Blind Standard Recognition Sensor Validation with Data from Measurement Campaign

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Outline

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- Measurement setup
- Spectrum occupancy results
- Blind standard recognition sensor
- Conclusions
Introduction

- Dynamic Spectrum Access (DSA) / Cognitive Radio (CR):
  - Promising solution to the conflicts between:
    - Spectrum demand growth.
    - Spectrum underutilisation.
- Basic underlying idea:
  - Opportunistic and non-interfering “secondary” access to temporarily unoccupied “primary” licensed bands.
- Main premise: Spectrum is underutilized.
  - Necessary to determine the degree to which allocated bands are used.
  - Previous spectrum campaigns, but mostly in the USA.
  - Spectrum use in Europe is a rather unexplored issue. Only a few studies:
    - Dublin, Ireland, 2007 (Shared Spectrum Company).
    - Aachen, Germany, 2007 (RWTH Aachen University).
    - Locations in Germany during FIFA world cup, 2006 (University of Karlsruhe).
Introduction

- Measurement of real network activities:
  - Can provide valuable insights into current spectrum use.
  - Important step towards realistic understanding of dynamic spectrum use.
  - Useful for policy makers to define adequate DSA policies.
  - Useful for the research community to identify suitable bands for DSA/CR.
  - Evaluation and validation of novel techniques:
    - Blind standard recognition sensor (BSRS).
      - Sensor embedded in a CR equipment to identify wireless standards without the need to connect to any network.

- This presentation reports the joint UPC-Supélec work in these areas.
Measurement setup

- Discone antenna (75 – 3000 MHz).
  - AOR DN-753.
  - Vertical polarization.
  - Omni-directional horizontal plane.
- High performance spectrum analyser.
  - Anritsu MS2721B.
- Controlling laptop.
- Location in building roof with LOS to:
  - TV and FM broadcast stations.
  - Cellular mobile comms base stations.
  - Military headquarter.
  - Aeronautical transmitters (airport).
  - Maritime transmitters (harbour).
  - Etc.
# Measurement setup

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center frequency</td>
<td>Block 1: 250 MHz  Block 4: 1750 MHz  Block 2: 750 MHz  Block 5: 2250 MHz  Block 3: 1250 MHz  Block 6: 2750 MHz</td>
</tr>
<tr>
<td>Frequency span</td>
<td>6 blocks of 500 MHz</td>
</tr>
<tr>
<td>Resolution/video bandwidth (RBW/VBW)</td>
<td>10 kHz / 10 kHz</td>
</tr>
<tr>
<td>Sweep time</td>
<td>Automatically selected</td>
</tr>
<tr>
<td>Reference level</td>
<td>– 20 dBm</td>
</tr>
<tr>
<td>Scale</td>
<td>10 dB/div</td>
</tr>
<tr>
<td>Detection type</td>
<td>RMS detector</td>
</tr>
<tr>
<td>Measurement period</td>
<td>48 hours</td>
</tr>
</tbody>
</table>
Spectrum occupancy results

- Relatively high use below 1 GHz.
- Sparse use between 1 and 3 GHz, with some exceptions:
  - DCS 1800 system.
  - UMTS system.
## Spectrum occupancy results

<table>
<thead>
<tr>
<th>Block</th>
<th>Frequency range (MHz)</th>
<th>Average duty cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75 – 500</td>
<td>60.98 %</td>
</tr>
<tr>
<td>2</td>
<td>500 – 1000</td>
<td>56.67 %</td>
</tr>
<tr>
<td>3</td>
<td>1000 – 1500</td>
<td>2.07 %</td>
</tr>
<tr>
<td>4</td>
<td>1500 – 2000</td>
<td>12.08 %</td>
</tr>
<tr>
<td>5</td>
<td>2000 – 2500</td>
<td>7.57 %</td>
</tr>
<tr>
<td>6</td>
<td>2500 – 3000</td>
<td>1.85 %</td>
</tr>
</tbody>
</table>
Spectrum occupancy results

- Below 235 MHz: Duty cycles between 90% and 100%.
  - FM broadcasting (87.5-108 MHz).
  - Maritime and aeronautical radio navigation (108-174 MHz).
  - Audio broadcasting (174-223 MHz).
  - Private/Professional Mobile Radio (PMR) systems (223-235 MHz)
Spectrum occupancy results

- 235 – 400 MHz:
  - Some potential opportunities / white spaces.
  - But exclusively reserved for government’s security services and systems.
Spectrum occupancy results

- **400 – 470 MHz:**
  - Allocated to PMR/PAMR, SRD, amateur and paging.
  - Available white spaces, but narrower available free bandwidths.
Spectrum occupancy results

- 470 – 862 MHz:
  - 470 – 830 MHz: An/Dig TV → 66.58% of the band (~130 MHz) is usable.
  - 830 – 862 MHz: Dig TV → Intensive usage (~100%).
Spectrum occupancy results

- 880 – 915 MHz / 925 – 960 MHz:
  - Allocated to E-GSM 900.
  - Unbalanced occupancy patterns: 4.03% in uplink, 96.20% in downlink.
  - Similar trends were observed in previous studies (e.g., Islam et al., CrownCom 2008).
Spectrum occupancy results

- Above 1 GHz:
  - The highest use is observed for mobile cellular communication systems:
    - Same unbalanced patterns:
      - DCS 1800: 3.52% uplink / 59.75% downlink.
      - UMTS: 2.86% uplink / 48.38% downlink.
Spectrum occupancy results

- Above 1 GHz:
  - The highest use is observed for mobile cellular communication systems:
    - These bands also provide some opportunities for secondary use:
      - DCS 1800: Temporal patterns day/night.
      - UMTS: Some “unoccupied” 5-MHz channels. UMTS TDD / extension → free.
Spectrum occupancy results

- Above 1 GHz:
  - The ISM-2450 band appears to be unused:
    - Our measurement location is a building roof!
    - Severe indoor-to-outdoor attenuation by walls.
Spectrum occupancy results

- Above 1 GHz:
  - The rest of spectrum seems not to be used at all, with some exceptions:
    - 960 – 1350 MHz: Aeronautical radio navigation.
    - 1880 – 1900 MHz: DECT cordless phones.
    - 2700 – 2900 MHz: Military radars.
Blind standard recognition sensor

- Sensor embedded in a CR equipment to identify wireless standards without the need to connect to any network.
- The received signal is analyzed in 3 steps:
  - **STEP 1:** Reduction of the bandwidth to be analyzed to non-zero regions.
    - Ratio between global and smallest recognizable bandwidths may be very high.
    - Solution: Iterative adaptation of the bandwidth to be analyzed:
      - Conventional periodogram to analyse signal energy.
      - Filtering.
      - Decimation around the detected peak of energy.
Blind standard recognition sensor

- Sensor embedded in a CR equipment to identify wireless standards without the need to connect to any network.
- The received signal is analyzed in 3 steps:
  - STEP 2: Analysis of signal characteristics with sensors.
    - Bandwidth recognition sensor.
    - Single/multi-carrier detection sensor.
    - Frequency hopping / direct sequence detection sensor.
Blind standard recognition sensor

- Sensor embedded in a CR equipment to identify wireless standards without the need to connect to any network.
- The received signal is analyzed in 3 steps:

  **STEP 2: Analysis of signal characteristics with sensors.**
  - Bandwidth recognition sensor.
    - Bandwidth and spectral shape of the received signal is obtained.
    - Empirical spectrum shape is compared with a reference shape.
    - Radial Basis Functional Neural Network (RBF NN) identifies matching patterns.
Blind standard recognition sensor

- Sensor embedded in a CR equipment to identify wireless standards without the need to connect to any network.
- The received signal is analyzed in 3 steps:
  - STEP 2: Analysis of signal characteristics with sensors.
    - Single/multi-carrier detection sensor.
      - DVB-T/LMDS and DAB/DECT systems may induce confusion.
      - Distinction between both systems relies on the guard interval of multi-carrier systems.
      - Autocorrelation function is computed.
      - Cyclic frequency corresponding to the guard interval is derived.
Blind standard recognition sensor

- Sensor embedded in a CR equipment to identify wireless standards without the need to connect to any network.
- The received signal is analyzed in 3 steps:
  
  **STEP 2: Analysis of signal characteristics with sensors.**
  - Frequency hopping / direct sequence detection sensor.
    - The previous analysis with 2 sensors is not enough.
    - Difficulties in discriminating between Bluetooth and IEEE 802.11b.
    - The use of the Wigner-Ville Transform (WVT) was proposed to address this problem.
    - This approach is able to distinguish between Bluetooth and IEEE 802.11b.
Blind standard recognition sensor

- Sensor embedded in a CR equipment to identify wireless standards without the need to connect to any network.
- The received signal is analyzed in 3 steps:
  - STEP 3: Fusion of information from sensors and decision.
    - After STEP 2, three indicators are obtained.
    - Simple way to fuse information:
      - Apply some logical rules on these indicators.
      - Could be improved with neural networks, like Multilayer Perceptron.
Conclusions

- Joint work UPC-Supélec:
  - Broadband spectrum measurement campaign.
    - Future work:
      - Extension to wider frequency ranges (75 – 7075 MHz).
      - More sophisticated and accurate measurement equipment.
      - Different environments: urban, sub-urban and rural.
      - Different locations: in outdoor and indoor environments.
  - Blind standard recognition sensor.
    - Future work:
      - Evaluation and validation of BSRS with empirical data.
      - Both research lines are expected to converge in the future.
Thank you for your attention

Any questions?