Application examples: cognitive radio

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Data Fusion and Bayesian Interaction Modeling for Cognitive Ambient Intelligence
Application example in cognitive radio

Growing success of wireless communications systems

Fundamental problem: **scarcity of available spectrum**
A lot of studies supported by FCC:
- point out a scarce effective utilization of the wireless spectrum
- encourage new solutions to exploit underutilized bands
- demand for the overcoming of the exclusive use of the allocated frequencies
- **COGNITIVE RADIO (CR) paradigm** is the proposed solution
In the last few years COGNITIVE RADIO (CR) paradigm has attracted a great number of researchers and industries.

From a technical point of view, Cognitive Radio exploits the concept of Software Defined Radio (SDR), enhancing SDR re-configurability and multi-standard management with self-adaptation capabilities to dynamic environment.
Which are the possible applications of a CR system?

- Exploitation of unused frequencies (or opportunities, in general) e.g. spectrum holes
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Which are the possible applications of a CR system?

- Self-interconnection and self-management of different systems with different standards
- Homeland security
- Signal interception and identification
- Military applications
- Emergency situations
One of the most important features of the CR is the **LEARNING CAPABILITY**

Provide the CR system with a sort of **intelligence** to increase its adaptivity and flexibility.

CR can be viewed as a **COGNITIVE SYSTEM**.

Hence the CR can be used not only in well-known situations but also in unexpected or unforeseen scenarios.
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This is the Cognitive Cycle proposed by Mitola [], the founder of the CR.
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This is the Cognitive Cycle re-elaborated by Simon Haykin [1]
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While in the Mitola’s vision the CR is suited to realize the user’s preferences, in the Haykin’s one it is well explained a cognitive communication between a transmitter and a receiver.

In both of the previous visions it is clear the effort to model the CR system as an entity able to

1. reason about and analyze the external world
2. modify its internal configuration to reach the best solution
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Haykin and Mitola’s cognitive cycles can be simplified in order to obtain the proposed bio-inspired cognitive cycle:
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It is also important to underline that the flexibility guaranteed by the previously described bio-inspired approaches can be extended not only at the physical layer of the communication (as in Haykin’s vision) but at the entire ISO-OSI communication model.
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These kinds of applications are aimed at obtaining a global optimization of the configuration parameters of the wireless systems by

- overcoming the traditional limits among different levels
- realizing a cross layer optimization management systems

This is the case of the most important European project E2R.
End-to-End Reconfigurability: Enabler of the Seamless Experience

Heterogeneous Systems
- Ubiquitous Access
- Pervasive Services
- Dynamic Resource Management

Heterogeneous Environments and Contexts
- Fixed
- WLAN
- WiMax
- 2/2.5G
- All-IP Infrastructure

Heterogeneous Devices
- DAB
- DVB
- 3G
- 4G

Video and Signal Processing for Telecommunications – ISIP40
E2R

End-to-End Reconfigurability (E2R) is the key enabler for providing a seamless experience to the end-user and the operators:

- Managing and increasing resilience growingly complex architectures
- Reducing costs deployment, evolution and operation of large communication systems
- Providing opportunities develop and experiment rapidly new services and applications
Most of the developed CR project are characterized by fixed or slightly flexible models.

In general, these models has to be accurate and often it is necessary to include in them some severe constraints.

To overcome these limits it is possible to apply the theory related to bio-inspired cognitive systems shown previously.
The chosen cognitive system is composed by a Cognitive Base Transceiver Station (CBTS) for mobile applications.

Task of CBTS is to manage communication with a set of mobile stations in a vehicular context CBTS is equipped by a “smart antenna” system.
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The cognitive cycle proposed in the general theory is well suited to chosen application
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Let us describe the cognitive cycle mapped for the chosen application:

- **Sensing**: the smart antenna system perform a scanning of the environment
Let us describe the cognitive cycle mapped for the chosen application:

- **Analysis**: extract from the context the presence of the users in the domain of interest
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The analysis map:
Let us describe the cognitive cycle mapped for the chosen application:

- **Decision**: allocate available resources

<table>
<thead>
<tr>
<th></th>
<th>USER1</th>
<th>USER2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direction</strong></td>
<td>-15 deg</td>
<td>+30 deg</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>10 dB</td>
<td>15 dB</td>
</tr>
</tbody>
</table>
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Let us describe the cognitive cycle mapped for the chosen application:

- **Action**: reconfigure the beamformer in order to provide a reliable communication link to the user.
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Damasio’s approach is used

- The proto-self and the core self are modeled to the internal and external state of the system

- In this application only core sensors (eso-sensors) i.e. the antennas are considered
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In particular external and internal state representation respectively are:

- \( x_c \) (external state):
  - number of detected terminals
  - associated directions
  - SNR of each established connection

- \( x_p \) (internal state):
  - beamformer configuration
  - power for each communication
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• For the proposed intelligent system a Reinforcement Learning (RL) approach it is chosen for decision phase.
• RL is a machine learning technique that unlike other machine learning approaches is:
  ▪ model free
  ▪ unsupervised
  ▪ able to learn on line
• RL approach allows the system to learn the correct strategies for interactions with the environment
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Decision phase, carried out using the RL, can be described by using:

• **Input**: high level description of the environment status $x_c$ (from analysis)

• **Output**: establish new configuration $x_p$ (to action)

• **Objective**: choose action that maximizes $r$ (reward)

• **Experience** = capability of predicting $r$ given $x_c$ and $x_p$
Learning task: estimation of the Q-function

\[ Q(x_c, x_p) = E\{ r \mid x_c, x_p \} : \]

- at the beginning \( Q = 0 \) for every couple \((x_c, x_p)\);
- if you encounter \((x_c, x_p)\) and receive a reward \( r \) then

\[ Q(x_c, x_p) = \alpha r + (1 - \alpha)Q(x_c, x_p) \]
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**Decision task**: balance exploration and exploitation $\rightarrow$ $\varepsilon$-greedy policy is the chosen strategy:

- with probability $1 - \varepsilon$, exploits: choose
  $$x_p = \text{arg}\left[\max_{x_p} (Q(x^k_c, x_p))\right]$$
- with probability $\varepsilon$, explores: pick $x_p$ randomly

It is a simple algorithms but theoretical results guarantee convergence
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Reward: maximize the SNR
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