COGNITIVE RADIO TECHNOLOGY

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Outline

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  - Transmit-power control and dynamic spectrum management
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What is Cognitive Radio (CR)

- Motivation
- Defining "Cognitive Radio"
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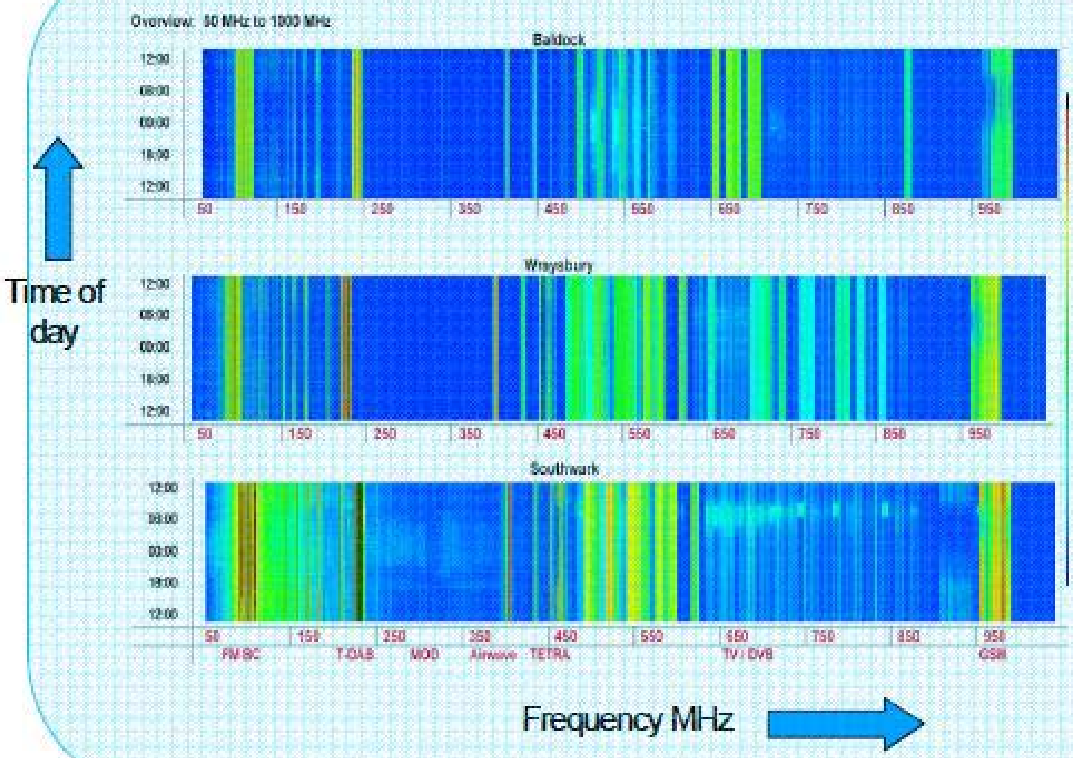
Motivation

- Report from FCC in Nov. 2002:
  - "In many bands, spectrum access is a more significant problem than physical scarcity of spectrum, in large part due to legacy command-and-control regulation that limits the ability of potential spectrum users to obtain such access."
- Scan portions of the radio spectrum:
  - some frequency bands in the spectrum are largely unoccupied most of the time;
  - some other frequency bands are only partially occupied;
  - the remaining frequency bands are heavily used.

Motivation



Spatial and temporal spectrum usage plots[3]

Diurnal and spatial spectrum usage measurements[3] indicate that the spectrum is not used all the time (blue regions) and that the usage (green regions) depends on location.

Cognitive radios have the potential to jump in and out of un-used spectrum gaps to increase spectrum efficiency and provide wideband services.

Not all the spectrum is used in space (geographic location) or time !

Defining "Cognitive Radio"

- Fixed radios:
  set by the operators
- Adaptive radios:
  adjust themselves to accommodate anticipated channels and environments
- Cognitive radios:
  can sense their environment and learn how to adapt

Cognitive Radios (CR)

- The FCC view :
  "A cognitive radio (CR) is a radio that can change its transmitter parameters based on interaction with the environment in which is operates."
- Simon Haykin:
  awareness, intelligence, learning, adaptivity, reliability, efficiency
- A software-designed radio with cognitive software

Defining "Cognitive Radio"

- A **Software-Defined Radio** (SDR) system is a radio communication system where components that have typically been implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors. etc.) are instead implemented using software on a personal computer or other embedded computing devices.

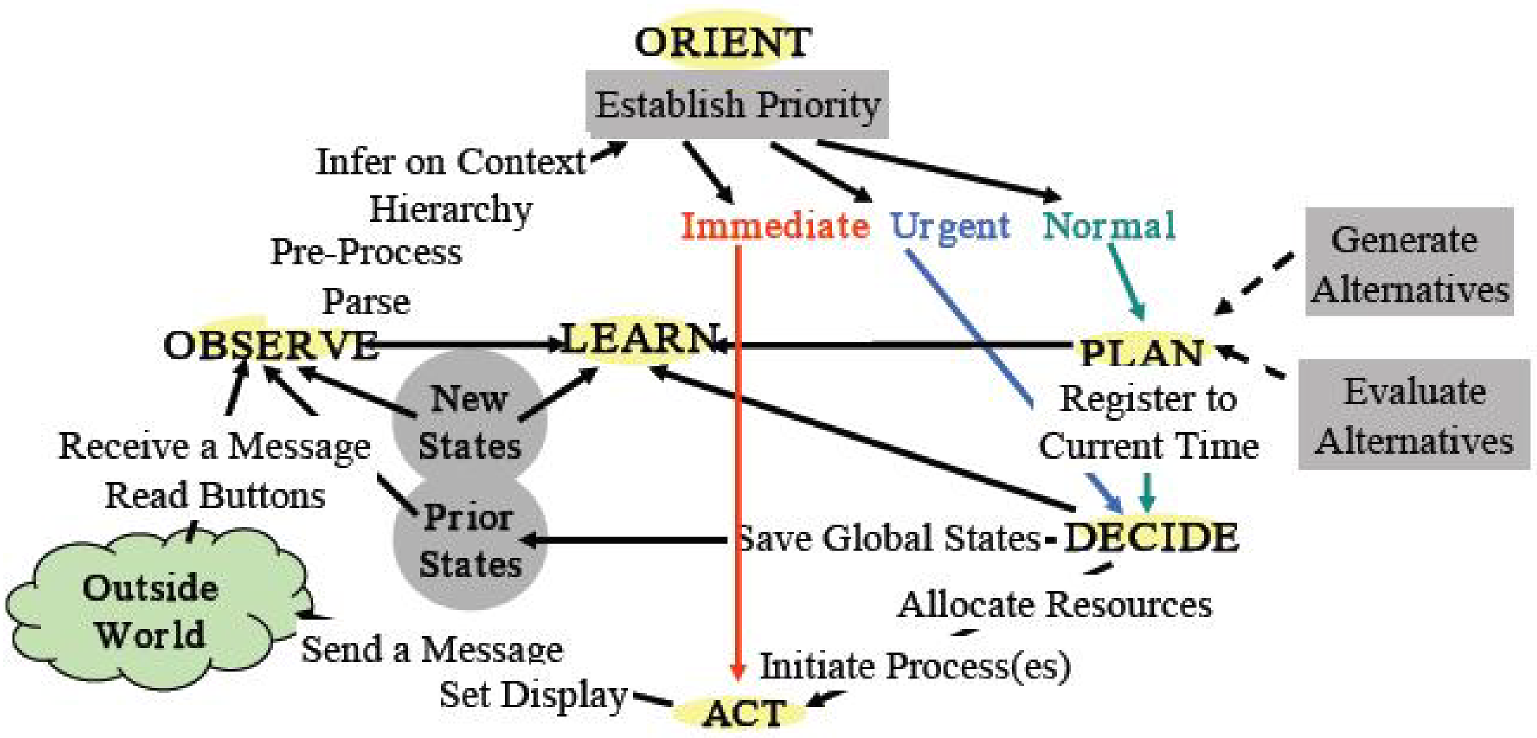
Types of Cognitive Radio

- Two main approaches
- Full Cognitive Radio ("Mitola Radio")

  every possible parameter taken into account
- Spectrum Sensing Cognitive Radio

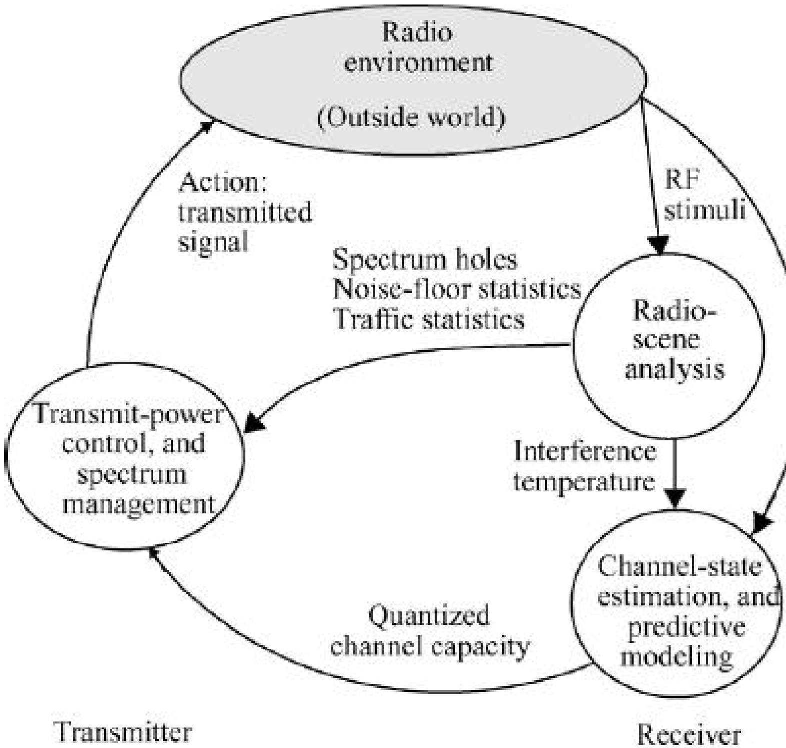
  only radio frequency spectrum considered

Cognition cycle



Introduced by Mitola in his paper in 1999, as a “top-level ” control loop for CR.

Cognition cycle



Cognitive Tasks

- Radio-scene analysis
  - estimation of interference temperature of the radio environment
  - detection of spectrum holes
- Channel identification
  - estimation of channel-state information (CSI)
  - prediction of channel capacity for use by the transmitter
- Transmit-power control and dynamic spectrum management

Cognitive Tasks

- Radio-scene analysis
- Channel-state estimation and predictive modeling
- Transmit-power control and dynamic spectrum management

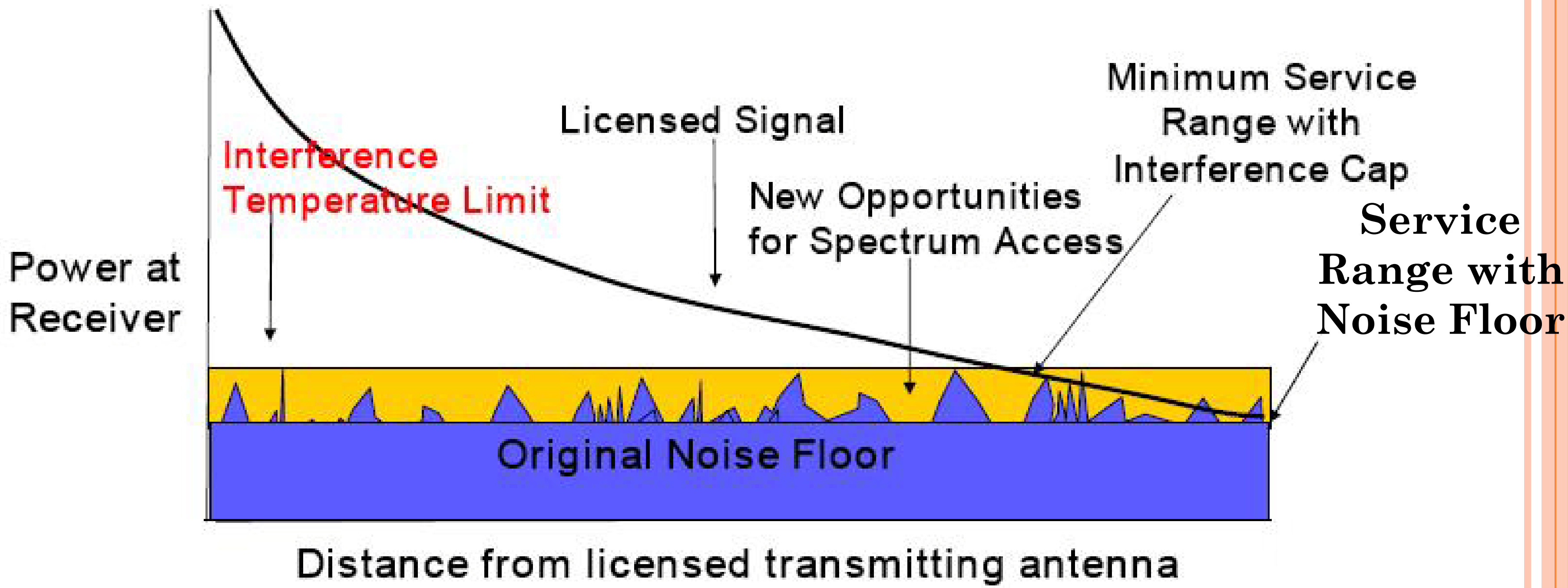
Radio-scene analysis

- The stimuli generated by radio emitters are nonstationary spatio-temporal signals in that their statistics depend on both time and space.
- Space-time processing:
  - two adaptive, spectrally related functions, namely, estimation of the interference temperature, and detection of spectrum holes
  - adaptive beamforming for interference control

Interference Temperature

- A measure of the power and bandwidth occupied by interference
- $T_I(f_c;B) = P_I(f_c;B)/kB$ (Kelvin)
- For a given geographic area, set the interference temperature limit be T_L.
- Serve as an upper bound or "cap" on the potential RF energy.
- The upper limit on permissible power = $T_{max} * k$.

Interference Temperature



Given a particular frequency band in which the interference temperature is not exceeded, that band could be made available to unserviced users.

Estimation of Interference Temperature

- Use the multitaper method to estimate the power spectrum of the interference temperature due to the cumulative distribution of both internal sources of noise and external sources of RF energy.
- Use a large number of sensors to properly "sniff" the RF environment.
- Conclusion: multitaper spectral estimation combined with singular value decomposition (MTM-SVD) provides an effective procedure for estimating the power spectrum of the noise floor in an RF environment.

Detection of Spectrum Holes

- A band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being utilized by that user.
- Classifying the spectra:
  - Black spaces, occupied by high-power "local" interferers some of the time;
  - Grey spaces, partially occupied by low-power interferers;
  - White spaces, free of RF interferers except for ambient noise.
- White spaces (for sure) and grey spaces (to a lesser extent) are obvious candidates for use by unserviced operators.

Adaptive Beamforming for Interference Control

- spatial characteristic of RF stimuli
- two stages:
- The transmitter exploits geographic awareness to focus its radiation pattern along the direction of the receiver.
- At the receiver, beamforming is performed for the adaptive cancellation of residual interference from known and unkonwn transmitters.

Channel-state Estimation and Predictive Modeling

- Why?
  - For receiver: coherent detection of the transmitted signal
  - For transmitter: calculation of the channel capacity for transmit-power control
- How?
  - Differential detection & Pilot transmission
  - Semi-blind training
- Rate feedback: quantize C and feed the quantized transmission rate back to the transmitter.

Transmit-power Control

- Given:

  (i) a set of spectrum holes known to be adequate to support the data-transmission needs of M secondary users, and

  (ii) measurements of the variance of interference plus noise at the receiver input at each of the N subcarriers of the OFDM for every user,

- determine the transmit-power levels of the M secondary users so as to jointly maximize their data-transmission rates, subject to the constraint that the interference-temperature limits in the subfrequency bands defining the spectrum holes are not violated.

Transmit-power Control

- The Multiuser Non-cooperative Cognitive Radio Networks Viewed as a Game-theoretic Problem;
- Information theory : Iterative Water-filling algorithm

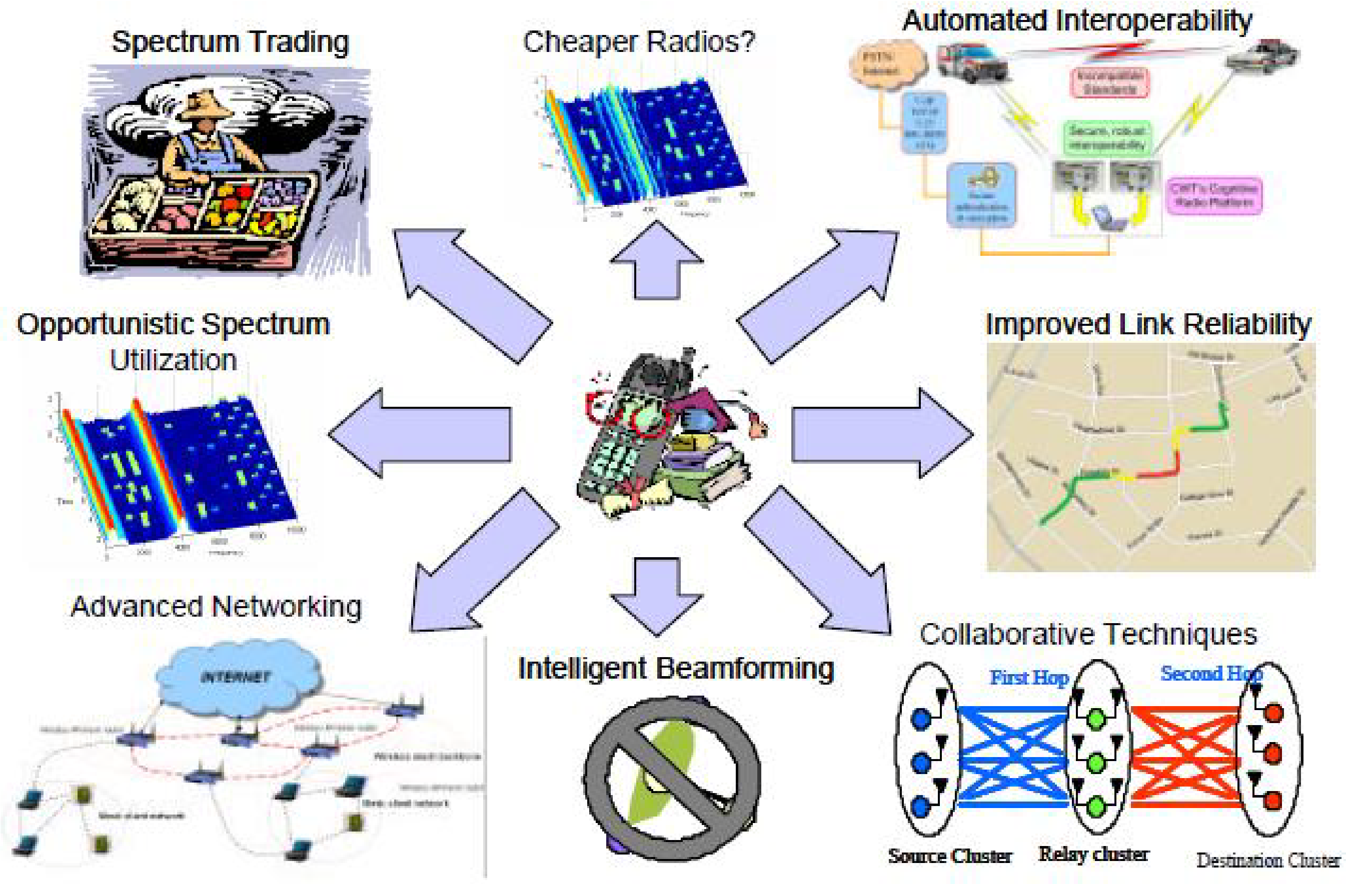
Dynamic Spectrum Management

- Purpose: to develop an adaptive strategy for the efficient and effective utilization of the RF spectrum.
- spectrum-management algorithm:

Building on the spectrum holes detected by the radio-scene analyzer and the output of transmit-power controller, select a modulation strategy that adapts to the time-varying conditions of the radio environment, all the time assuring reliable communication across the channel.

Applications

APPLICATIONS



APPLICATIONS

- Improving spectrum utilization & efficiency
- Improving link reliability
- Less expensive radios
- Advanced network topologies
- Enhancing SDR techniques
- Automated radio resource management.

Applications

Improving link reliability

Reference

- [1] Haykin S. Cognitive Radio, “Brain-Empowered Wireless Communications”, IEEE Journal on Selected Areas in Communications, 2005,23(2):201-220.
- [2] J. Mitola III, "Cognitive Radio for flexible Mobile Multimedia Communications", IEEE 1999 Mobile Multimedia Conference (MoMuC, November, 1999).
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- [4] Anwida Prompijit, “Cognitive Radio (CR)”.
- [5] “Cognitive Radio Technology”, QINETIQ/06/00420 Issue 1.1 12th February 2007.

Questions?