ADAPTIVE FILTER ALGORITHMS

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Equalization Techniques

Fig. 3 Classification of equalizers
Equalizer Techniques

- Linear transversal equalizer (LTE, made up of tapped delay lines as shown in Fig.4)
  
  ![Fig.4 Basic linear transversal equalizer structure](image)

- Finite impulse response (FIR) filter (see Fig.5)
- Infinite impulse response (IIR) filter (see Fig.5)
Equalizer Techniques

Fig. 5 Tapped delay line filter with both feedforward and feedback taps
Structure of a Linear Transversal Equalizer [5]

\[ \hat{d}_k = \sum_{n=-N_1}^{N_2} C^*_n y_{k-n} \]

\[ E[|e(n)|^2] = \frac{T}{2\pi} \int_{-\pi}^{\pi} \frac{N_o}{|F(e^{j\omega})|^2 + N_o} d\omega \]

\( F(e^{j\omega}) \): frequency response of the channel

\( N_o \): noise spectral density
Structure of a Lattice Equalizer [6-7]

Fig. 7 The structure of a Lattice Equalizer
Characteristics of Lattice Filter

- Advantages
  - Numerical stability
  - Faster convergence
  - Unique structure allows the dynamic assignment of the most effective length

- Disadvantages
  - The structure is more complicated
Nonlinear Equalization

- Used in applications where the channel distortion is too severe
- Three effective methods [6]
  - Decision Feedback Equalization (DFE)
  - Maximum Likelihood Symbol Detection
  - Maximum Likelihood Sequence Estimator (MLSE)
Nonlinear Equalization--DFE

• Basic idea: once an information symbol has been detected and decided upon, the ISI that it induces on future symbols can be estimated and substracted out before detection of subsequent symbols.

• Can be realized in either the direct transversal form (see Fig. 8) or as a lattice filter:

\[ d_k = \sum_{n=-N}^{N} C_n y_{k-n} + \sum_{i=1}^{N} F_i d_{k-i} \]

• \( E[e(n)^2]_{\text{min}} = \exp\{\frac{T}{2\pi} \int_{-\pi}^{\pi} \ln\left[ \frac{N_o}{F(e^{j\omega})^2 + N_o} \right] d\omega \} \)
Nonlinear Equalizer-DFE

Fig. 8 Decision feedback equalizer (DFE)
Nonlinear Equalization--DFE

• *Predictive DFE* (proposed by Belfiore and Park, [8])
• Consists of an FFF and an FBF, the latter is called a *noise predictor* (see Fig.9)
• Predictive DFE performs as well as conventional DFE as the limit in the number of taps in FFF and the FBF approach infinity
• The FBF in predictive DFE can also be realized as a lattice structure [9].

The RLS algorithm can be used to yield fast convergence
Nonlinear Equalizer-DFE

Fig. 9 Predictive decision feedback equalizer
Nonlinear Equalization--MLSE

• MLSE tests all possible data sequences (rather than decoding each received symbol by itself), and chooses the data sequence with the maximum probability as the output
• Usually has a large computational requirement
• First proposed by Forney [10] using a basic MLSE estimator structure and implementing it with the Viterbi algorithm
• The block diagram of MLSE receiver (see Fig.10)
Nonlinear Equalizer-MLSE

- MLSE requires knowledge of the channel characteristics in order to compute the matrices for making decisions.
- MLSE also requires knowledge of the statistical distribution of the noise corrupting the signal.

Fig. 10 The structure of a maximum likelihood sequence equalizer (MLSE) with an adaptive matched filter.
Algorithm for Adaptive Equalization

- Excellent references [6, 11--12]
- Performance measures for an algorithm
  - Rate of convergence
  - Misadjustment
  - Computational complexity
  - Numerical properties
- Factors dominate the choice of an equalization structure and its algorithm
  - The cost of computing platform
  - The power budget
  - The radio propagation characteristics
Algorithm for Adaptive Equalization

• The speed of the mobile unit determines the channel fading rate and the Doppler spread, which is related to the coherent time of the channel directly.

• The choice of algorithm, and its corresponding rate of convergence, depends on the channel data rate and coherent time.

• The number of taps used in the equalizer design depends on the maximum expected time delay spread of the channel.

• The circuit complexity and processing time increases with the number of taps and delay elements.
Algorithm for Adaptive Equalization

• Three classic equalizer algorithms: zero forcing (ZF), least mean squares (LMS), and recursive least squares (RLS) algorithms
• Summary of algorithms (see Table 1)
## Summary of algorithms

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Number of Multiply Operations</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMS Gradient DFE</td>
<td>$2N + 1$</td>
<td>Low computational complexity, simple program</td>
<td>Slow convergence, poor tracking</td>
</tr>
<tr>
<td>Kalman RLS</td>
<td>$2.5N^2 + 4.5N$</td>
<td>Fast convergence, good tracking ability</td>
<td>High computational complexity</td>
</tr>
<tr>
<td>FTF</td>
<td>$7N + 14$</td>
<td>Fast convergence, good tracking, low computational complexity</td>
<td>Complex programming, unstable (but can use rescue method)</td>
</tr>
<tr>
<td>Gradient Lattice</td>
<td>$13N - 8$</td>
<td>Stable, low computational complexity, flexible structure</td>
<td>Performance not as good as other RLS, complex programming</td>
</tr>
<tr>
<td>Gradient Lattice DFE</td>
<td>$13N_1 + 33N_2 - 36$</td>
<td>Low computational complexity</td>
<td>Complex programming</td>
</tr>
<tr>
<td>Fast Kalman DFE</td>
<td>$20N + 5$</td>
<td>Can be used for DFE, fast convergence and good tracking</td>
<td>Complex programming, computation not low, unstable</td>
</tr>
<tr>
<td>Square Root RLS DFE</td>
<td>$1.5N^2 + 6.5N$</td>
<td>Better numerical properties</td>
<td>High computational complexity</td>
</tr>
</tbody>
</table>

Table 1 Comparison of various algorithms for adaptive equalization