Cognitive Radio Emerges from Obscurity

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January 23, 2004
Rev 2

Focus

- To give an overview of current cognitive radio initiatives and applications:
  - Regulatory: Federal Communications Commission (FCC)
  - Standards: IEEE 802 Wireless
- To keep the discussion limited to the near term, not “pie in the sky by and by”.
- To focus primarily on unlicensed applications.

What is Cognitive Radio?

- The term Cognitive Radio means different things to different audiences:
- Mitola, addressing the broad issue of wireless personal digital assistants in his dissertation, says[1]:

> "The term cognitive radio identifies the point at which wireless personal digital assistants (PDAs) and the related networks are sufficiently **computationally intelligent** about radio resources and related computer-to-computer communications to:
>
> (a) detect user communications needs as a function of use context, and
>
> (b) to provide radio resources and wireless services most appropriate to those needs."

1. Dr. Joseph Mitola III, *Cognitive Radio An Integrated Agent Architecture for Software Defined Radio Dissertation*, p. 1, para 1.1, Royal Institute of Technology, May 8, 2000.

What is Cognitive Radio?

- Mitola continues[2]:

  "Cognitive radio increases the **awareness that computational entities** in radios have of their locations, users, networks, and the larger environment."

- Mitola includes the concept of machine learning as a property of cognitive radio[3].

- Mitola's approach includes a high level of awareness and autonomy[4]:

  "Cognition tasks that might be performed range in difficulty from the goal-driven choice of RF band, air interface, or protocol to **higher-level tasks of planning, learning, and evolving new protocols**."

2. Ibid p.13, para 2.3
3. Ibid p.47, para 4.2
4. Ibid p.49, para 4.3

What is Cognitive Radio?

- The FCC[5] view of cognitive radio[6]:

  "A cognitive radio (CR) is a radio that can change its **transmitter** parameters based on **interaction with the environment** in which is operates."

- The FCC refers to a Software Defined Radio (SDR) as[7]:

  "a **transmitter** in which the operating parameters … can be **altered by making a change in software** that controls the operation of the device **without … changes in the hardware components** that affect the radio frequency emissions."

- According to the FCC[8]:

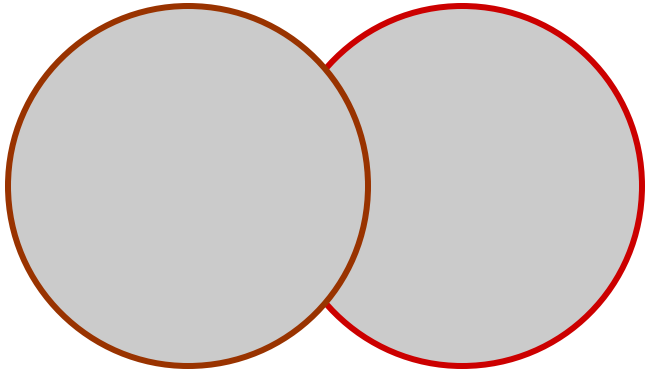
  "The majority of **cognitive radios will probably be SDRs**, but neither having software nor being field reprogrammable are requirements of a cognitive radio."

5. Federal Communications Commission
6. FCC 03-322, Notice of Proposed Rulemaking on Cognitive Radio, p.5, para 10
7. Ibid p.4, para 9
8. Ibid p.5, para 10

What is Cognitive Radio?

- Notor's Simplified View

Cognitive Radio Adapts to Spectrum Environment



SDR Adapts to Network Environment

- Mitola adds another level: device/network intelligence which adapts to user activity.
- The FCC seems primarily concerned with a regulatory friendly view, focused on transmitter behavior for the moment.

What is Cognitive Radio?

- A fully cognitive radio should have the ability to do the following[9]:
  1. Tune to any available channel in the target band.
  2. Establish network communications and operate in all or part of the channel.
  3. Implement channel sharing and power control protocols which adapt to spectrum occupied by multiple heterogeneous networks.
  4. Implement adaptive transmission bandwidths, data rates, and error correction schemes to obtain the best throughput possible.
  5. Implement adaptive antenna steering to focus transmitter power in the direction required to optimize received signal strength.

9. Adapted from the presentation by John Notor, *Radio Architectures for Unlicensed Reuse of Broadcast TV Channels*, Communications Design Conference, September, 2003.

Evidence of Primitive Cognitive Radio Life Forms

- In the commercial networking arena, the cognitive radio landscape is primitive at best.
  - Limited by the current regulatory framework to operation within a given frequency band.
- Some examples of cognitive radio cited by the FCC in their cognitive radio NPRM:
  - Cordless telephones in the 43.71-44.49 MHz band avoid channels occupied by private land mobile systems using passive scanning techniques to automatically select unoccupied channels.
  - U-NII band devices operating in the 5.25-5.35 GHz and 5.47-5.725 GHz bands are required to use similar techniques to avoid interference with Federal Government operations.

Evidence of Primitive Cognitive Radio Life Forms

- Two protocols have emerged as early cognitive radio behavior:
  - Dynamic Frequency Selection (DFS):
    - Originally used to describe a technique to avoid radar signals by 802.11a networks which operate in the 5 GHz U-NII band.
    - Now generalized to refer to an automatic frequency selection process intended to achieve some specific objective (like avoiding harmful interference to a radio system with a higher regulatory priority).
  - Transmit Power Control (TPC):
    - Originally a mechanism for 802.11a networks to lower aggregate transmit power by 3 dB from the maximum regulatory limit to protect ESSS (Earth Exploration Satellite Systems) operations.
    - Now generalized to a mechanism that adaptively sets transmitter power based on the spectrum or regulatory environment.

Evidence of Primitive Cognitive Radio Life Forms

- Another key cognitive radio behavior is Incumbent Profile Detection[10] (IPD).
- IPD is the ability to detect an incumbent user (one with regulatory priority) based on a specific spectrum signature.
  - DFS requires an IPD protocol identify unoccupied, or lightly used frequencies.
  - IPD includes detection schemes focused on the characteristics of the specific incumbents in the band, or bands, that the cognitive radio is designed to support.
  - IPD eliminates the need for geolocation techniques (GPS, etc.) to determine the location of the radio and, using a database, identify unused channels.

10. John Notor, *Radio Architectures for Unlicensed Reuse of Broadcast TV Channels*, Communications Design Conference, September, 2003.

Recent FCC Activity Related to Cognitive Radio

- December 20, 2002, NOI[11]: *Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band,* FCC-02-328.
  - Opens the question of **using fallow TV band channels** for unlicensed services on a non-interference basis.
  - In the NOI, para.16, the FCC states "Specifically, **an unlicensed device should be able identify unused frequency bands** before it can transmit." (i.e. DFS and IPD).

11. Notice of Inquiry (NOI)

Recent FCC Activity Related to Cognitive Radio

- November 13, 2003, NOI and NPRM[12]: *Establishment of an Interference Temperature Metric…,* FCC-03-289.
  - Proposes an interference temperature model for quantifying and managing interference.
  - In para.11, the FCC states "For an interference temperature limit to function effectively **on an adaptive or real-time basis**, a system would be needed to measure …, and **a response process** would also be needed…"
- Interference temperature is calculated as:

$$T_{Int} = \frac{N + I}{kB}$$

12. Notice of Proposed Rulemaking(NPRM)

Recent FCC Activity Related to Cognitive Radio

- December 17, 2003, NPRM and Order: *Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies,* FCC-03-322.
  - A wide ranging NPRM exploring a broad range of issues related to cognitive radio technology.
  - In para.1, the FCC points to advances in technology which support more effective spectrum use:

    "Among these advances are **cognitive radio technologies** that can make possible **more intensive and efficient spectrum use** by licensees within their own networks, and by spectrum users **sharing spectrum access on a negotiated or an opportunistic basis**."

Recent FCC Activity Related to Cognitive Radio

- The FCC is proposing specific rulemaking in the unlicensed arena related to cognitive technology:
  - Opening three new bands to unlicensed operation based on DFS and TPC protocols (interference temperature NPRM).
    - 6525-6700 MHz (175 MHz)
    - 12.75-13.15 GHz (400 MHz)
    - 13.2125-13.25 GHz (37.5 MHz)
  - Allowing 6x more transmitter power for cognitive radio devices (under Part 15.247 and Part 15.249) where the ISM band is lightly used (cognitive radio NPRM).

Recent FCC Activity Related to Cognitive Radio

- The FCC numbers game:
  - DFS thresholds at which frequency change is required:
    - For Tx power levels < 23 dBm: -62 dBm
    - For Tx power levels ≥ 23 dBm: -64 dBm
    - DFS threshold averaging time varies with rule: U-NII is 1 us, new interference temperature bands: 1 ms (?).
    - DFS thresholds are referenced to the output of an omni directional antenna.
  - The definition of an unoccupied band: RSL < -83 dBm measured in a 1.25 MHz bandwidth (?) using an omni (?) antennna.
  - Minimum TPC backoff from maximum allowed Tx power: -6 dB, triggered by a vendor specific criterion for link quality.

Recent IEEE 802 Standards Activity in Cognitive Radio

- A recently approved amendment to IEEE 802.11 operation is 802.11h, which incorporates DFS and TPC protocols for 5 GHz operation.
- IEEE 802.18 SG1
  - Established at the Albuquerque Plenary in November 2003.
  - Focused on creating the following:
    - Recommendations for a rule making proposal to the FCC on TV band use by unlicensed devices.
    - A Project Authorization Request (PAR) and associated 5 Criteria document to create a network standard aimed at unlicensed operation in the TV band.

Cognitive Radio Futures

- Spectrum Facts:
  - A lot of spectrum has been assigned for licensed use by the FCC
  - Actual spectrum use varies dramatically:
    - More congested in urban areas, hardly used in rural areas
    - Some licensed services only operate in a few locations nationally (ex. Fixed Satellite Services).
    - Even in urban areas, only a fraction of available spectrum is in continuous use.
- In terms of reclaiming fallow spectrum, a lot of low hanging fruit is available for harvest using cognitive techniques.
- Regulatory activity is just beginning to open up opportunities to reclaim lightly used spectrum for new services.

Summary and Q&A

- Cognitive radio technologies are coming of age, supported by the growth in processing power in radio chipsets.
- The FCC is beginning to open up the regulatory landscape for more extensive applications of cognitive radio technologies.
- The FCC is looking for innovative ways to enable “the next new thing” in spectrum management and commercial wireless activity
- IEEE 802 is moving with the regulatory process to bring cognitive techniques into new networking standards.
- Questions? Comments?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