Cognitive Radio:

Brain-Inspired Wireless Communications

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Growth of Cognitive Radio during the last 3 to 4 years (Starting with about 6 to 8 Reports and Conference Papers)

IEEE Papers: **982**

Springer Papers: **178**

Elsevier Papers: **31**

Outline of The Lecture

Introductory Remarks

1. **The Essence of Human Cognition**

2. **The Motivation behind Cognitive Radio**

3. **Cognitive Radio Networks**

4. **Major Functional Blocks Constituting a Cognitive Radio**

5. **Research Projects on Cognitive Radio in my Laboratory at McMaster**

6. **Cognitive Hand-held Wireless Devices**

Concluding Remarks

References

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Introductory Remarks

- **Cognitive Radio is growing in leaps and bounds, both in depth and breadth, all over the world.**

- **The question is: Why this surge of interest in a topic so relatively new?**

- **The answer is:**

  (i) It solves a pressing need: Underutilization of a precious natural resource: The Radio Spectrum.

  (ii) Cognitive radio is challenging in ways few, if any, other wireless technologies are today.

Introductory Remarks (continued)

- **It is not just cognitive radio that is attracting the attention of researchers all over the world. Rather, it is:**

  Cognitive Multiple-input multiple-output (MIMO) wireless

  Cognitive Radar

  Cognitive Car

  ⋮

  Cognitive Information Processing

  Cognitive Computation

  Cognitive Optimization

- **What I am leading up to is the new discipline:**

  "Cognitive Dynamic Systems"

Point-of-View Article, Proc. IEEE, Nov. 2006.

I see the emergence of a new discipline, called Cognitive Dynamic Systems[1], which builds on ideas in statistical signal processing, stochastic control, and information theory, and weaves those well-developed ideas into new ones drawn from neuroscience, statistical learning theory, and game theory. The discipline will provide principled tools for the design and development of a new generation of wireless dynamic systems exemplified by cognitive radio and cognitive radar with efficiency, effectiveness, and robustness as the hallmarks of performance.

1. S. Haykin, Cognitive Dynamic Systems, book under preparation.

1. The Essence of Human Cognition

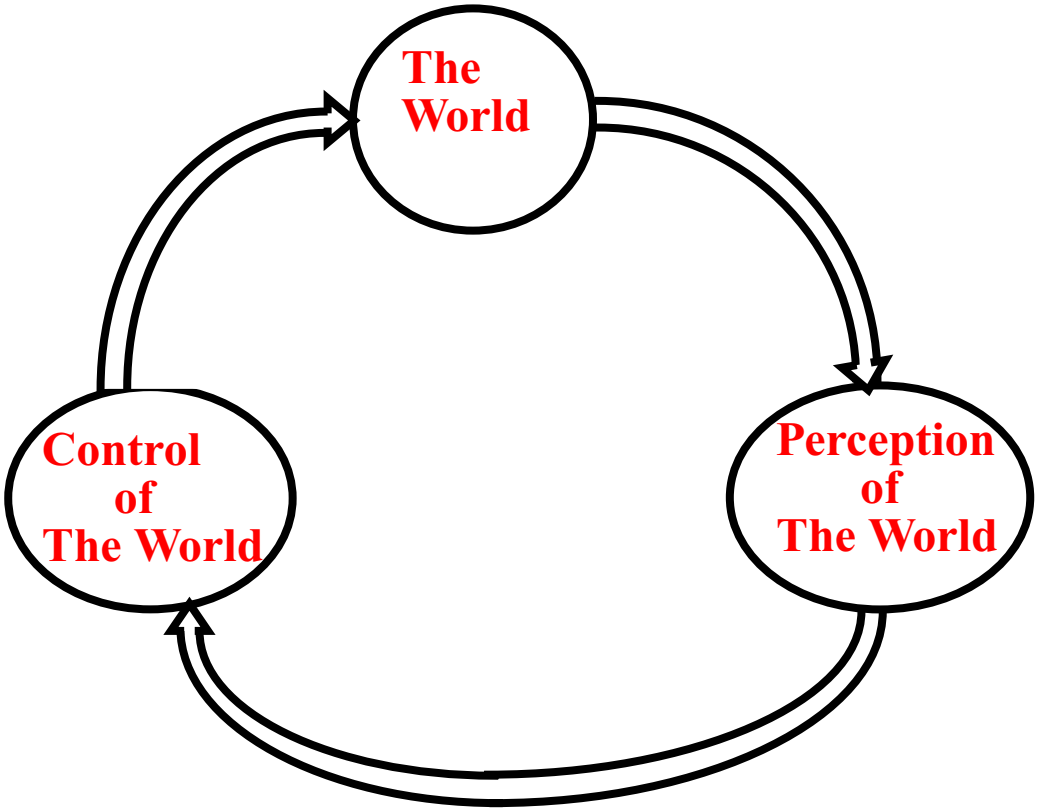

Figure 1. Human Cognitive Cycle in its most basic form

Tasks of a Human Mind

An extract taken from the book:

"The Computer and the Mind"
by
Johnson-Laird

- **to perceive the world;**
- **to learn, to remember, and to control actions;**
- **to think and create new ideas;**
- **to control communication with others;**
- **to create the experience of feelings, intentions, and self-awareness.**

Johnson-Laird, a prominent psychologist and linguist, went on to argue that theories of the mind should be modelled in computational terms.

2. Motivation Behind Cognitive Radio

- **Significant underutilization of the radio spectrum**

- **The Cognitive Radio solution to the spectrum underutilization problem:**

  (i) Sense the radio environment to detect spectrum holes (i.e., underutilized sub-bands of the radio spectrum).

  (ii) Make the spectrum holes available for employment by secondary users efficiently, subject to the constraint that the received power in each spectrum hole does not exceed a pre-scribed limit (set by the legacy user).

2. Cognitive Radio Networks

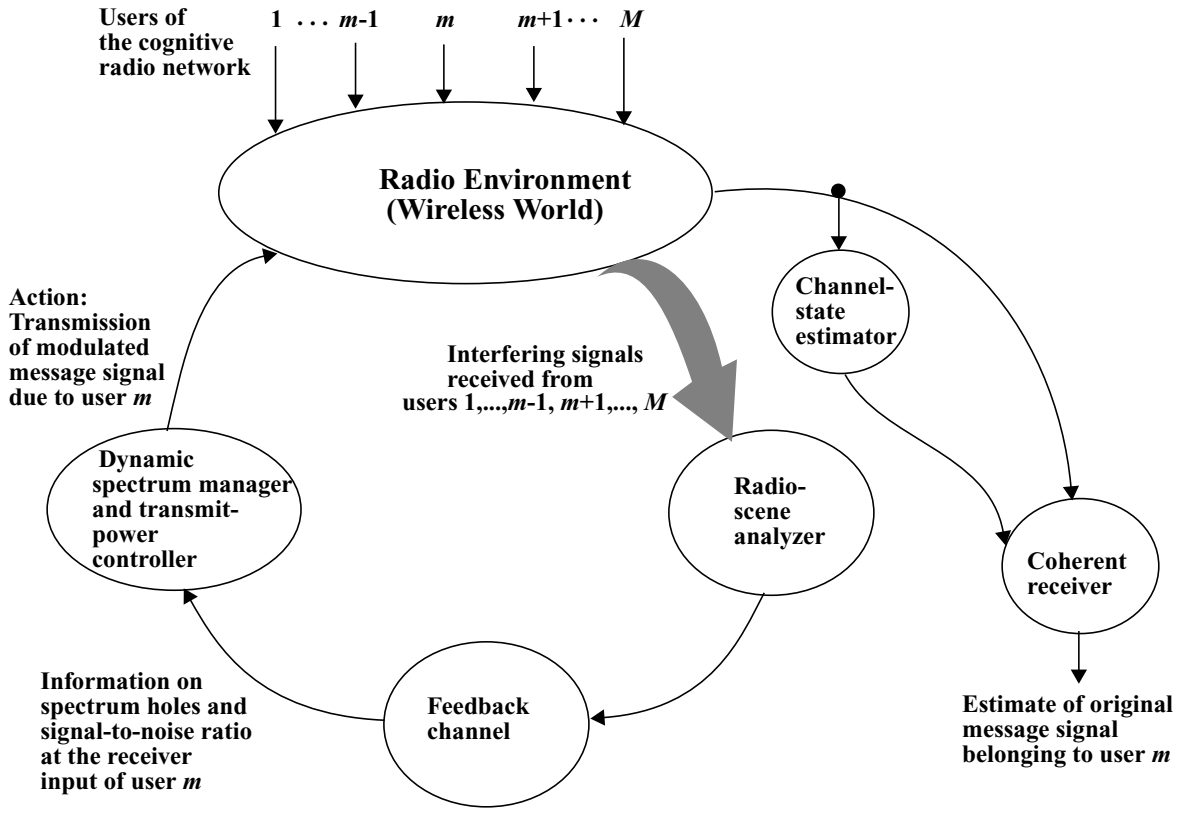

Figure 2. Basic signal-processing cycle.

Notes:

1. **A user refers to a transmitter and receiver engaged in communication with each other.**

2. **Signalling channel from transmitter to receiver has been omitted.**

Cognitive Radio Defined

The cognitive radio network is a complex multiuser wireless communication system capable of emergent behaviour.

It embodies the following functions:

- **to *perceive* the radio environment (i.e., outside world) by empowering each user's receiver to sense the environment on a continuous-time basis;**
- **to *learn* from the environment and *adapt* the performance of each transceiver (transmitter-receiver) to statistical variations in the incoming RF stimuli;**
- **to *facilitate communication* between multiple users through cooperation in a self-organized manner;**
- **to *control* the communication processes among competing users through the proper allocation of available resources;**
- **to create the experience of *intention and self-awareness*.**

Primary objectives:

1. **To provide *highly reliable communication* for all users of the network.**

2. **To facilitate *efficient utilization of the radio spectrum* in a fair-minded way.**

4. Major Functional Blocks of Cognitive Radio

Function	Objective
1. Spectrum sensing	Detection of spectrum holes and estimation of their average power contents.
2. Predictive modeling	Prediction of how long the spectrum hole is likely to remain available for employment by secondary user.
3. Transmit-power control	Maximize the data rate of each user subject to power constraints
4. Dynamic spectrum management	Distribute the spectrum holes fairly among secondary users, bearing in mind usage costs.
5. Packet routing	Design a self-organized scheme for routing of packets across the radio network

5. Research Projects on Cognitive Radio in My Laboratory at McMaster University

Masters Student: Kenny Szeto

Routing of packets across the Cognitive Radio Network in a self-organized manner using the ideas of locality and associativity

Ph.D. Students:

Farhad Khozeimeh: **Self-organized management of radio spectrum using Hebbian learning and reinforcement learning, assuming:**

Common control channel for all users.

This channel could be provided in unlicensed band.

Research Projects

Peyman Setoodeh: **Transmit-power controller using a robust iterative-water filling algorithm**

Jiaping Zhu: **Emergent behaviour of cognitive radio networks**

Post-doctoral Fellow (to be appointed)

Spectrum sensing

6. Cognitive Hand-held Wireless Devices

(i) **Exploiting ideas rooted in cognitive information processing is not confined to cognitive radio, cognitive radar; couple of applications currently attracting a great deal of attention.**

(ii) **As a matter of interest in the course of preparing my lecture notes for the visit to RIM, I believe that I have discovered a novel way of making any hand-held wireless device cognitive.**

(iii) **I think I know how to make the blackberry into a cognitive device, and am currently in the process of filing a patent on it.**

Concluding Remarks

- **The Study of Cognitive Dynamic Systems will be one of the most influential scientific endeavours in the 21st century:**

  The Computer is the Driving Force

- **Cognitive Radio is already being considered as the candidate for the 5th Generation of Wireless Communications.**

- **Under the umbrella of Cognitive Dynamic Systems, what I have been working on for much of my professional career, namely,**

  Signal Processing
  Communication Theory
  Control Theory
  Radar Systems
  Neural Networks and Learning Machines

  has come into focus for the first time.

Two New Books to watch out for:

1. **Neural Networks and Learning Machines**
   Simon Haykin
   Prentice-Hall, 3rd edition
   September 2008

2. **Cognitive Dynamic Systems**
   Simon Haykin
   Cambridge University Press
   (In preparation)

References

A. Papers

S. Haykin, "Cognitive Radio: Brain-empowered wireless communications, IEEE Journal on Selected Areas in Communications, Special Issue on Cognitive Networks, vol. 23, pp. 201-220, February. invited

S. Haykin, "Fundamental Issues in Cognitive Radio", In Cognitive Wireless Communications Networks, edited by Vijay Bhargava and Ekram Hossain, 2007, Springer.

P. Setoodeh and S. Haykin, "Robust Control for Cognitive Radio, Proc. IEEE, Feb. 2009. Accepted for publication subject to revision.

S. Haykin, J. Reed, and D.J. Thomson, "Spectrum Sensing for Cognitive Radio", ibid, under preparation.

B. Patents

S. Haykin, "Operating Environment Analysis Techniques for Wireless Communication Systems - Transmit Power Control", US Provisional 60/617,639.

S. Haykin, "Operating Environment Analysis Techniques for Wireless Communication Systems - Radio Scene Analysis", US Provisional 60/617,638.

C. Special Issue

S. Haykin, J. Reed, G. Li, and M. Shafi. "Cognitive Radio", Proc. IEEE, Feb. 2009.

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