Term Project

Adaptive Channel Equalization

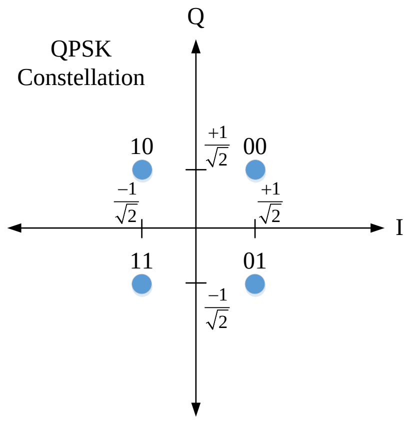
The purpose of adaptive channel equalization is to compensate for signal distortion in a communication channel. Consider a digital communication system that transmits data from one terminal to another through an unknown wireless multipath channel with additive white Gaussian noise (AWGN). During the transmission process, a transmitted signal that contains information symbols becomes distorted at the receiver. For the sake of recovering the information symbols (or called original data), one can apply an adaptive filter to the received signal as a way of distortion compensation.

As illustrated in Figure 1, an adaptive filter works as a channel equalizer (i.e., adaptive equalizer) with two operating modes as follows:

1) **Training Mode**: The adaptive equalizer works with a known training sequence to identify the channel characteristics.
2) **Decision-Directed Mode**: The output of the decision device is used to generate the error signal for adaptation of the filter coefficients.

At the transmitter using quadrature phase shift keying (QPSK) modulation, the training sequence followed by a sequence of information data is transmitted over the channel. At the receiver, the received signal $v(n)$ is passed through the adaptive equalizer, whose output $y(n)$ is fed into the decision device for symbol-by-symbol detection with the following rule:

$$z(n) = \begin{cases} \dfrac{+1+j}{\sqrt{2}}, & \text{if } \operatorname{Re}\{y(n)\} \geq 0 \text{ and } \operatorname{Im}\{y(n)\} \geq 0 \\ \dfrac{-1+j}{\sqrt{2}}, & \text{if } \operatorname{Re}\{y(n)\} < 0 \text{ and } \operatorname{Im}\{y(n)\} > 0 \\ \dfrac{-1-j}{\sqrt{2}}, & \text{if } \operatorname{Re}\{y(n)\} < 0 \text{ and } \operatorname{Im}\{y(n)\} < 0 \\ \dfrac{+1-j}{\sqrt{2}}, & \text{if } \operatorname{Re}\{y(n)\} > 0 \text{ and } \operatorname{Im}\{y(n)\} < 0 \end{cases}.$$



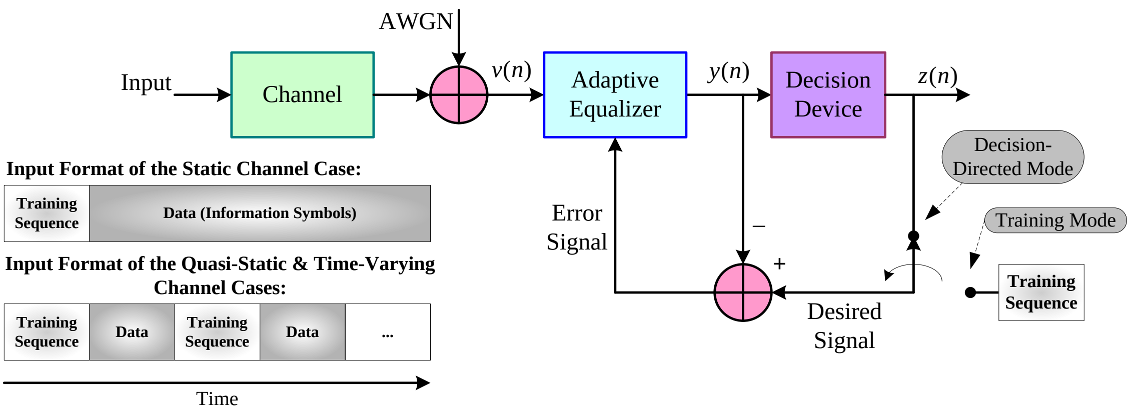


Figure 1. An adaptive equalizer for digital communications.

Initially, the adaptive equalizer operates in the training mode, using the known training sequence as the desired signal. Then, it switches to the decision-directed mode, where the output of the decision device is directly used as the desired signal.

In this project, please design adaptive channel equalizers to recover the original data for each of the following channels: a static channel, a quasi-static channel, and a time-varying channel. Also, compare the output of the decision device in the decision-directed mode with the transmitted data to evaluate both the symbol error rate (SER) and the bit error rate (BER) performances of the designed adaptive equalizers. You will have to showcase your design in terms of the algorithm design/analysis, BER performance, and computational complexity.

I. Static Channel Case:

For the static case, the channel is fixed during the transmission, and the channel input consists of a *1000-symbol training sequence followed by a 200000-symbol data sequence.*

II. Quasi-Static Channel Case:

For the quasi-static case, the channel remains unchanged within a block interval, where the channel input for each block interval consists of a *200-symbol training sequence followed by a 1000-symbol data sequence*. In this case, the training mode and the decision-directed mode are required for each block interval.

III. Time-Varying Channel Case:

For the time-varying case, the channel changes rapidly and may change during a block interval, where the channel input for each block interval consists of a *50-symbol training sequence followed by a 400-symbol data sequence*. In this case, the training mode and the decision-directed mode are required for each block interval.

Detailed Project Information:

QPSK modulation: $(+1+j)/\sqrt{2}$, $(-1+j)/\sqrt{2}$, $(-1-j)/\sqrt{2}$, $(+1-j)/\sqrt{2}$.

Data file: **project_data2024.mat** (You can use MATLAB function ‘`load`’ to open it)

Part 1: Static Channel Case

- trainseq_static_1 and trainseq_static_2: The known training sequence with length of 1000 symbols
- data_static_1 and data_static_2: The received sequence, which is given in the format of data_static = [**a**, **b**], where **a** is the received training sequence and **b** the received data (information symbols) sequence.
- Design an adaptive equalizer to recover the original data.
- Save the recovered data as ***ans_static.mat*** (including **ans_static_1** and **ans_static_2**).

Part 2: Quasi-Static Channel Case

- trainseq_qstatic_1 and trainseq_qstatic_2: The training sequence with length of 200 symbols. Note that this training sequence is applied whenever operating in the training mode.
- data_qstatic_1 and data_qstatic_2: The received sequence, given as the format of data_qstatic = [$\mathbf{a}_1$, $\mathbf{b}_1$, $\mathbf{a}_2$, $\mathbf{b}_2$, …, $\mathbf{a}_{200}$, $\mathbf{b}_{200}$], where $\mathbf{a}_n$ are the received training sequences; $\mathbf{b}_n$ are the received data (information symbols) sequences, 1000 symbols for each.
- Design an adaptive equalizer to recover the original data. (Note: There are 200 times that the system operates in the training mode, and 200 times in the decision-directed mode, where each training sequence of 200 symbols is followed by a data sequence of 1000 symbols.
- Save sequentially the recovered data as ***ans_qstatic.mat*** (including **ans_qstatic_1** and **ans_qstatic_2**).

Part 3: Time-Varying Channel Case

- trainseq_varying_1 and trainseq_varying_2: The training sequence, with a length of 50 symbols, applied in the training mode.
- data_varying_1 and data_varying_2: The received sequence, given as the format of data_varying = [$\mathbf{a}_1$, $\mathbf{b}_1$, $\mathbf{a}_2$, $\mathbf{b}_2$, …, $\mathbf{a}_{500}$, $\mathbf{b}_{500}$], where $\mathbf{a}_n$ is the n-th received training sequences; $\mathbf{b}_n$ is the n-th received data (information symbols) sequences, 400 symbols for each.
- Design an adaptive equalizer to recover the original data. (Note: There are 500 times that the system operates in the training mode, and 500 times in the decision-directed mode, where each training sequence of 50 symbols is followed by a data sequence of 400 symbols.)
- Save sequentially the recovered data as ***ans_varying.mat*** (including **ans_varying_1** and **ans_varying_2**).

Note:

- The sizes of data used for simulations are given as follows:

  trainseq_static: 1×1000; data_static: 1×201000
  trainseq_qstatic: 1×200; data_qstatic: 1×240000
  trainseq_varying: 1×50; data_varying: 1×225000

- The simulation results have to be recorded in the following format:
  (You need to turn symbols into bits according to the given gray code.)
  ans_static: ans_static_1 (1×400000) and ans_static_2 (1×400000);
  ans_qstatic: ans_qstatic _1 (1×400000) and ans_qstatic _2 (1×400000);
  ans_varying: ans_varying _1 (1×400000) and ans_varying _2 (1×400000).