DNN-Based Power Amplifier Pre-Distortion for Communications in Contested Environments

Presenter: Yi Feng
Power Amplifier in Communication Systems

- Hardware limitations can be key issues in efficient communications in complex and contested environments.
- Power amplifiers (PA) are crucial and most common elements in many hardware implementations.
- Ideal power amplifiers operate linearly.
- Real-world PA encounters many non-linearities.
- Non-linearity leads to:
  - Spectrum growth
  - Constellation distortion
- Performance degradation in communications.
Digital Pre-Distortion & PA Modeling

- Digital pre-distortion is an efficient method to compensate PA non-linearities (flexible and re-configurable).

- Traditional methods: In order to design the pre-distorter, the first step is often to have a good model of PA.

- Classic PA models:
  - Memoryless model, e.g., Saleh
  - Models with memory, e.g., Volterra
Indirect Learning and Direct Learning in Pre-Distorter Design

- Key steps:
  - Step 1: Train/fit the model by optimizing the model parameters using the reversed Input-Output PA measurements.
  - Step 2: Duplicate the fully trained Post-Distortion model and use it as a Pre-Distortion model.
- Can lead to a biased solution, but still very popular and widely used.

- Two-stage process:
  - Stage 1: First identify and model power amplifier.
  - Stage 2: Fixed PA model and identify Pre-distorter.
- Two networks needed (PD & PA) with special overall training.
Pre-Distorter Design via Normalizing Flow based Neural Network

The idea of normalizing flow:

- Model the non-linearities using reversible neural networks with forward/backward mode.
- Train the network in the forward mode for the power amplifier modeling, and directly use trained neural network in the backward mode as pre-distorter (for power amplifier system inversion).

Pre-distorter design idea:
Reversible Neural Network Structure and PA Datasets

- Gaussian input/output training datasets
- Higher probabilities for selecting larger PA input power data while forming training batch
- Test: OFDM signal samples (4x oversampling)

Construct training sets (input/output of PA) using Wiener model

\[ H(z) = 1 + 0.154z^{-1} + 0.077z^{-2}, \]

\[ |y_s(n)| = \frac{\alpha_a |x(n)|}{1 + \beta_a |x(n)|^2}, \]

\[ \angle y_s(n) = \frac{\alpha_p |x(n)|^2}{1 + \beta_p |x(n)|^2}, \]

\[ \alpha_a = 5, \beta_a = 1, \alpha_p = \pi/3, \beta_p = 1. \]
Flow-based Neural Network Predistortion

- Static vs dynamic non-linearities
- Linearization performance
Phase Linearization

<table>
<thead>
<tr>
<th>Linearized</th>
<th>Mean (degree)</th>
<th>Std (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All region</td>
<td>-0.2468</td>
<td>1.2361</td>
</tr>
<tr>
<td>5-25 dBm</td>
<td>-0.2590</td>
<td>0.6009</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Original</th>
<th>Mean (degree)</th>
<th>Std (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA signal</td>
<td>3.5753</td>
<td>12.2959</td>
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</tbody>
</table>
Performance Metrics

![Graph showing performance metrics](image)

**Table I: Performance Parameters**

<table>
<thead>
<tr>
<th></th>
<th>PA</th>
<th>PD-PA</th>
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</thead>
<tbody>
<tr>
<td>NMSE</td>
<td>-13.9</td>
<td>-32.1</td>
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<tr>
<td>ACPR</td>
<td>-22.7</td>
<td>-26.7</td>
</tr>
<tr>
<td>EVM</td>
<td>0.1915</td>
<td>0.0196</td>
</tr>
<tr>
<td>P_{clip}</td>
<td>49.54%</td>
<td>0.83%</td>
</tr>
</tbody>
</table>
Summary

- Proposed a reversible neural network for doing non-linear power amplifier modeling & pre-distortion.
- Can be used as add-ons to non-linear power amplifiers in the wireless communication systems for linearization improvements (for both static and memory non-linearities).
- Can provide better performance in communications, e.g., inter-carrier interference reduction, in complex and contested wireless environments.
- Can be combined with additional PAPR reduction pre-processing techniques, e.g., coding, clipping and filtering.