Cognitive Radio Communications for Dynamic Spectrum Access #17

Slides based on set provided by
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Outline

- Motivation
- What are Cognitive Radios?
- How are they "cognitive"?
- Agile Transmission
- Conclusion

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Presentation Overview

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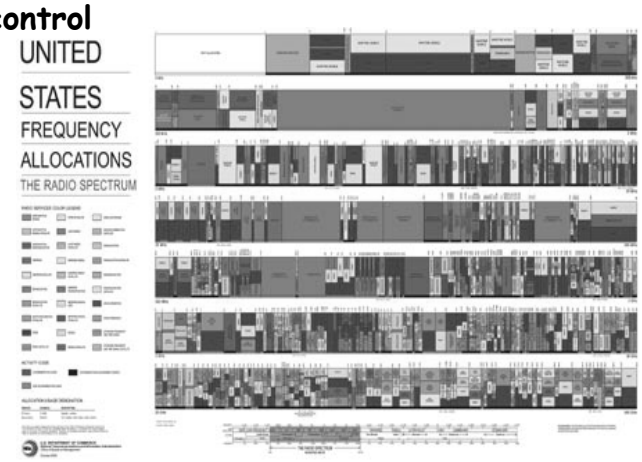
Current Spectrum Allocation

Command-and-control regulation



FCC frequency allocations for US radio spectrum

Current Spectrum Allocation

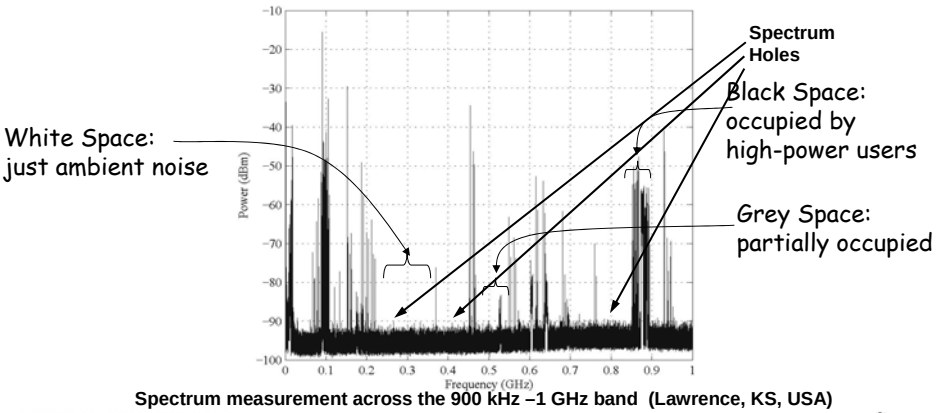
- "Command-and-control" Approach
  - License holders maintain exclusive rights to their allocated spectrum
    - Purchased during a spectrum auction, e.g., 3G auctions
    - Allocated via government decree, e.g., military, television
  - Unlicensed devices not permitted to transmit in licensed bands
    - Allocated unlicensed bands (with transmit constraints)
      - Industrial, Scientific, Medical (ISM) bands
        - » 900 MHz, 1.8 GHz, 2.4 GHz, 5.8 GHz
      - Unlicensed National Information Infrastructure (UNII) band
        - » 5.15 GHz – 5.825 GHz

Increasing Demand

- Rapid growth in the wireless communications sector, requiring *more* spectral bandwidth
  - Increasing number of users
  - Plethora of new wireless services being offered
    - Some applications are bandwidth-intensive
- As a result of this demand, available spectrum under the legacy command-and-control regime is becoming increasingly *scarce*
  - Number of licensed transmissions are increasing within a finite allocated bandwidth
  - Unlicensed users constrained to a few overloaded bands

Apparent Scarcity

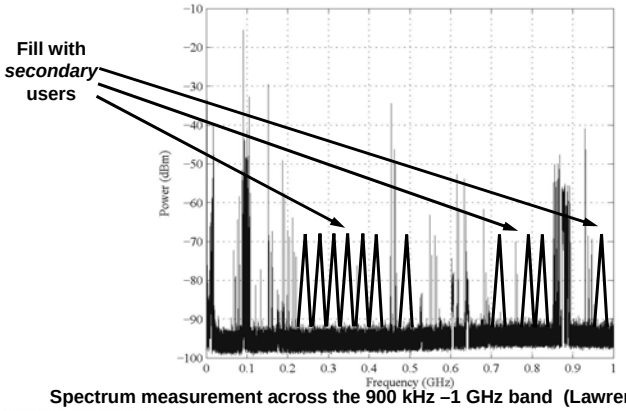
- Measurement studies have shown that in both the time and frequency domains that spectrum is ***underutilized***



Spectrum measurement across the 900 kHz –1 GHz band (Lawrence, KS, USA)

Potential Solution

- Dynamic Spectrum Access (DSA)

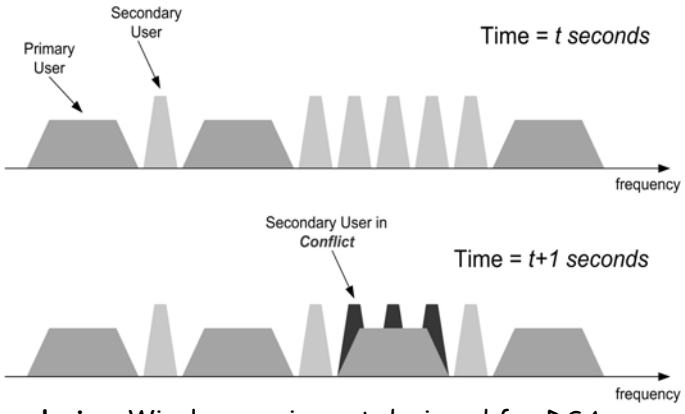


Spectrum measurement across the 900 kHz –1 GHz band (Lawrence, KS, USA)

But not in my spectrum!

- Incumbent license holders are ***very concerned*** about co-existing transmissions from unlicensed users
  - Large-scale investments in developing communication infrastructure around spectrum
    - Maintain quality-of-service to its ***paying*** customers
  - Unlicensed users providing competing services (e.g., VoIP) but without the large-scale investment
  - Transmissions are a time-varying phenomena … a signal not interfering at one point in time may do so at another
  - Consider all the adaptive mechanisms in:
    - HSDPA/HSUPA
    - EV-DO
    - IEEE 802.16
- Trust
  - Validation that cognitive radios provide real benefits
  - Confidence that cognitive radios will not interfere with legacy users

Example



- **Conclusion**: Wireless equipment designed for DSA communications must be ***rapidly reconfigurable*** and ***spectrum-aware***

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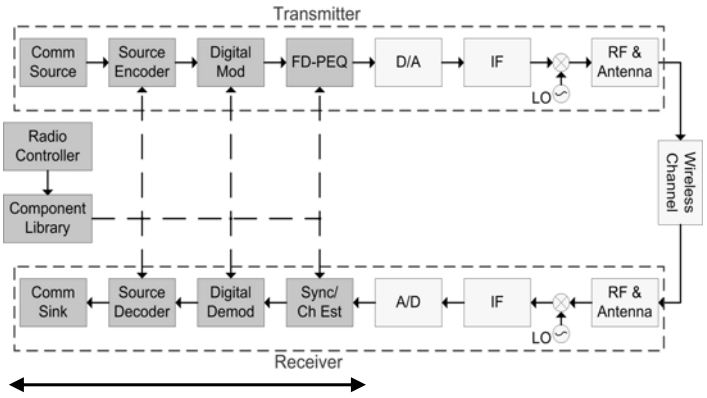
Software-Defined Radios

- Rapid evolution of microelectronics over the past several decades
- Wireless transceivers are becoming more ***versatile***, ***powerful***, and ***portable***
- These advancements have given rise to Software-Defined Radio (SDR) technology
  - Baseband radio functions can be ***entirely*** implemented in digital logic and software
- SDR's are a prerequisite for Cognitive Radio

Software-Defined Radios



Radio functions performed in the software domain

What is a Cognitive Radio?

"Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

- highly reliable communications whenever and wherever needed;
- efficient utilization of the radio spectrum."

S. Haykin, "Cognitive Radio: Brain-Empowered Wireless Communications", IEEE J-SAC, Feb. 2005.

What is a Cognitive Radio?

- An intelligent wireless communications system
- Based on SDR technology
  - Reconfigurable
  - Agile Functionality
- Aware of its environment
  - RF spectrum occupancy
  - Network traffic
  - Transmission quality
- Learns from its environment and adapts to new scenarios based on previous experiences
- Access techniques are
  - Distributed, e.g., like in ad hoc networks.
  - Cooperative
- Shared resources
  - Interference temperature (interference at the receiver)
  - Spectrum holes

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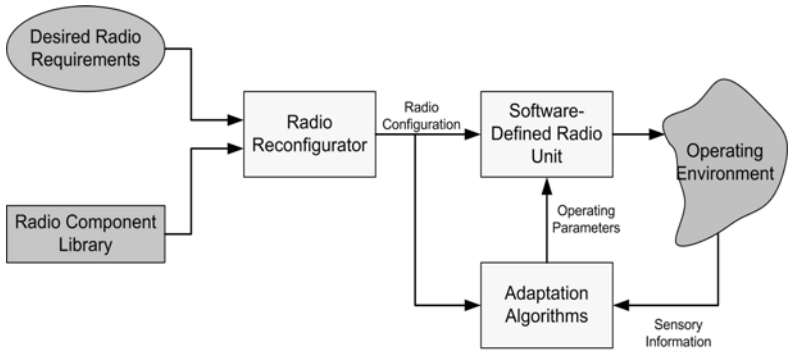
Cognition Framework

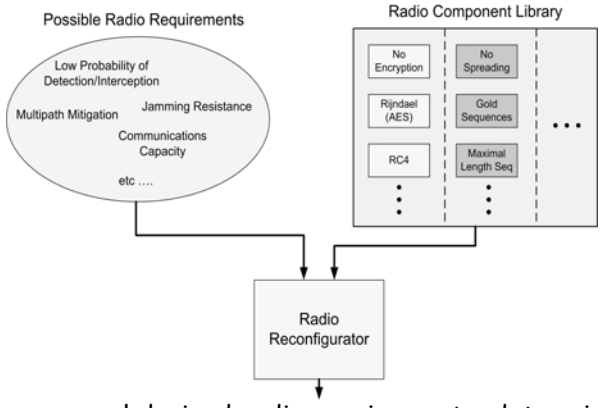
- Distinction between ***reconfigurability*** and ***adaptability***
- Reconfigurability
  - Involves choosing radio building blocks
  - Choice of blocks lasts for relatively long period of time
  - Requires "flashing" of programmable logic
- Adaptability
  - Fine-tunes radio operating parameters
  - Parameter choices last for a short period of time
  - Does not require "flashing" of programmable logic

Cognition Framework



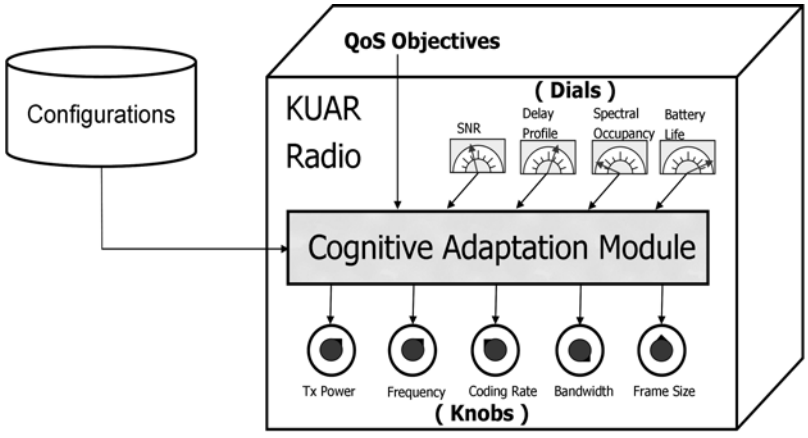
Basic schematic of the cognition component of a cognitive radio

Reconfigurability



- Given several desired radio requirements, determine ***best-possible*** choices for radio components

Adaptation in Cognitive Radios

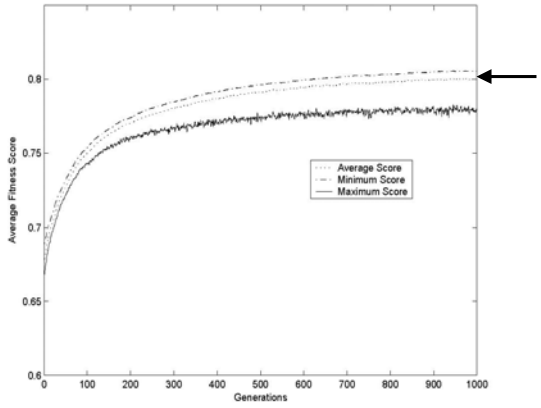


Cognitive adaptation module possessing several *knobs* and *dials*

AI-Based Adaptation

- Genetic Algorithms (GA)
  - Biologically-inspired technique used typically for problems with large parameter spaces
  - Execution time becomes larger as number of operational and environmental parameters grows
  - Does not require much memory to run; requires long execution time
- Expert Systems
  - Decisions determined offline and stored in radio memory
  - Decision making time is very fast
  - Interesting trade-off exists between rule base size and the efficiency of decision

Example: GA Convergence

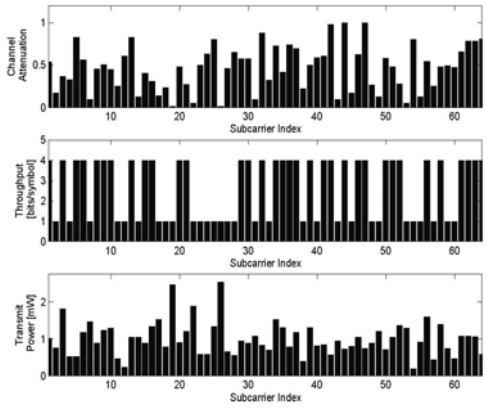


Converges to an overall fitness score of 0.8

GA Convergence for a cognitive radio operating in *emergency mode*

T. R. Newman *et al.*, "Cognitive Engine Implementation for Wireless Multicarrier Transceivers", To appear in the Wiley Wireless Communications and Mobile Computing Journal, 2007.

Example: GA Solution



Subcarrier channel attenuation, throughput, and transmit power levels

T. R. Newman *et al*., "Cognitive Engine Implementation for Wireless Multicarrier Transceivers", To appear in the Wiley Wireless Communications and Mobile Computing Journal, 2007.

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Transmission Approaches for DSA

- Transmission in licensed spectrum classified into three categories
  - **Cooperative Approach**
    - Primary and secondary users coordinate with each other regarding spectrum usage
  - **Underlay Approach**
    - Secondary signals transmitted at very low power spectral density; undetected by primary users
    - e.g., ultra wideband (UWB)
  - **Overlay Systems**
    - Secondary signals fill in the spectrum unoccupied by primary users

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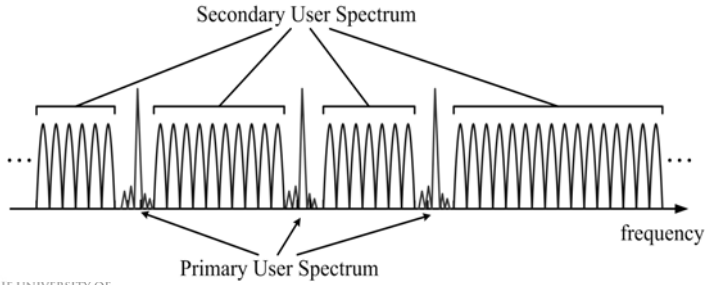
NC-OFDM Transmission

- Based on conventional orthogonal frequency division multiplexing (OFDM)
- Uses spectrum sensing measurements to "turn off" potentially interfering subcarriers



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Required functions for Cognitive Radios

- Radio scene analysis
  - Spectral estimation,
    - Finding the white spaces/spectral holes
    - Determining the channel conditions
  - Interference temperature
    - Worst case RF environment in a specific band at a specific location for the receiver to operate satisfactorily
- Transmit power control
- Dynamic spectrum management, what to do with the finding white spaces/spectral holes
- Possibility of emergent behavior

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Conclusion

- DSA approach to spectrum management is a reality
  - FCC Proposed Rule-Making with respect to TV bands
- Cognitive Radios can help us realize DSA networks
  - Increased spectral efficiency
  - Enhanced transmission performance
- Much work still required before deploying reliable DSA networks
  - Continue work on developing communication techniques that enable DSA

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- R. Rajbanshi *et al.*, "An Efficient Implementation of NC-OFDM Transceivers for Cognitive Radios", Proc. CrownCom, June. 2006.

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