Design of Expanded Constellations for PAPR Reduction in OFDM Systems

Speaker: Dr. Ali Al-Shaikhi
Assistant Professor, EE department
Outline

- Communication System Demand
- OFDM
  - Basic Principle
  - The Overall System
  - Advantages, Applications, Problems (High PAPR)
- Techniques Used to Reduce the High PAPR
- The Proposed Technique to Reduce the High PAPR
  - Redial Symmetry Based Technique
  - Constellation Expansion for Alternative Points on:
    - External Circle
    - External Square
- Application of the Design and Results for:
  - QPSK and 16 QAM (external circle)
  - 64QAM and 256 QAM (external square)
- Conclusion

Dr. Ali Al-Shaikhi, EE Dept.
Communication System

- The demand is increasing for:
  - Wireless communication
  - High data rate transmission
- Under such demand → multipath fading channel
- Multipath: multiple reflected signals with different phases and times arrivals
  - The time difference between first and last multipath components is the delay spread distortion
  - The signal spreads due to the different phases leading to ISI
- The Best Solution?! OFDM
Orthogonal Frequency Division Multiplexing (OFDM)

- Multi-tones modulation
- The wide bandwidth is divided into a number of small equally spaced frequency bands
- A subcarrier carrying a portion of the user information is transmitted in each band
- The subcarriers are overlapping but they are recoverable since they are orthogonal

Dr. Ali Al-Shaikhi, EE Dept.
OFDM System

Dr. Ali Al-Shaikhi, EE Dept.
Advantages

- Immunity to delay spread
  - Symbol duration > channel delay spread
- Robust against ISI
  - Simple or no equalization
- High spectral efficiency
  - Because of subcarriers overlapping
- Efficient implementation using FFT
  - No need for mixers
Applications

- ADSL and VDSL broadband access via telephone network copper wires
- IEEE 802.11a and 802.11g Wireless LANs
- The Digital audio broadcasting systems EUREKA 147, Digital Radio Mondiale, HD Radio, T-DMB and ISDB-TSB
- Terrestrial digital TV systems DVB-T, DVB-H, T-DMB and ISDB-T
- IEEE 802.16 or WiMax Wireless MAN
- IEEE 802.20 or Mobile Broadband Wireless Access (MBWA)
- Flash-OFDM cellular system
- Some Ultra wideband (UWB) systems
- Power line communication (PLC)
OFDM Problems

- Sensitive to Doppler shift
- Sensitive to frequency synchronization
- High PAPR

\[
PAPR = \max_{0 \leq t < T} \frac{\left| x^m(t) \right|^2}{E\left[ \left| x^m(t) \right|^2 \right]}\]

Dr. Ali Al-Shaikhi, EE Dept.
High PAPR Problem

- The high PAPR causes the peaks to enter the saturation region of the HPA
- Non-linear amplification by the HPA:
  - In-band distortion: increases the BER at the receiver
  - Out-off-band distortion: causes spectral regrowth
Solutions to High PAPR

- Use HPA that is highly linear
  - Very expensive
- Try to operate the HPA in the linear region
  - Large back off is required
  - Not efficient use of the HPA
- Linearize the HPA by using pre-distorters
- Try to reduce the high PAPR
PAPR Reduction Techniques

- Clipping/filtering
- Coding
  - FEC
  - Phase Optimization
  - Partial Transmit Sequence
  - Selected Mapping (SLM)
- Probabilistic
  - Tone Reservation (TR)
  - Tone Injection (TI)
  - Active Constellation Extension (ACE)
  - Error Insertion (EI)
- PAPR reduction at the expense of: complexity↑, average power↑, BER↑, and data rate↓
Tone Injection
Error Insertion
Active Constellation Extension
Proposed Technique to Reduce the High PAPR

- Radial symmetric mapping provides the most reduction to the high PAPR in OFDM system.
- Design the constellation in such a way that we take advantage of such location using two form of constellation expansion:
  - On an external circle: each alternative point is radially symmetric to original point(s). High average power increase especially for high level QAM.
  - On an external square: each alternative point is radially symmetric to a group of original points. Minimum average power increase. It is good for high level QAM.
- In both designs, the minimum distance of the constellation is maintained.
- When we have ambiguity, the alternative signalling points represent recoverable erasures introduced at the transmitter for the purpose of reducing PAPR.
Radial Symmetry Concept

\[ x_H[n] = |x_H[n]|x_H[n] \]
\[ \bar{\rho} e^{j\phi} = x_L[n] - x_H[n] \]
\[ \rho e^{j\phi} = x_L[n] - x_H[n] \]
\[ x_L[n] < x_L[n] \]
\[ x_L[n] = x_H[n] + (x_L[n] - x_H[n]) \]
\[ = x_H[n] + \rho e^{j\phi} \]
\[ = |x_H[n]| e^{j\arg(x_H[n])} + \rho e^{j\phi} \]
Test and Statistics

QPSK, 64 Tones

<table>
<thead>
<tr>
<th>Location</th>
<th>RS</th>
<th>FA</th>
<th>OP</th>
<th>FS</th>
<th>CO</th>
<th>SA</th>
<th>CL</th>
<th>CRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>46.2</td>
<td>17.4</td>
<td>17.5</td>
<td>6.8</td>
<td>6.7</td>
<td>2.1</td>
<td>2.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Dr. Ali Al-Shaikhi, EE Dept.
Alternative Points on External Circle: QPSK and 16QAM Designs

QPSK

16QAM

Dr. Ali Al-Shaikhi, EE Dept.
Alternative Points on External Square: 256QAM with 4-to-1 Mapping
Framework: Frequency Perturbation
Search Model: QPSK
Symbols From Pass 1

Pass 2: Iteration 0

Pass 2: Iteration 1

Pass 2: Iteration N-1

\( f_0 \)

\( f_1 \)

\( f_2 \)

\( f_{n+1} \)

PAPR = 6.4 dB

PAPR = 5.5 dB

Skip This Iteration

PAPR = 5.2 dB

(2)
Search Model: QPSK

Dr. Ali Al-Shaikhi, EE Dept.
CCDF: QPSK and 64 Tones

Dr. Ali Al-Shaikhi, EE Dept.
CCDF: 16QAM and 64 Tones (NE)
CCDF: 16QAM and 64 Tones (WE)
CCDF: 256QAM and 64 Tones
## Tone Usage and Average Power Increase

<table>
<thead>
<tr>
<th></th>
<th># Tone Changes</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QPSK</td>
<td>0.32</td>
<td>0.61</td>
<td>0.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16QAM (Fixing Inner Points)</td>
<td>0.19</td>
<td>0.38</td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16QAM (Erasure Decoding)</td>
<td>0.24</td>
<td>0.48</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64QAM</td>
<td></td>
<td>0.171</td>
<td></td>
<td>0.304</td>
<td>0.340</td>
<td></td>
</tr>
<tr>
<td>256QAM</td>
<td></td>
<td>0.140</td>
<td></td>
<td>0.259</td>
<td>0.292</td>
<td></td>
</tr>
<tr>
<td><strong>Tones</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>QPSK</td>
<td>99</td>
<td>93</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16QAM (Fixing Inner Points)</td>
<td>99.5</td>
<td>94</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16QAM (Erasure Decoding)</td>
<td>99.7</td>
<td>95.5</td>
<td>87</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64QAM</td>
<td></td>
<td>95.3</td>
<td></td>
<td>58.9</td>
<td>37.3</td>
<td></td>
</tr>
<tr>
<td>256QAM</td>
<td></td>
<td>95.9</td>
<td></td>
<td>61.2</td>
<td>39.6</td>
<td></td>
</tr>
</tbody>
</table>
PSD of the proposed technique: 16-ary QAM and 64 sub-carriers
PSD of the proposed technique: 16-ary QAM and 64 sub-carriers
Conclusion

- Radial symmetric mapping provides the most reduction to the high PAPR in OFDM system.
- We designed expanded constellations to exploit the concept of radial symmetry by location the external points on an external square.
- The minimum distance is maintained and the square is specially suitable for high level QAM since the increase in average power is very small.
- Erasure decoding was used to deal with the ambiguity when a radial symmetric point corresponds to multiple original points.
- The average power increase was discussed and found to be relatively small.
- This scheme is very flexible and easily extendable to high level QAM.
- The proposed method offers tradeoff between PAPR reduction and the system’s ability to recover from errors in the channel.
Design of Expanded Constellations for PAPR Reduction in OFDM Systems

Thank You For Your Attention