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Decision Feedback Equalization in Single-Carrier FDMA

Gillian Huang, Andrew Nix and Simon Armour
Outline

• 3GPP LTE uplink – Single-Carrier Frequency Division Multiple Access (SC-FDMA)
• Decision feedback equalizer (DFE) for SC-FDMA
• A performance comparison of SC-FDMA with linear equalizer (LE) and DFE
• Conclusions
• Solutions to error propagation problem in DFE
3GPP Long-Term Evolution (LTE)

- 3GPP LTE: Meet the customer’s need in the next 10-15 years
- SC-FDMA has a low PAPR (Peak-to-Average Power Ratio), which means power efficient transmission at the mobile terminal.
SC-FDMA Transceiver Architecture

- SC-FDMA can be seen as DFT precoded OFDMA or SC-FDE with the flexibility in spectrum allocation.
- Flexibility in spectrum allocation → subcarrier mapping scheme?
**SC-FDMA Subcarrier Mapping Schemes – Distributed and Localized**

**DFDMA**
- Exploit frequency diversity
- FD upsampling → Repetition of the TD baseband symbols at DFDMA output.

**LFDMA**
- Exploit frequency selectivity via CDS (Channel-Dependent Scheduling)
- FD zero padding → Interpolation of the TD baseband symbols at LFDMA output.

- Can we use randomized subcarrier mapping for SC-FDMA? No, high PAPR.
- DFDMA and LFDMA are the only two special cases for SC-FDMA systems to be SC!
Impact of Frequency-Domain Equalization (FDE) to MC and SC systems

**MC systems: OFDM and OFDMA**

- Baseband symbols are mapped directly onto the subcarriers in the FD.
- One-tap FDE is used to correct the amplitude and phase distortion due to the channel on each subcarrier. However channel itself does not introduce ISI (i.e. ICI) to a MC system as long as the subcarriers remain orthogonal.
- Hence MMSE-FDE is the best way of equalizing OFDM signals.

**SC systems: SC-FDE and SC-FDMA**

- Transmission and the detection of baseband symbols is still in the TD.
- A wideband channel introduces ISI to a SC system. MMSE-FDE is equivalent to MMSE-LE in the TD.
- Although one-tap FD-LE is simple, it does not give the best performance for equalizing a SC signal in a wideband channel.
- DFE can be used to improve the performance.
DFE vs. LE for a SC system

**MMSE-LE**
- Minimizes the filtered noise and residual-ISI at the equalizer output.
- In the presence of noise, there will be residual-ISI at both precursors and postcursors.

**MMSE-DFE**
- Minimizes the filtered noise and residual precursor-ISI at the equalizer output, assuming that postcursor-ISI can be removed by the FB filter (ideal-DFE).
- In decision-directed mode, DFE is liable to error propagation.
- For DFE structure in SC-FDE, Falconer proposed to use a FD-FF (feedforward) filter and a TD-FB (feedback) filter. This hybrid DFE structure can be extended to SC-FDMA.
SC-FDMA Receiver with DFE

Length of FB filter: where $L$ can be maximum channel delay spread or the CP length.

- DFDMA: $N_{FB} = L - 1$
- LFDMA: $N_{FB} = \text{ceil} \left( L \times \frac{N_{used}}{N_{sub}} \right) - 1$
SC-FDMA with DFE (no channel coding) – SCME Channel Model

- DFDMA has better performance than LFDMA due to the frequency diversity.
- DFE outperforms LE in the uncoded case.
LFDMA with DFE (with channel coding)

- DFE has worse performance than LE when channel coding is applied.
- DFE has more error-free blocks than LE before decoding. However, DFE has less correctable blocks than LE due to error propagation.
Performance comparison of LFDMA with DFE and LE (with and without channel coding)

- Note: Uncoded QPSK with DFE has similar BLER as ½-rate coded 16QAM with LE. Both give the same data-rate and throughput.
- QPSK with DFE is more advantageous since QPSK signals have smaller PAPR than 16QAM signals.
For pulse shaped signal (RC filter with roll-off factor = 0.2), pi/4-QPSK gives a 2dB PAPR reduction compared to 16QAM.

This PAPR reduction can translate to more power efficient transmission at the mobile terminal or coverage extension. Both are desirable on the uplink.
Conclusions

• FD-LE is the simplest way to equalize SC-FDMA signal in a wideband channel. However, DFE can be used to improve the performance with additional complexity at the BS.
• DFE outperforms LE in the uncoded case but gives worse performance than LE in the coded case due to error propagation.
• In order to achieve better DFE performance in the coded case, error propagation problem needs to be overcome!
Possible Solutions to Error Propagation

• Tomlinson-Harashima Precoding (THP) can be used at the transmitter. However the drawback of THP is the increase PAPR, which conflicts with the uplink design goal → Not the best solution.

• Iterative block DFE (IB-DFE) was proposed by Chan in 2001. IB-DFE is robust against error propagation and hence outperforms LE in the coded case. Design challenge of IB-DFE is the FB reliability calculation.
Thank You

Gillian Huang, Andrew Nix and Simon Armour

G.Huang@bristol.ac.uk
Andy.Nix@bristol.ac.uk
Simon.Armour@bristol.ac.uk