Iterative Equalization Schemes with Efficient Frequency Domain Implementation

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PRESENTATION OUTLINE

✔ Frequency Domain implementation of equalizers for single carrier – single user systems
✔ Hybrid DFE
✔ Iterative block DFE
✔ Numerical results
✔ Application to CDMA: parallel interference cancellation and FD-DFE
FREQUENCY DOMAIN DFE

✓ **Performance:**
  - Linear equalizers are not effective for highly dispersive channels
  - We consider implementations of decision feedback equalization (DFE)

✓ **Complexity (operations/sample):**
  - Both linear and non-linear equalizers are based on filters
  - Efficient implementation of filters is achieved by operating in the frequency domain (FD) by means of Discrete Fourier Transforms (DFTs)
IMPLEMENTATION IN THE FREQUENCY DOMAIN

Time domain convolution

= Product of discrete Fourier transforms

if convolution between the transmitted signal and channel is forced to be circular on blocks
TRANSMISSION FORMATS

Two transmission formats force circularity:

- Cyclic extended transmission (OFDM)

\[
\begin{align*}
D_2(k) & & D_1(k) & & D_2(k) & & D_2(k+1) & & D_1(k+1)
\end{align*}
\]

- UW-extensions (or zero padding) (FD-DFE)

\[
\begin{align*}
UW & & D(k) & & UW & & D(k+1)
\end{align*}
\]
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**HDFE SCHEME**

- **In HDFE:**
  - the feedforward is implemented in the FD on a block-basis
  - the feedback is implemented with a filter in TD on a symbol-basis

Only UW extension can be used in order to start the FB process
HDFE WITH NO UW EXTENSION

✓ The UW extension
  • Protects the received signal from inter-block interference
  • Forces circularity of the convolution with the channel
✓ DRAWBACK: UW extension reduces the system throughput; long DFTs must be used to increase spectral efficiency
✓ In OFDM, channel shortening techniques for the reduction of the channel impulse response length can be used, at the expense of increased complexity
OVERLAP AND SAVE TECHNIQUE

✓ With overlap-and-save (OS) techniques the UW can be removed.
✓ OS allows the use of H-DFE for existing single carrier transmission standards
✓ The partitioning of the received and detected signal for OS becomes:

\[
\begin{array}{c}
\text{overlap} \\
L \\
\hline
r(k-1) \ldots r(k) \ldots r(k+1) \\
\end{array}
\]

\[\text{DFT size (P)}\]

\[\text{decoded block (M)}\]
SCHEME OF THE HDFE WITH OS

- The S/P with OS block is the serial to parallel converter according to OS
- Filters are designed to minimize ISI and IBI
- Still a linear system must be solved
PROS/CONS OF HDFE

✓ ADVANTAGES:
  • Efficient implementation of the feedforward filter in the FD
  • Low PAPR (single carrier transmission)

✓ DISADVANTAGES:
  • Time domain (= high complexity) implementation of the feedback filter
  • Matrix inversion required for the design of non-adaptive DFE
  • Coding of the transmitted data is not exploited in the feedback part
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THE ITERATIVE BLOCK DFE

- Both FF and FB filters are implemented in the FD.
- The DFE iterates equalization and detection.
- At the first iteration the received block signal is equalized in the FD and detected.
- For next iterations, the detected data of the previous iteration are used as input of the FB.
SCHEME OF THE IBDFE

FF filter with UW removal

FB filter with UW restoring

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CORRELATION-BASED DESIGN

✓ Filter design includes the reliability of the detected data at the previous iteration.

✓ The input to the feedback is the block of hard detected symbols, in the FD.

✓ The design criterion is the minimization of the mean square error (MSE) at the input of the receiver.

✓ At iteration $l$ filter coefficients are $C^{(l)}$ and $B^{(l)}$. 
SOFT-DETECTION BASED DESIGN (1/3)

- In the correlation-based IBDFE only the average reliability of the block is considered for the filter design.

- The actual distribution of reliability among samples affects significantly the performance.

- New approach: the reliability of each detected symbol is used to generate directly the FB signal.

- Soft decisions are used to feed the feedback, i.e. the average symbol according to the log-likelihood ratio of the symbols, as provided by the previous iteration.
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PERFORMANCE EVALUATIONS

✓ Two scenarios for the transmission channel:
  • Channel C [Proakis] with two spectral nulls
  • Rayleigh fading multipath channel with a rms delay spread of two symbols and exponentially decaying power delay profile.

✓ QPSK with ideal channel estimate.
✓ DFT: $P = 128$, PN-extension length: $L = 16$.
✓ TD-DFE with filters of 16 taps.
Channel C - HD-IBDFE

✓ The iterative process is not very effective beyond the second iteration due to the spectral nulls of the channel.

At the first iteration HD-IBDFE corresponds to linear equalizer.
The first two iterations yield a significant gain in performance.

Performance of H-DFE is also shown.

HD-IBDFE has a gain of about .5 dB over H-DFE @ BER = $10^{-3}$.
Rayleigh channel – SD-IBDFE

- SD-IBDFE outperforms HD-IBDFE of about 1 dB at BER = 10^{-3}.

- TD-DFE-ID: ideal TD-DFE where the FB filter is fed with the transmitted data.

- SD-IBDFE is 2 dB from the matched filter bound.
THROUGHPUT COMPARISON

- Throughput comparison for transmission with ARQ.
- Throughput as a function of the channel delay spread. Rayleigh fading channel.
- The length of CP/UW has been adapted to the channel ds.
- 20 MHz band; BPSK transmission.
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INTERFERENCE CANCELLATION FOR CDMA

Interference cancellation (IC): multistage or iterative schemes are used where MAI is cancelled on the basis of tentative decisions.

DRAWBACKS OF IC TECHNIQUES

- High complexity due to time-domain implementation of rake receiver and interference generation.
- Error floor due to ISI which is not cancelled by rake receiver.

NEW ARCHITECTURE

- Frequency-domain (FD) implementation of filters.
- Block DFE to combat ISI.
FREQUENCY DOMAIN PIC (FD-PIC)

- Users are detected in parallel and detection, MAI generation and cancellation are performed iteratively.
- The interference $k$ block generates the contribution of user $k$ to the received signal with increasing reliability.
**INTERFERENCE_{k} BLOCK**

- Regenerates the interference of user \( k \).
- The DFE operates iteratively on sample blocks. Each block is equalized and detected.
- Feedback signal:
  - Initially, the FB filter of the DFE is not active and MMSE linear equalization is performed;
  - Next, the FB filter of the DFE has as input the detected data of the previous iteration.
CHIP INTERLEAVING

- Detection errors of previous iterations are propagated by the feedback.
- CDMA transmission format worsens the error propagation, since an error on one symbol yields many chips in error.
- To reduce the problem we interleave the chips at the transmitter.
✓ Walsh-Hadamard codes
✓ BPSK modulation
✓ Quasi-synchronous transmission on Rayleigh fading dispersive channel
  • exponential power delay profile ($r_{ms_{ds}} = 2T$, $T$: chip period)
✓ DFT (PN) length: 256 (16)
✓ PIC and one DFE iteration
✓ $E_b/N_0 = 16$ dB.

✓ Dashed lines: RAKE-FD-PIC.
✓ Continuous lines: DFE-FD-PIC.

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OPEN PROBLEMS AND FUTURE WORK

✓ Investigation on the stability and convergence of the iterative equalizer

✓ Evaluation of the impact of channel estimation errors/phase noise and other impairments

✓ Study of adaptive techniques that can be applied to HDFE and IBDFE

✓ Further studies and simplifications of the IBDFE scheme when applied to CDMA
Thank you for your attention

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