Cognitive Radio in HF Communications

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Supélec
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Outline

• IDeTIC: A little bit about us.
• Communications in the HF band
• Cognitive Radio in HF communications
  – Using wideband HF receivers for spectrum sensing
  – Learning with Hidden Markov Models
  – Decision making for dynamic spectrum access
• Conclusion
IDeTIC

Research institute within Universidad de Las Palmas de Gran Canaria

Around 65 people

- Staff (PhD): 29
- Staff (no PhD): 8
- Hired (no permanent staff): 16
- MSc students: 6
- BSc students: 3

... and 12 external collaborators

www.idetic.eu
IDeTIC: Academic activities

A²TECHS
Master on home automation, architecture and sustainable for tourism

Expert course on IT and tourism

Expert course on aeronautical and airport management

BIMeTIC
Master on IT solutions for the environment and welfare

PhD program on Communications Systems

Short course on “the port city”
IDeTIC: Research fields

- Biometrics & Signal Processing
- RF Systems & Radar
- Sensor networking, SmartSpaces & IoT
- Automatic geolocation of wildfires
- Space & Aircraft Electronics
- IT applied to Social Sciences
- Wireless Photonics & In-home Services
- Maritime communications & surveillance
HF Communications

• Research line between IDeTIC (ULPGC) and GAPS (UPM).

• Long-distance HF communications

• HFDVL System (HF Data+Voice Link):
  – Based on Software Radio with multicarrier modulations.
  – Digital interactive voice and high-data rate transmissions.
  – Operates with commercial transceivers.
  – SISO & SIMO (up to 4 Rx) configurations.

• Three configurations in data transmission:
  – File transfer
  – Short message (SMS)
  – HFMail

![Graph showing rate vs. bps with example of 77% efficiency at 5400 bps]
HFDVL: Real Tests

Tests done by the Spanish Department of Defense

Arnomendi ship (60 days)

Flight from Manas to Zaragoza (14 h)
Hercules C-130 airplane

3864 Km

6021 Km

7950 Km

Canary Islands
Spectrum activity in the 14 MHz amateur band.

- Power measurements in the frequency domain.
- 600 kHz bandwidth (200 channels simultaneously): amateur band and other stations.
- Duration: 10 minutes.
- Weekdays & Weekends.
- Each sample represents a 3kHz channel in 2 seconds.
Spectrum activity in the 14 MHz amateur band.
Cognitive Radio in the HF band

• Challenges to face in this environment
  – There is no coordination among users.
    • Frequency allocation per country.
    • Trans-horizon behaviour.
  – Use of wideband receivers:
    • The dynamic range of the received power is wider than cellular environments.
    • Strongly affected by narrowband interference.
Outline

Learning/Knowledge extraction

- Decision making
  - Wireless transmitter

- Spectrum sensing
  - Wireless receiver

- Frequency spectrum

Narrowband Interference

Transmit

Observe
NBI in wideband HF receivers
NBI in wideband HF receivers
NBI in wideband HF receivers

Wideband HF transceiver – Receiver diagram block

We must detect and mitigate in the analog domain
NBI detection in wideband HF receivers

Our proposal based on Compressive Sensing for NBI detection

ADC with $f_s << f_{Nyq}$

A parallel system to the wideband receiver with:
- Detection phase
- Mitigation block
Basics of Compressive Sensing:

\[ y = \Phi x \]
NBI detection in wideband HF receivers

Basics of Compressive Sensing:

\[ y = \Phi \, x \]

\[ x = \Psi \, s \]

Sparse Signal

Fourier basis

Compressible Signal

-10
-20
-30
-40
-50
-60
-70
-80
-90
-100

Power (dBm)

13.9 14.0 14.1 14.2 14.3 14.4 14.5

Frequency (MHz)
NBI detection in wideband HF receivers

\[ M = \Phi \Psi s \]

- \( y = \) Compressive Measurements
- \( \Phi = \) Measurement Matrix
- \( \Psi = \) Sparsity Basis
- \( K = \) Sparsity level
- \( s = \) Sparse Signal
- \( x = \) Original Signal
- \( \Psi = \) Sparsity Basis
- \( N = \) K-sparse
NBI detection in wideband HF receivers

Our proposal based on Compressive Sensing for NBI detection

Unpublished Results
Learning/Knowledge extraction

- Decision making
- Wireless transmitter
  - Transmit

- Spectrum sensing
- Wireless receiver
  - Observe

Frequency spectrum
Hidden Markov Model

Doubly embedded stochastic process with an underlying stochastic process that is not observable (it is hidden), but it can only be observed through another set of stochastic processes that produce the sequence of observations.
Hidden Markov Model

• The three basic problems of HMM
  – The evaluation problem:
    Forward step of Forward-Backward procedure
  – The decoding problem:
    Viterbi algorithm
  – The learning problem:
    Baum-Welch method
Data segmentation

2 s. 1 minute

1 0 0 ... 1 0 0 1 1 1 ... 1 1 1 0 1 0 ... 1 1 0 0 0 0 ... 0 0 0

3 2 3 1 ... 1

10 minutes
HF Spectrum Activity Prediction

- **Main model:**
  - Ergodic HMM
  - 10 minutes sequences

- **3 submodels:**
  - Left-right HMM
  - Observation symbols for 1 minute
HF Spectrum Activity Prediction

Submodel 1
$\lambda_1 = (A_1, B_1, \pi_1)$

Submodel 2
$\lambda_2 = (A_2, B_2, \pi_2)$

Submodel 3
$\lambda_3 = (A_3, B_3, \pi_3)$

$P(O_T|\lambda_1)$
$P(O_T|\lambda_2)$
$P(O_T|\lambda_3)$

$B'_{11}$
$B'_{22}$
$B'_{33}$

New definition of the high-level model:
$\lambda = (A, B', \pi)$

$max(P(O_{T+1}|\lambda))$

Predicted state

... Previous detected states
T-2  T-1  T

High-level model
$\lambda = (A, B', \pi)$

Submodels
High-level model

Observations
$O_T$

$B' = \begin{bmatrix} B'_{11} & 0 & 0 \\ 0 & B'_{22} & 0 \\ 0 & 0 & B'_{33} \end{bmatrix}$
HF Spectrum Activity Prediction

![Chart showing the relationship between average error rate and acquired knowledge for different activity levels.](chart.png)
Joint work at Supélec

Outline

Learning/Knowledge extraction

Decision making

Wireless transmitter

Wireless receiver

Spectrum sensing

Frequency spectrum

Transmit

Observe
Decision making with UCB

Upper Confidence Bound (UCB) algorithm to provide HF secondary users with dynamic access to the spectrum.

\[ B_{t,k,T_k(t)} = \overline{X}_{k,T_k(t)} + A_{t,k,T_k(t)} \]

**Exploitation**

\[ \overline{X}_{k,T_k(t)} = \sum_{m=0}^{t-1} \frac{r_m \mathbf{1}_{\{a_m = k\}}}{t} \]

**Exploration**

\[ A_{t,k,T_k(t)} = \sqrt{\frac{\alpha \ln(t)}{T_k(t)}} \]

Joint work at Supélec
Unpublished Results
Conclusion

The application of Cognitive Radio to HF communications might be feasible

- Both Learning with HMM and decision making with UCB can help secondary HF users to avoid collisions with other users.
- A compressive detector can be used in wideband HF receivers to detect NBI.
Thank you for your attention!
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