dynamic multipath impairments pose a major challenge to receiver design. If the path difference is 1 km (2 km), it corresponds to multipaths with delays of 3 μs (6 μs).

- At the data rate of 40Mbits/sec, this requires equalizers with more than 120 (240) taps.
- At the proposed frequency band of operation (in the GHz) range, the nature of the multipaths has to be investigated and taken into account [3]. Thus equalizers with lengths of several hundred taps are required.
- To combat dynamic multipaths due to propagation effects such as flutter from moving objects, e.g., airplanes and changing atmospheric conditions, the equalizer must update its coefficients at high rate.

A large number of arithmetic units are required which adds to the complexity of the system and the resulting processing delays. In addition, the power consumption of these equalizers is very high, due to the large number of concurrently operating arithmetic logic units. This provides the motivation to develop a method to adaptively filter digital television signals, with faster response to dynamic multipaths, resulting in shorter acquisition time.

3 Equalizer Architecture

A variation of the decision feedback equalizer, namely the partial feedback equalizer, is introduced in this section. A conventional decision feedback equalizer has two parts, the forward equalizer and the feedback equalizer. The forward equalizer processes the output of the channel (or the broadcast signal). The feedback equalizer feeds the previously detected symbols at the slicer output to refine the estimate of the transmitted symbols at the output of the forward equalizer.

In the new equalizer structure introduced in this section, there is another equalizer called the partial feedback equalizer, in addition to the forward and the feedback equalizer. The slicer output is processed through a partial feedback equalizer and is then subtracted from the channel output (broadcast signal) to produce the input signal into the forward equalizer. Let $x(k)$ be the received signal, $\tilde{x}(k)$ be the input signal to the forward equalizer, $e(k)$ and $\tilde{e}(k)$ be the input and the output of the slicer. If $\mathbf{a}$, $\mathbf{b}$ and $\mathbf{c}$ be the weights of the forward, feedback and the partial equalizers, then the defining equations are

$$\tilde{x}(k) = x(k) - \sum_{M_0}^{M} c_n \tilde{e}(k-n)$$

$$e_k = \sum_{-L}^{0} a_n \tilde{x}(k-n) + \sum_{1}^{M_1} b_n \tilde{e}(k-n)$$

The advantage of this configuration is that it reduces the calculation load on the feedback as well as the forward equalizer, after an initial condition has been established where only the forward equalizer is turned on. The partial feedback equalizer can then use the estimate of the previously detected symbol and process it and subtract an estimate of some multipath from the channel output. This reduces the calculation load on the feedback and the forward equalizer and might lead to increased convergence speed. In a fixed wireless access system, when the reception may be hampered by multipaths with long delays, the feedback equalizer is three or more times longer than the forward equalizer. The partial feedback equalizer, by cancelling some of the multipath, allows one to have fewer, but suitably spaced, taps in the feedback equalizer, therby reducing the hardware.

3.1 Sparse Channel Equalizer

• This portion of this algorithm also involves having fewer taps in the equalizers by having taps at appropriate locations. This is obtained by exploiting the sparse channel characteristics of terrestrial digital television transmission, and the profile of multipath impairments.

• The sparseness of the channel indicates that while several hundred taps span over tens of microseconds of the signal, most of the time only the main signal and few multipath reflected signals will generate any significant amount of the energy at a few of the taps. There will be no multipath corresponding to the other tap locations.

• The equalizer only needs to operate on the taps corresponding to the main signal and the multipaths, and reject the multipath signals.

• The idea above is akin to subspace based adaptive filters. By exploiting the sparseness of the channel, not only does one update fewer taps but it results in improved performance. Filtering only in those subspaces which contain dominant signal components results in performance improvement due to exclusion of noise only modes.

3.2 Tap Coefficient Updating

• The least mean square (LMS) algorithm is used for updating the equalizer coefficients, as it is the most popular algorithm employed in commercial demodulator chips.

• The step size of the equalizer weight is multiplied by a scalar w. Only taps with substantial energy and their few adjacent taps have w equal to 1, all other taps have w equal to 0.

- The energy of the i th tap weight $c(i)$ is given by $E_{tap}(i) = c^2(i)$. The energy of the taps is determined during the early duration of the training phase. The energy of the non-zero weighting taps is continuously monitored, and these taps are updated by the LMS algorithm. Taps with zero w are not updated, unless dynamic ghost signals are detected. This is described in the next subsection.

3.3 Dynamic Ghost

We now consider the scenario of dynamic ghost, i.e. when a ghost appears at a certain time and operates dynamically on the channel.

- The full equalizer is able to handle this dynamic ghost adequately, as an adaptive algorithm is designed to handle non-stationarity in the channel.

- However for a reduced equalizer, which updates its taps selectively, a criterion is developed to detect this non-stationarity. The equalizer then switches back to training mode and determines additional tap weights to be updated.

- This criterion is developed in the following manner. If $E(k)$ is the mean-squared error at iteration k, then the criterion $C(k)$ computes the following,

$$C(k) = E(k) - \frac{\sum_{i=1}^{10} E(k-i)}{10}$$

If $C(k)$ is greater than a threshold, the equalizer switches back to training mode and determines additional tap weights to be updated.

4 Advantages of proposed Equalizer Architecture

Channel

The sparse channel considered here, has 3 multipaths, in addition to the main signal. The multipath with the longest delay is at 1 μ sec. The noise variance is 0.1.

Value	Full DFE	New DFE
Mean	0.1560	0.0984
Steady state mean	0.1324	0.0899
Speed	200	25

Table 1:

Equalizer Taps

The full DFE has 80 contiguous taps in its forward equalizer and 240 taps in its feedback equalizer. There are 80 taps in the partial equalizer. For the new equalizer, the number of taps is determined in an automated manner.

Please see Table 1. The mean is calculated as the mean of the ensemble averaged mean squared error; the steady state mean is calculated as the mean (of the mean squared error) from iteration number 500 onwards. The speed is defined as the number of iterations needed for the ensemble averaged mean squared error to attain a value of 0.6.

Convergence Speed

About 8 times faster convergence speed is achieved by the new algorithm.

Steady state mean squared error

The steady state mean squared error is reduced by about 50 %.

Variable Step-size

The step-size can be varied, to regulate convergence speed and stability of the algorithm. The step-size in the windowed (or reduced) equalizer can be increased.

Other

A channel with 4 multipaths is considered, with a multipath at a delay of 5 μ sec. The results are plotted in Figure 1.

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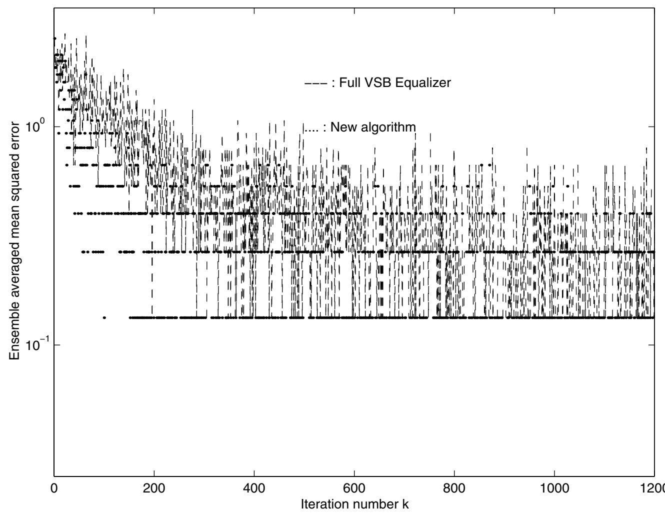

Figure 1: *Simulation Results, Multipath delay = 5 μ s*

• New structures and algorithms for decision feedback equalization, resulting in faster acquisition time and lower steady state mean squared error, are proposed.

• The sparse channel characteristics of wireless terrestrial is utilized to achieve that.

5 Reference

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