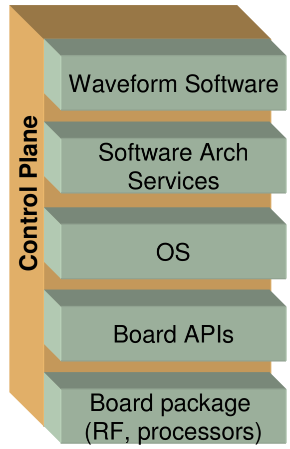
Cognitive Radio: Basic Idea

- Software radios permit network or user to control the operation of a software radio
- Cognitive radios enhance the control process by adding
  - Intelligent, autonomous control of the radio
  - An ability to sense the environment
  - Goal driven operation
  - Processes for learning about environmental parameters
  - Awareness of its environment
    - Signals
    - Channels
  - Awareness of capabilities of the radio
  - An ability to negotiate waveforms with other radios



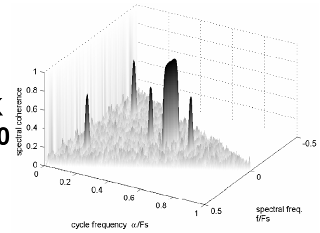
Spectral Coherence Function

- Spectral Coherence Function

$$C_x^\alpha = \frac{S_x^\alpha(f)}{\sqrt{S_x^0(f+\alpha/2)\,S_x^0(f-\alpha/2)}}$$

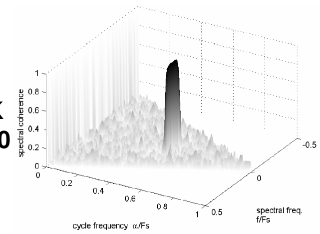
- Normalized, i.e., $\left|C_x^\alpha(f)\right| \leq 1$
- Terminology:
  - α = cycle frequency
  - f = spectrum frequency
- Utility: Peaks of *C* correspond to the underlying periodicities of the signal that may be obscured in the PSD
- Like periodogram, variance is reduced by averaging

Resolution

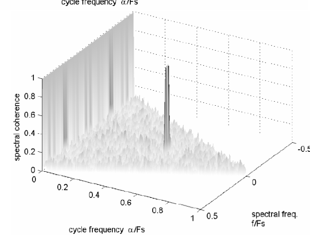


BPSK 200x200

- High α resolution may be needed to capture feature space
  - High computational burden
- Lower resolution possible if there are expected features
  - Legacy radios should be predictable
  - CR may not be predictable
  - Also implies an LPI strategy



BPSK 100x100



AM

Plots from A. Fehske, J. Gaeddert, J. Reed, "**A new approach to signal classification using spectral correlation and neural networks,**" *DySPAN 05*, pp. 144-150.

The Neuron and Threshold Logic Unit

- Several inputs are weighted, summed, and passed through a transfer function
- Output passed onto other layers or forms an output itself
- Common transfer (activation) functions
  - Step $f(a)=\begin{cases}1 & a>\theta \\ 0 & a\le\theta\end{cases}$
  - Linear Threshold $f(a)=a-w_{n+1}$
  - Sigmoid $f(a)=\dfrac{1}{1+e^{-(a-\theta)/\rho}}$
  - tanh $f(a)=\tanh\left(\dfrac{a-\theta}{\rho}\right)$

Neuron

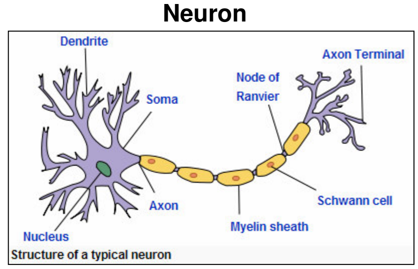
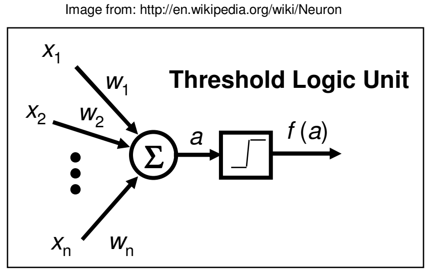


Image from: http://en.wikipedia.org/wiki/Neuron



Language Capabilities and Complexity

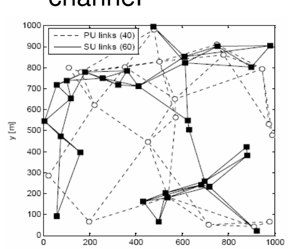
- Increasing capabilities significantly increases complexity

Language	Features	Reasoning	Complexity
XTM	Higher order relationships	None	$O(N)$
RDF	Binary Relationships	None	$O(N)$
RDFS	RDF plus subclass, subproperty, domain, and range	Subsumption	$O(N^m)$
OWL Lite	RDFS plus some class constructors; no crossing of metalevels	Limited form of description logic	$O(e^N)$
OWL-DL	All class constructors; no crossing of metalevels	General description logic	<∞
OWL Full	No restrictions	Limited form of first order predicate logic	?

Modified from Table 13.1 in M. Kokar, *The Role of Ontologies in Cognitive Radio* in **Cognitive Radio Technology**, ed., B. Fette, 2006.

Example Application:

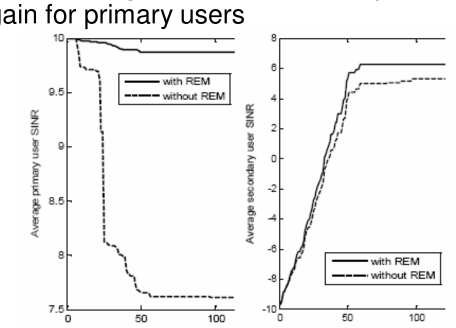
- Overlay network of secondary users (SU) free to adapt power, transmit time, and channel



Parameter	Value
Transmission range of radio node (PU or SU)	450 meters
Sensing range of SU	450 meters
Interference range of SU	450 meters
Speed of SUs	Uniformly distributed in (0, 10m/s)
Data rate of wireless link	2 Mbps
Interface queue length	50 packets
Radio channel model	two-ray ground model
Simulation period	200 seconds

- Without REM:
  - Decisions solely based on link SINR
- With REM
  - Radios effectively know everything

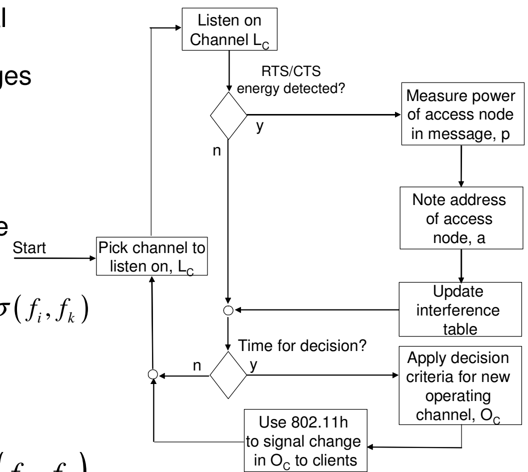
Upshot: A little gain for the secondary users; big gain for primary users



From: Y. Zhao, J. Gaeddert, K. Bae, J. Reed, "Radio Environment Map Enabled Situation-Aware Cognitive Radio Learning Algorithms," SDR Forum Technical Conference 2006.

An IRN 802.11 DFS Algorithm

- Suppose each **access node measures** the received signal **power** and **frequency** of the RTS/CTS (or BSSID) messages sent by observable access nodes in the network.
- Assumed out-of-channel interference is negligible and RTS/CTS transmitted at same power



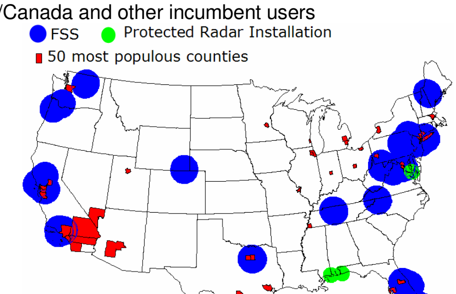
$$u_i(f) = -I_i(f) = -\sum_{k \in N \setminus i} g_{ki} p_k \sigma(f_i, f_k)$$

$$\sigma(f_i, f_k) = \begin{cases} 1 & f_i = f_k \\ 0 & f_i \neq f_k \end{cases}$$

$$g_{jk} p_j \sigma(f_j, f_k) = g_{kj} p_k \sigma(f_k, f_j)$$

802.11y

- Ports 802.11a to 3.65 GHz – 3.7 GHz (US Only)
  - FCC opened up band in July 2005
  - Ready 2008
- Intended to provide rural broadband access
- Incumbents
  - Band previously reserved for fixed satellite service (FSS) and radar installations – including offshore
  - Must protect 3650 MHz (radar)
  - Not permitted within 80km of inband government radar
  - Specialized requirements near Mexico/Canada and other incumbent users
- Leverages other amendments
  - Adds 5,10 MHz channelization (802.11j)
  - DFS for signaling for radar avoidance (802.11h)
- Working to improve channel announcement signaling
- Database of existing devices
  - Access nodes register at http://wireless.fcc.gov/uls
  - Must check for existing devices at same site



Source: IEEE 802.11-06/0YYYr0