Cooperative and Reconfigurable Telecommunication Systems based on FPGA.

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Alma Mater University of Bologna
Outline

Video over wireless:

FPGA design and implementation of a pulse-based echo canceller for DVB-T.

- Problems and Goals;
- The BB-OCR solution for DVB-T signal;
- FPGA Design and Implementation;
- Workbench Test-Bed;
- Measurements and Results.

Pilot Design in a Multi-Cell Multi-User MIMO-OFDM Network with Beamforming

- Scenario and System Model;
- Pilot Aided Channel Estimation (PACE);
- SINR and Capacity evaluation.

Conclusions

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Echo canceller for DVB-T/H: Problems and goals

- Single Frequency Network (SFN) constituted by:
  - a DVB-T/H broadcasting station;
  - many stationary and mobile users.

- Main goal: covering with the DVB-T signal an area not reachable by the DVB-T broadcast station (fixing the performance at the final users).
Echo canceller for DVB-T/H: Problems and goals

- **Adopted strategy:** DVB-T repeater (OCR).

- **Main problem:** coupling between the transmitting and the receiving antennas (echoes).

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Echo canceller for DVB-T/H: Problems and goals

- **Consequence:** instability problem; the amplifier power must be limited

- **Reduced service area!**
Echo canceller for DVB-T/H: Target Situation

- The echo canceller permits to increase the coverage area
### Echo canceller for DVB-T/H: Classical Solution

<table>
<thead>
<tr>
<th></th>
<th>Antenna Isolation</th>
<th>Time Delay</th>
<th>Quality of Tx signal</th>
<th>Selectivity of Rx signal</th>
<th>Mantain Sync.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF OCR</td>
<td>✗</td>
<td>↓</td>
<td>↑↑</td>
<td>↓</td>
<td>↑↑</td>
</tr>
<tr>
<td>IF OCR</td>
<td>✗</td>
<td>↓</td>
<td>↑↑</td>
<td>↓</td>
<td>↑↑</td>
</tr>
<tr>
<td><strong>BB OCR</strong></td>
<td>✓</td>
<td>↓</td>
<td>↑</td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>Dec. OCR</td>
<td>✗</td>
<td>↓</td>
<td>↓</td>
<td>↑↑</td>
<td>↓↓</td>
</tr>
</tbody>
</table>

- **BB-OCR Direct relay scheme:**
  - Low delay techniques, based basically on:
    - **ESTIMATION** of the loop-back channel;
    - **(ADAPTIVE) FILTERING** to cancel the echoes.

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Echo canceller for DVB-T/H: Problem Solving

- $W(f)$: Echo Canceller introduced to suppress the effects due to $H_c(f)$;
- $H_c(f)$: Feedback Channel Transfer Function;

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Echo canceller for DVB-T/H: Target Solution

Repeater based on DVB-T pilots;
Repeater “general-purpose”:

► **The Base-Band Pulse-based Echo Canceller**
Echo canceller for DVB-T/H: Features

- Two operative phases:
  - **Start-Up** (*open-loop*)
    - determination of the number and position of the cancelling windows (*pulse-based*);
    - initial coupling channel (*pulse*) estimation;
    - FIR’s set-up (*$W(f)$*).
  - **Steady-State** (*closed-loop*)
    - effective DVB-T signal repetition;
    - fast echo tracking (*LMS-algorithm*);
    - stability and coupling channel monitoring (periodical check of new echoes with the pulse technique).
Echo canceller for DVB-T/H:

**Features**

- **Search window:** from 3-6 ms to about 60 ms (nearly correspondent to reflections from obstacles at 8 km);
- **Cancelling window:** about 5 ms (for 8 MHz BW);
- **Target:** suppressing a single echo with power 15 dB over the useful DVB-T signal power

\[ |h(t)|^2 \]

*echo suppression > 40 dB*
Echo canceller for DVB-T/H: 
**FPGA Features**

- **FPGA Stratix II Altera dev. Kit EP2S180F1020C3**

**Analog I/O:**
- Two-channel, 12-bit, 125-million samples per second (MSPS) analog-to digital (A/D);
- Two-channel, 14-bit, 165-MSPS digital-to-analog (D/A).

**Digital I/O**
- Connector for the Texas Instruments (TI) Evaluation Module (TI-EVM);
- Two 40-pin connectors for Analog Devices' A/D converter evaluation boards;
- Power connector for Agilent and Tektronix logic analyzers;
- RS-232 serial port;
- 10/100 Ethernet physical layer/media access control (PHY/MAC) and RJ-45 jack.

**Memory**
- 32-Mbyte SDR SDRAM
- 16-Mbyte flash
- 1-Mbyte SRAM
- 16-Mbyte compact flash

<table>
<thead>
<tr>
<th>Feature</th>
<th>EP2S180</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALMs</td>
<td>71,760</td>
</tr>
<tr>
<td>Adaptive look-up tables (ALUTs)</td>
<td>143,520</td>
</tr>
<tr>
<td>Equivalent LUTs (2)</td>
<td>179,400</td>
</tr>
<tr>
<td>M512 RAM blocks</td>
<td>930</td>
</tr>
<tr>
<td>M4K RAM blocks</td>
<td>768</td>
</tr>
<tr>
<td>M-RAM blocks</td>
<td>9</td>
</tr>
<tr>
<td>Total RAM bits</td>
<td>9,383,040</td>
</tr>
<tr>
<td>DSP blocks</td>
<td>96</td>
</tr>
<tr>
<td>18-bit x 18-bit multipliers (3)</td>
<td>384</td>
</tr>
<tr>
<td>Enhanced PLLs</td>
<td>4</td>
</tr>
<tr>
<td>Fast PLLs</td>
<td>8</td>
</tr>
<tr>
<td>Maximum user I/O pins</td>
<td>1,170</td>
</tr>
</tbody>
</table>

*Notes to Table 1-1:*
(1) One ALM contains two ALUTs. The ALUT is the cell used in the Quartus® II software for logic synthesis.
(2) This is the equivalent number of LUTs in a Stratix device (four-input LUT-based architecture).
(3) These multipliers are implemented using the DSP blocks.
Echo canceller for DVB-T/H: System Implementation

- OCR architecture implemented on the FPGA board:

- Channel Simulator architecture implemented on a second FPGA board:

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Echo canceller for DVB-T/H: 
Echo Canceller Implementation

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Echo canceller for DVB-T/H: Feedback Channel Implementation

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Echo canceller for DVB-T/H: Workbench Configuration

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Echo canceller for DVB-T/H: Measurements Results

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Measured impulse response of the channel between the modulator and the demodulator.

Echo suppression when the echo level is 0.2 dB lower than the input DVB-T signal.
Echo canceller for DVB-T/H: 
Measurements Results

- MER measured vs \( P_{\text{MOD}} \) of the modulator only and with/without echo canceller.

The modulation error ratio or MER is a measure used to quantify the performance of a digital radio transmitter or receiver in a communications system using digital modulation.

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Echo canceller for DVB-T/H: Measurements Results

Punctual and minimum attenuation $A_P$ and $A_{min}$ vs Echo Level

System Lock Times for the start-up phase for different numbers of pulse estimations.
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Conclusions
Pilot Design in a MC-MU MIMO-OFDM Network

Scenario and System Model

- Single Frequency Network (SFN)

The scenario is constituted by:
- MIMO-OFDM System;
- many Tri-sectors Base Stations (BS);
- many User Equipments (UE).

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Pilot Design in a MC-MU MIMO-OFDM Network

Scenario and System Model

\[ y_{n,\ell} = \sum_{s=1}^{N_{BS}} [s] h_{n,\ell}^T \cdot [s] V \cdot [s] x_{n,\ell} + z_{n,\ell} \]

\[ y_{n,\ell} = \sum_{s=1}^{N_{BS}} [s] s_{n,\ell}^T \cdot [s] x_{n,\ell} + z_{n,\ell} \]

\[ = [1] g_{n,\ell}^{(i)} x_{n,\ell}^{(i)} + \sum_{j=1, j \neq i}^{N_{t}} [1] g_{n,\ell}^{(j)} x_{n,\ell}^{(j)} + \sum_{a=2}^{N_{BS}} \sum_{j=1}^{N_{t}} [s] g_{n,\ell}^{(s)} x_{n,\ell}^{(j)} + z_{n,\ell} \]

\[ = \text{USEFUL SIGNAL} \]

\[ \text{INTER-CELL INTERFERENCE} \]

\[ \text{INTER-BEAM INTERFERENCE} \]

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Pilot Design in a MC-MU MIMO-OFDM Network

Pilot Aided Channel Estimation (PACE)

Dedicated Pilots per Beam (DPB)

Common Pilots per Antenna (CPA)

DPB support detection of transmitted data and allow to directly measure the effective channel. These pilots undergo the same user-specific spatial processing as the associated data symbols.

CPA enable link adaptation at the transmitter, exclude spatial precoding and allow to measure the CTF over the entire band. These pilots are inserted on all the beams but only on the selected antenna in each sector.

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Pilot Aided Channel Estimation (PACE)

- **Wiener Filter**
  
  \[
  \tau_{\text{max}} \leq \tau_w < \frac{T}{D_f},
  \]
  
  \[
  f_{D,w,\text{max}} \leq f_{D,w} < \frac{1}{2D_f T_{\text{sym}}},
  \]

- **Estimates**

  - **DPB:**
    \[
    \hat{y}^{(i)} = [1] \tilde{X}^{(i)} \cdot [1] \tilde{g}^{(i)} + \tilde{\zeta}^{(i)} + \hat{\eta} + \tilde{z}
    \]
    with \( [1] \tilde{X}^{(i)} = \text{diag}( [1] x^{(i)} ) \),

    \[
    [1] \tilde{g}^{(i)}_{n,\ell} = w^H \cdot [1] \tilde{X}^{-1} \cdot \tilde{y}^{(i)}
    \]

  - **CPA:**
    \[
    \hat{y}^{(\mu)} = [1] \tilde{X}^{(\mu)} \cdot [1] \tilde{h}^{(\mu)} + \tilde{\eta} + \tilde{z}
    \]
    with \( [1] \tilde{X}^{(\mu)} = \text{diag}( [1] x^{(\mu)} ) \),

    \[
    [1] \tilde{h}^{(\mu)}_{n,\ell} = w^H \cdot [1] \tilde{X}^{-1} \cdot \hat{y}^{(\mu)}
    \]

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**SINR and Capacity evaluation**

- **Pilot Overhead:**
  - Pilot symbols consume transmission resources which are constraint to bandwidth and power. One spatial stream is assigned $N_p$ pilot and $N_d$ data symbols, which amounts to

  \[ N_c L = N_d + \alpha N_p \]

- Total pilot overhead and Total transmit power:

  \[ \Omega_p = \frac{\alpha N_p}{N_c L} \]

$D_f$ and $D_t$ are the pilot spacings in frequency and time respectively, while $M_f$ and $M_t$ are the number of pilots in frequency and time.

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(a) Pilot grid configuration and filter estimation orders table; (b) Comparison among SINR CDF for different pilot overhead values, perfect CSI with and without MCI; (c) MSE CDF of the reference system for different pilot overhead values in presence of MCI; (d) Comparison among Capacity CDF for different pilot overhead values and for perfect CSI in presence of MCI.
Conclusions

- A low-complexity digital echo canceller based on the transmission of locally generated pulse trains and the practical implementation of the system on an FPGA board was shown. Finally, a measurement campaign which validated our theoretical model and design strategies was presented.

- A MC MU-MIMO-OFDM downlink was studied. A unified analytical model is developed that allows to assess the performance of two different pilot types, in terms of effective SINR and MSE and channel capacity in presence of MCI. The effects and the bounds introduced by MCI and the trade off between channel estimation accuracy, capacity and pilot overhead have been clarified.
Further Studies

- Adaptive Pulse Estimation;
- Pseudo-Noise based Echo Canceller.

- CoMP (Cooperative Multi-Point Transmission) Architectures;
- More complex Pilot schemes;
- FPGA Implementation.
Publications

PROGETTO DI RICERCA DVB2006, Jul. 2007

PROGETTO DI RICERCA DVB2006, Jan. 2008


PROGETTO DI RICERCA DVB2006, Sep. 2008

[5] "Attività di misura per la caratterizzazione del Cancellatore d'eco a finestra fissa, con tecnologia ad impulsi e LMS."
PROGETTO DI RICERCA DVB2006, Mar. 2009

"FPGA design and performance evaluation of a pulse-based echo canceller for DVB-T/H"

[7] "Deliverable Finale DVB2006 (Polo tecnologico TV digitale)":
- DVB-T Echo Canceller (design & implementation);
- DVB-T Echo Canceller (measurements).
PROGETTO DI RICERCA DVB2006, Sep. 2010

"Experimental Characterization of UMTS Femtocell Propagation"
accepted to 2011 IEEE 73rd Vehicular Technology Conference Spring Budapest Workshop (W4:BeFEMTO)

"Pilot Design for Multi-Cell MU-MIMO-OFDM with Beamforming"
submitted to Future Network and MobileSummit 2011 Conference Proceedings

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Giovanni Chiurco
Thank you for your attention!

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