Research context and motivation

- Single Frequency Network (SFN) Terrestrial Broadcasting
  - All stations transmit signal at the same time over the same frequency channel
  - Orthogonal Frequency Division multiplexing (OFDM)
  - Symbol by symbol detection
  - CP length increases with Inter Site Distance (ISD)
  - Symbol length reduces with user speed
  - DVB-T2 & ASTC 3.0
- The LTE-based Terrestrial Broadcasting
  - Dedicated for Terrestrial Broadcasting (2.5 kHz and 0.37 kHz)
  - Mobile handheld users and roof-top reception
- The fifth generation New Radio (5G NR)
  - 15 kHz, …, and 240 kHz carrier spacing
  - Uni-cast and low latency transmission (Maximum ISD 5 km)
  - Not compatible with broadcaster infrastructures (short CP length 4.7 us)

Addressed research questions/problems

- Modelling an SFN network with Tap Delay Line (TDL-A)
  - Properly scaling maximum delay spread according to the considered ISD
  - Carrier frequency 700 MHz
  - Maximum Doppler shift 130 Hz (160 km/h)
  - Single Frequency networks
  - High Power High Tower (HPHT)
  - Low Power Low Tower (LPLT)

**SFN Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LPLT</th>
<th>HPHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISD [km]</td>
<td>15</td>
<td>125</td>
</tr>
<tr>
<td>DS [µs]</td>
<td>20</td>
<td>50</td>
</tr>
</tbody>
</table>

The classical OFDM system and position of proposed RNN detector

- The OFDM design for SFN networks becomes progressively inefficient
- Trade-offs between CP length, channel delay spread, carrier spacing a user mobility
- To remove ISI, the CP larger than the delay spread (DS)
- To remove ICI, symbol smaller than channel coherence time
- Pilots introducing a large overhead
- To support 5GNR numerologies for Terrestrial broadcasting
  - An advanced OFDM detector capable of dealing with large ISII/ICI
  - May eliminate the CP inefficiency, but cannot eliminate inefficiency due to the required pilot density

Novel contributions

- 5G NR SFN Terrestrial broadcasting with Bidirectional Long Short-Term Memory
  - Replacement of the channel estimator, channel equalization, and LLR with one RNN
  - Superimposing pilot and data signals
  - \( z = d \sqrt{1 - a^2 + pa} \)

Input vector to the RNN

- M consecutive OFDM symbols
- Output of RNN receiver
- \( N_{\text{max}} \) \hspace{1cm} log-likelihood ratios of bits for the following decoder

Complexity of a LSTM cell

- \( F = 2m \times 4(1 \times U + U^2 + U) \)
- \( U \) is number of units in a cell

Unrolled RNN detector

Adopted methodologies

- RNN System parameters and preliminary data generation for training
  - 12 OFDM carriers with 5G NR (15 kHz)
  - 4-QAM constellation and number of receiver antennas \( K = 2 \)
  - Speed: LPLT (100 km/h) and HPHT (3 km/h)
  - 10 million pairs \((y_n, c_n)\) at fixed SNR=5 dB one for LPLT and one for HPHT
- Minimizing the binary cross entropy loss between target and response
- First RNN preliminary Hyper-Parameter optimization \((\alpha, M)\)
  - Fixing the number of units in RNN cell to \( U = 400 \) and dropout probability 0.5
- Then Full training one for LPLT RNN network and one HPHT RNN network

**Reference systems**

<table>
<thead>
<tr>
<th>Carrier Spacing</th>
<th>Max ISD</th>
<th>Target</th>
<th>( F_1 )</th>
<th>( F_2 )</th>
<th>( F_3 )</th>
<th>network</th>
<th>( \eta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 kHz</td>
<td>15 km</td>
<td>Mobile users</td>
<td>2</td>
<td>2</td>
<td>LPLT</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>0.37 kHz</td>
<td>175 km</td>
<td>Roof-top</td>
<td>3</td>
<td>2</td>
<td>HPHT</td>
<td>0.75</td>
<td></td>
</tr>
</tbody>
</table>

**Performance of RNN vs Classical Terrestrial Broadcasting system**

- RNN largely outperforms the classical system and provides excellent performances in large ranges of SNRs and user speeds
- Flexibility to face rapid channel changes and strong ISII/ICI

Simulation results

- Reduction of complexity of RNN network
- Higher order modulations
- The scaling of the proposed receiver solution to the practical bandwidth
- Adoption for mobile SFN network with 5G NR numerology of other types of advanced but classical receivers
- The flexibility of a single trained RNN also to different network infrastructures ISD

List of attended classes


Submitted and published works

- 01UNIvHR – Advanced iterative techniques for digital receivers (12/1/2021, 4)
- 01UNIvHR – Adversarial training of neural networks (1/7/2020, 3)
- 01UNIvHR – Data mining concepts and algorithms (20/1/2020, 4)
- 01Student – Entrepreneurship and start-up creation (3/7/2019, 8)
- 01UNIvHR – Human-AI Interaction (9/2/2019, 8)
- 01REMR – Optimization methods for engineering problems (15/5/2020, 6)
- 01FURV – Advanced scientific programming in MATLAB (29/6/2020, 4)
- 01UNIvHR – Lingua italiana I livello (17/2/2020, 3)