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NOMS 2008 Keynote Speech

Spectrum, network and operations management
in cognitive radio networks

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I.F. Akyildiz, W. Y. Lee, M.C. Vuran and S. Mohanty,
"NeXt Generation/Dynamic Spectrum Access/Cognitive Radio
Wireless Networks: A Survey,"
Computer Networks (Elsevier) Journal, Sept. 2006.

I. F. Akyildiz, W.Y. Lee, M. C. Vuran, and S. Mohanty,
"A Survey on Spectrum Management in Cognitive Radio Networks,"
IEEE Communications Magazine, April 2008.

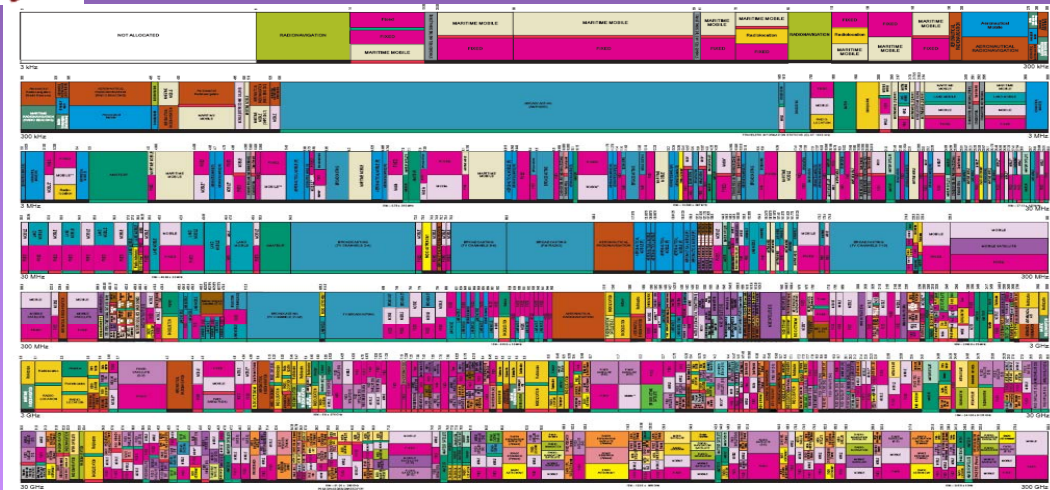
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FIXED SPECTRUM ASSIGNMENT



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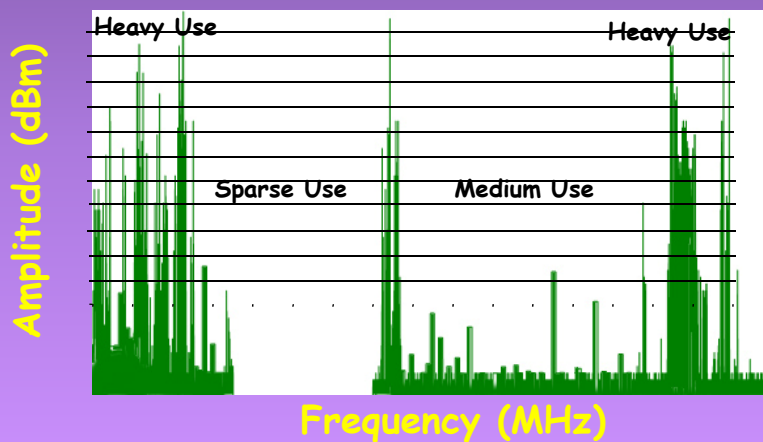
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Fixed Spectrum Utilization

Maximum Amplitudes



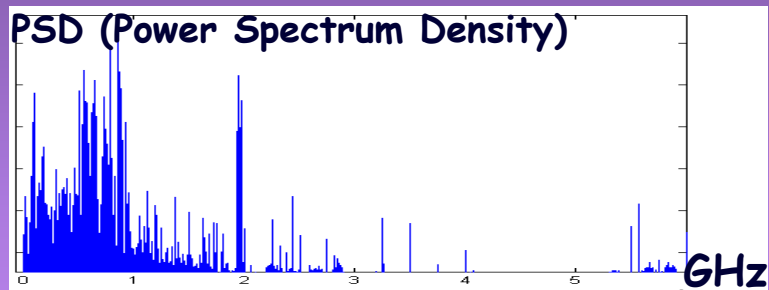
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Fixed Spectrum Utilization



Freq (GHz)	0~1	1~2	2~3	3~4	4~5	5~6
Utilization (%)	54.4	35.1	7.6	0.25	0.128	4.6

Measurements show that there is a wide range of spectrum utilizations across 6 GHz of spectrum

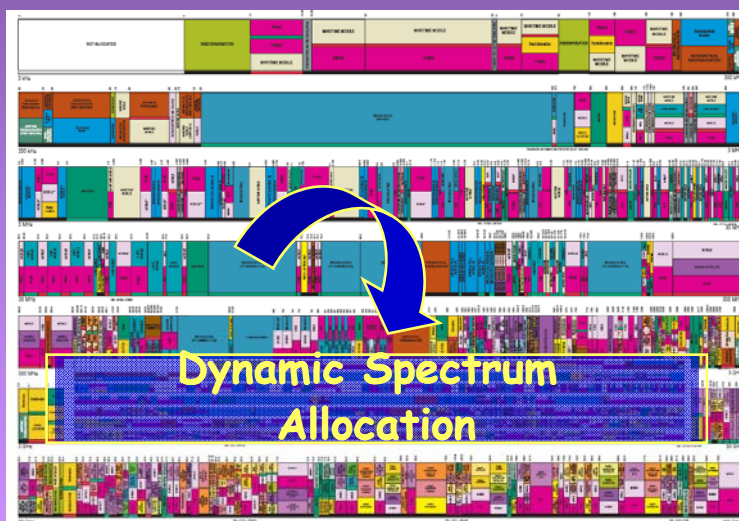
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COGNITIVE RADIO NETWORKS; DYNAMIC SPECTRUM ALLOCATION NETWORKS (DSANs); xG INITIATIVE



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COGNITIVE RADIO

- A "Cognitive Radio" is the key enabling technology for Dynamic Spectrum Access!!
- Capability to use or share the spectrum in an opportunistic manner -> "BANDWIDTH HARVESTING"
- Dynamic spectrum access techniques allow the CR to operate in the best available channel

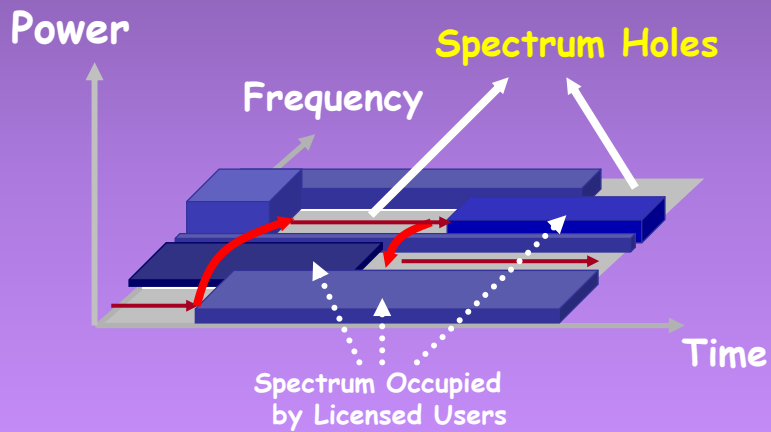


Ultimate Objective of Cognitive Radio

- CR enables the usage of temporally unused spectrum
→ *Spectrum Hole* or *White Space*.
- If this band will be used by a licensed user, CR moves to another spectrum hole
- Alters its transmission power level or modulation scheme to avoid interference



Spectrum Hole Concept



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FEATURES OF COGNITIVE RADIO

- Senses RF Environment and modifies frequency, power or modulation
- Dynamic Spectrum Selection
- Adaptive Modulation
- Adaptive Power Control
- Real Time Spectrum Management
- Significantly Increases Spectrum Efficiency

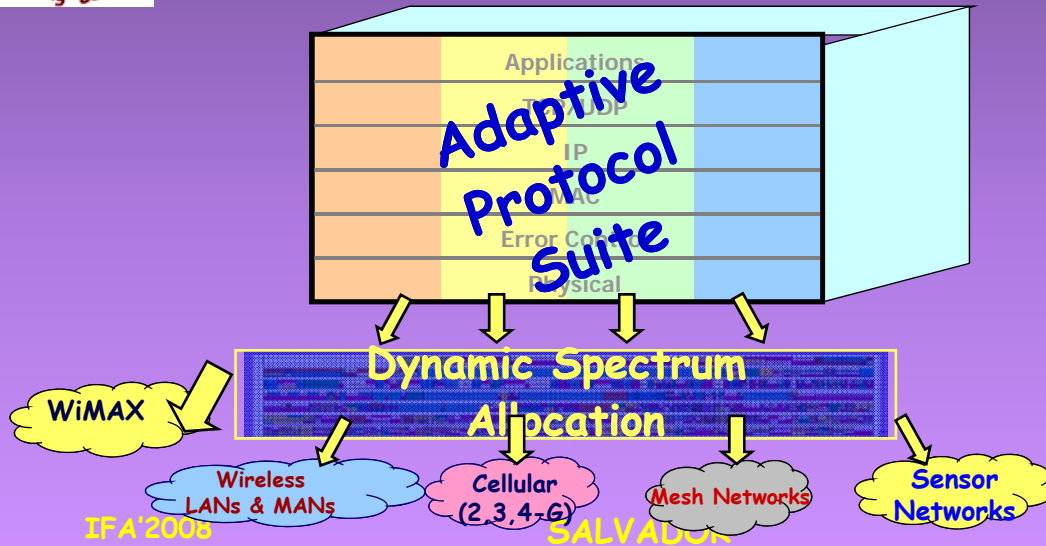
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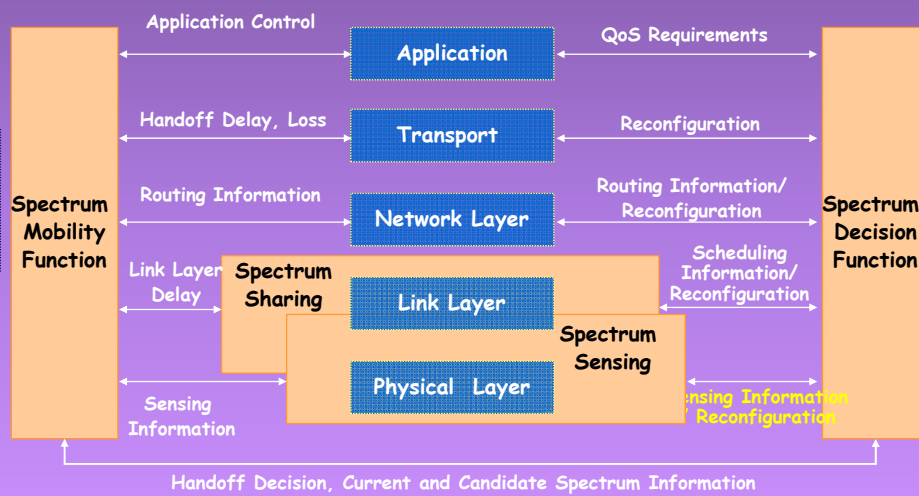
OVERALL VIEW



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COGNITIVE RADIO NETWORK COMMUNICATION FUNCTIONALITIES



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WHAT IS A COGNITIVE RADIO?

A "Cognitive Radio" is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. (Federal Com Commission'2005)

FCC (Non-Federal Use of the Spectrum)

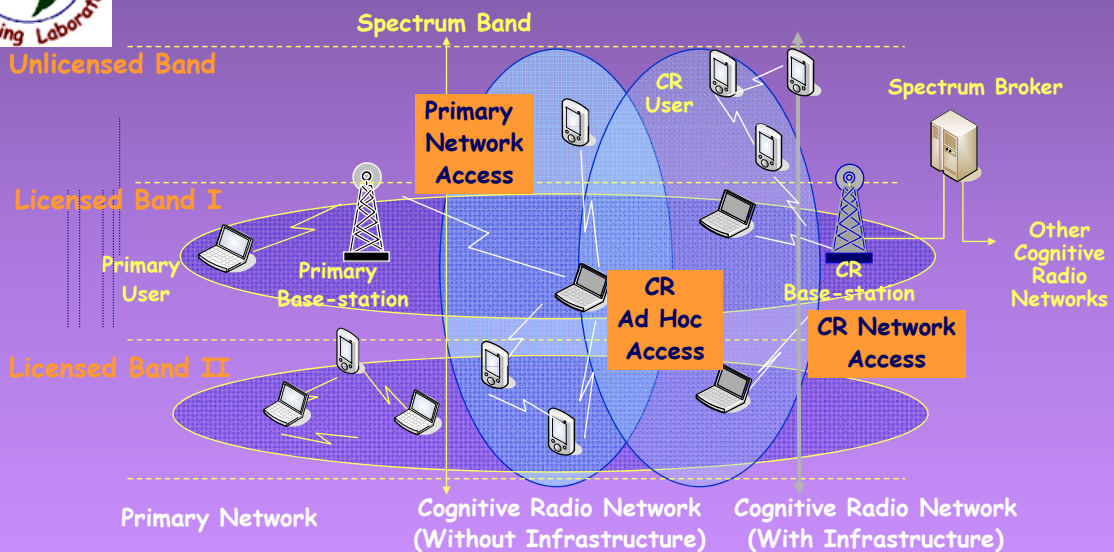
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Cognitive Radio Network Architecture



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Primary Network

An existing network infrastructure which has an access right to a certain spectrum band.

e.g., Common cellular systems and TV broadcast networks.

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Primary User (or Licensed User)

* Has a license to operate in a certain spectrum band.

REMARK:

Primary users do not need any modification or additional functions for co-existence with CR users

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Cognitive Radio Network

(or Dynamic Spectrum Access Network,
or Secondary Network or Unlicensed Network)

- * Does not have license to operate in a desired band.
- * Hence, the spectrum access is allowed only in an opportunistic manner !

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Cognitive Radio User

(or Unlicensed User, Secondary User)

→ has no spectrum license

Hence, additional functionalities are required to share the licensed spectrum band !

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SPECTRUM MANAGEMENT FRAMEWORK

- 1) Determine which portions of the spectrum is available and detect the presence of licensed users when a user operates in a licensed band (*Spectrum Sensing*)
- 2) Select the best available channel (*Spectrum Decision*)
- 3) Coordinate access to this channel with other users (*Spectrum Sharing*)
- 4) Vacate the channel when a licensed user is detected (*Spectrum Mobility* → *Spectrum Handoff*)

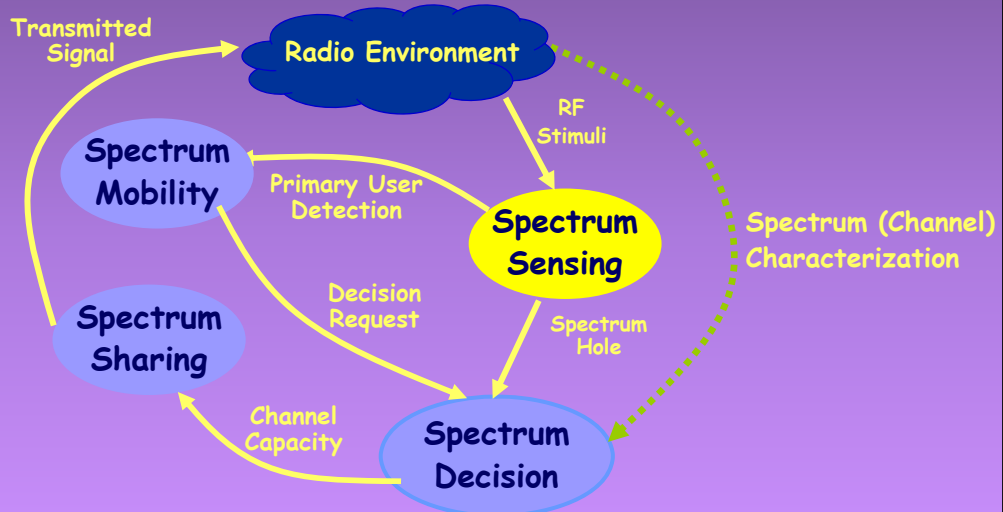
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COGNITIVE CYCLE



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What is Spectrum Sensing ?

How to detect spectrum holes by the **COGNITIVE RADIO** so that it can adapt itself to its environment !!

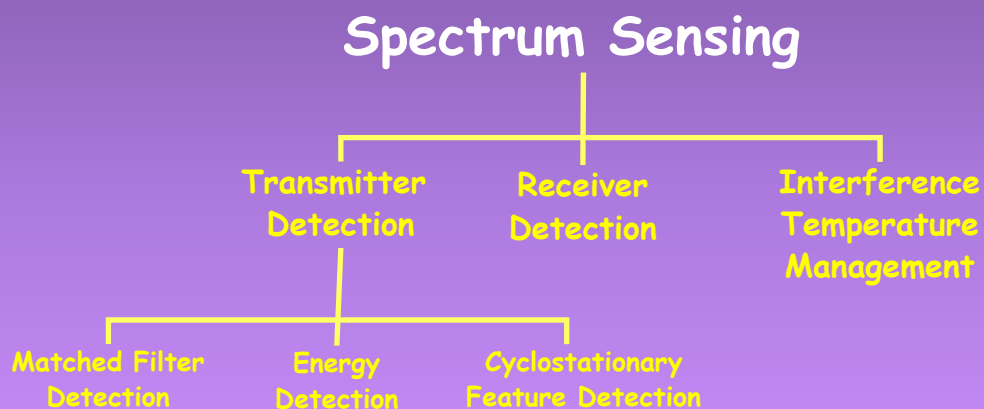
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Classification of Spectrum Sensing Techniques



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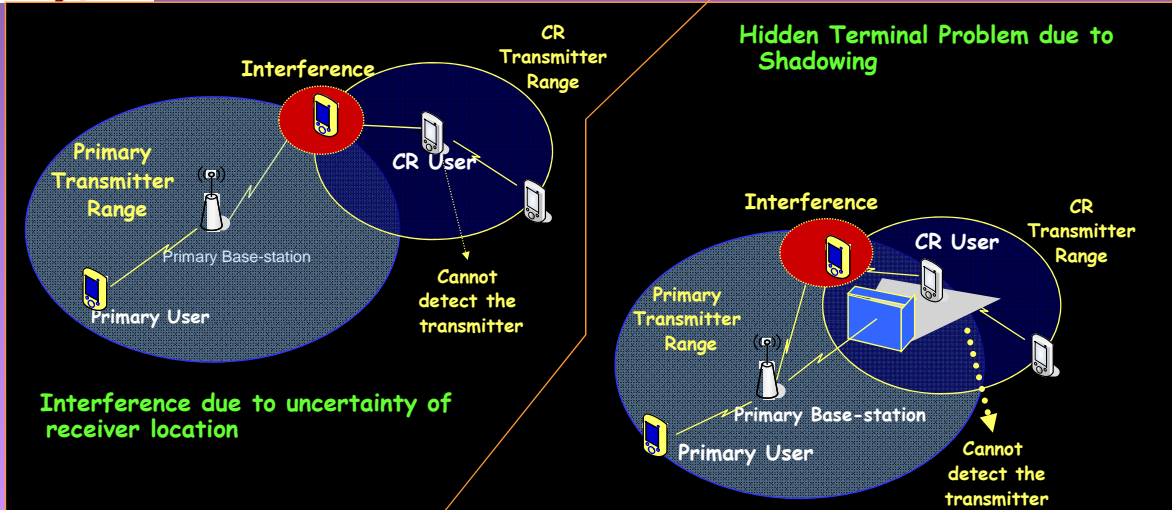
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Limitations of the Transmitter Detection

Receiver Uncertainty Problem

Shadowing Problem



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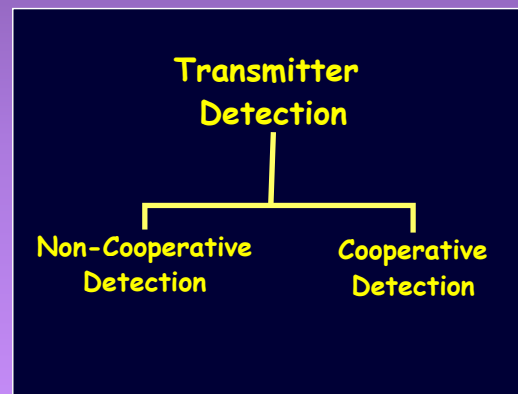
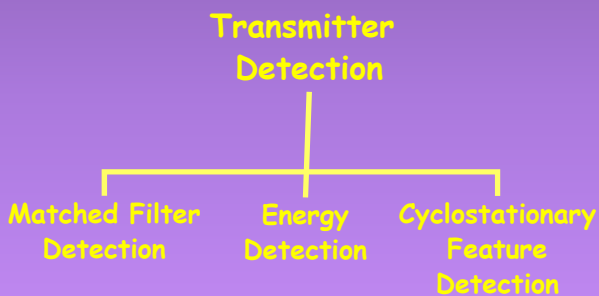
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Transmitter Detection

Non-Cooperative vs Cooperative Detection

■ Detection Method

■ Detection Behavior

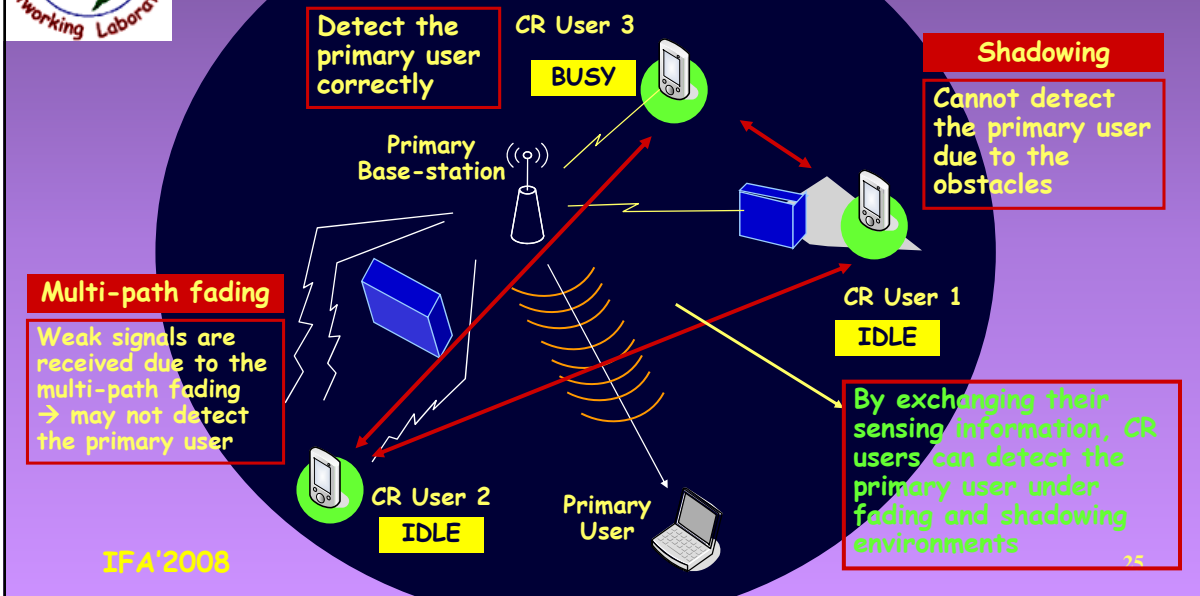


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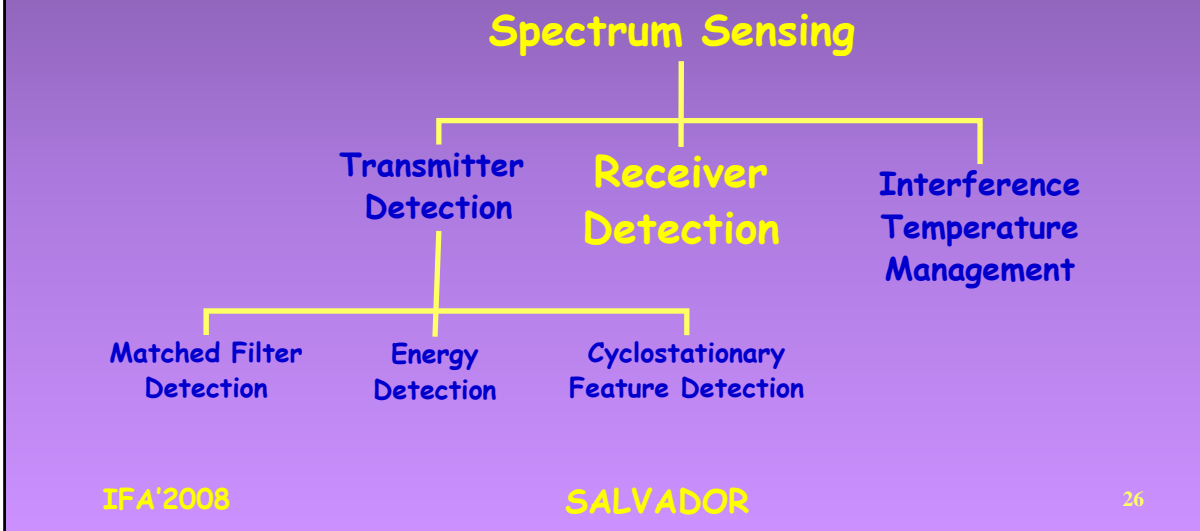
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Cooperative Detection



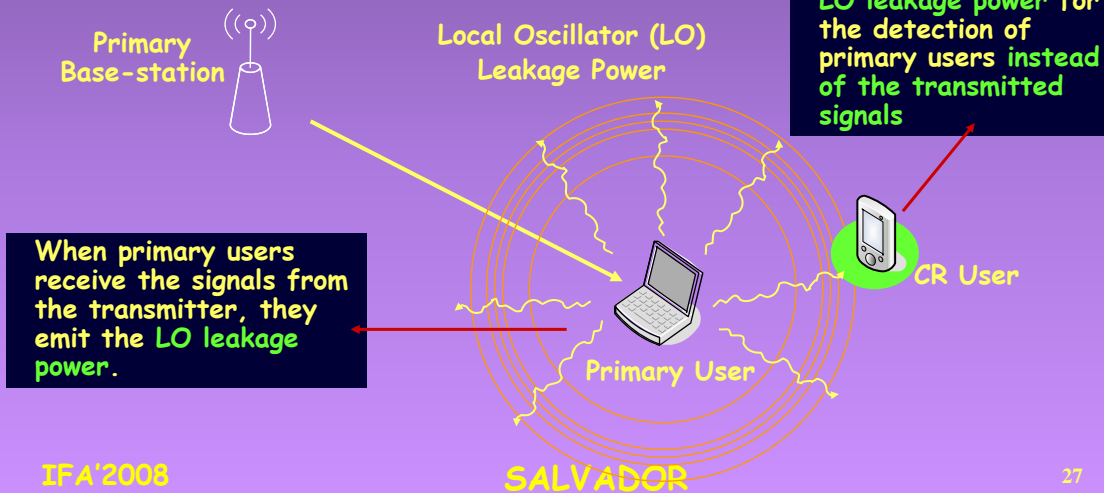
Primary Receiver Detection



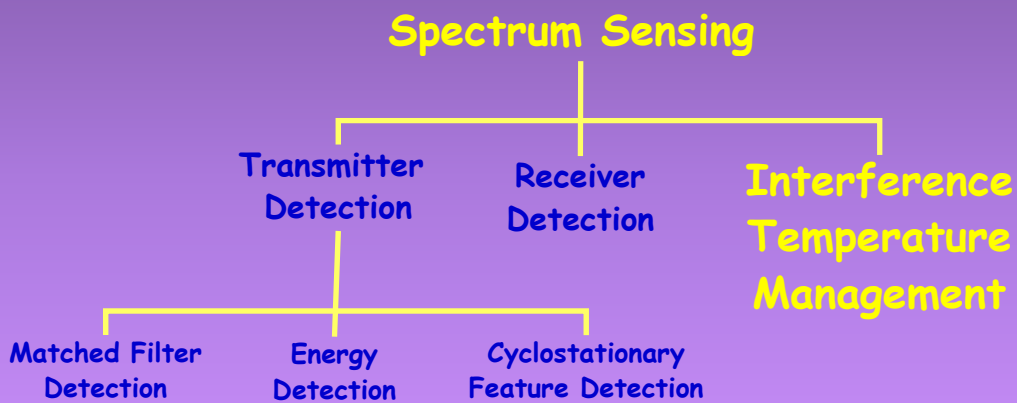


Primary Receiver Detection

B. Wild and K. Ramchandran, "Detecting Primary Receivers for Cognitive Radio Applications" in Proc. IEEE DySPAN, pp. 124-130, Nov. 2005.



Interference Temperature Management



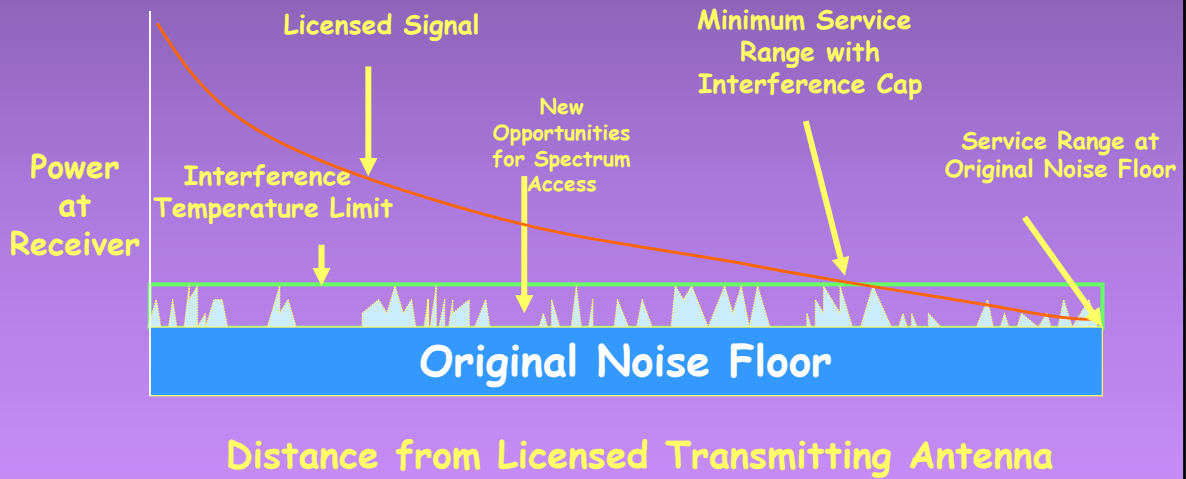
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Interference Temperature Model



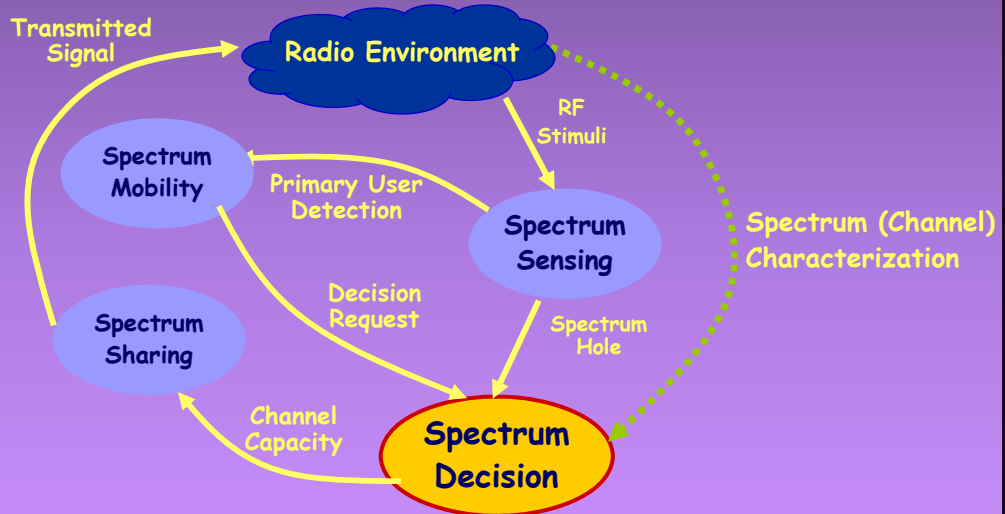
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Spectrum Decision



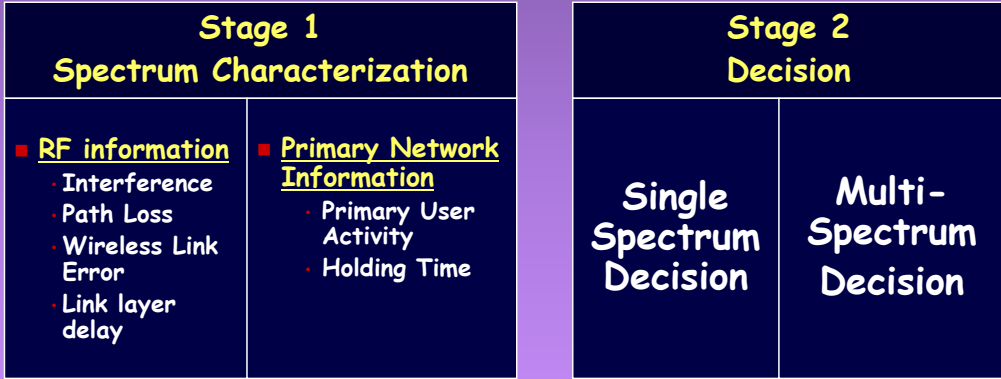
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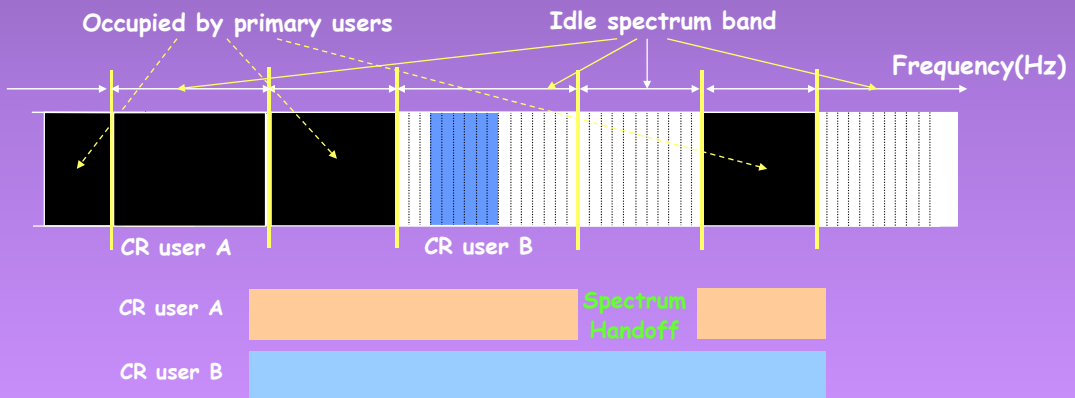


Spectrum Decision



SINGLE SPECTRUM DECISION

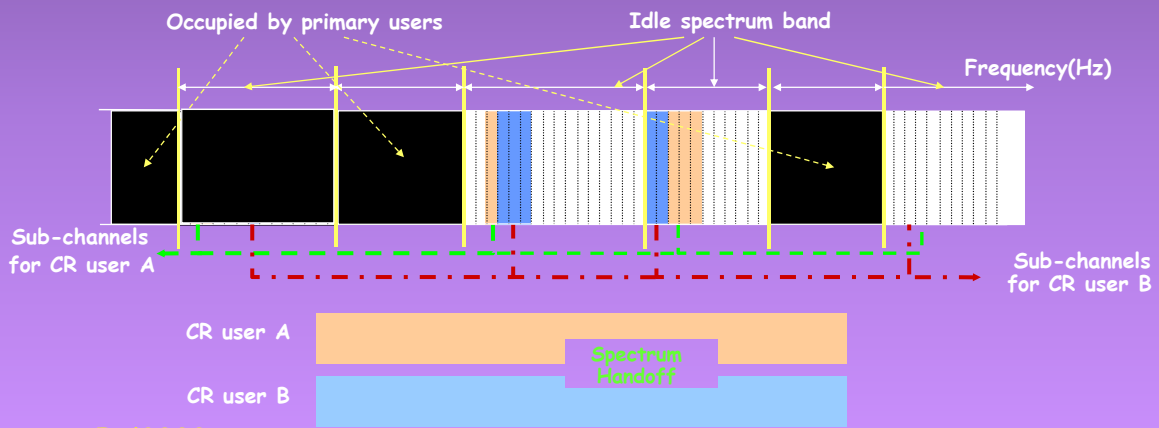
- Each CR user selects only one spectrum band according to the application requirements





Multi-Spectrum Decision

- CR users select multiple non-contiguous spectrum bands and use them simultaneously for the transmission.



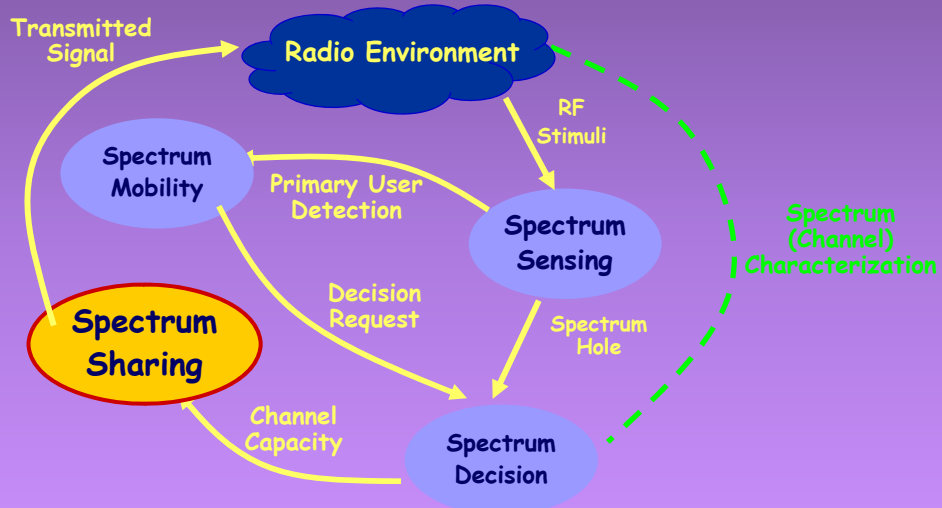
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Spectrum Sharing



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Spectrum Sharing

- **Spectrum Sharing** → similar to MAC Problems
 - Multiple CR users try to access the spectrum
 - Access must be coordinated (to prevent collisions in overlapping portions of the spectrum)
- **Uniqueness**
 - Coexistence with licensed (primary) users
 - Wide range of available spectrum

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SPECTRUM SHARING CLASSIFICATION

Intra-Network SS

Inter-Network SS

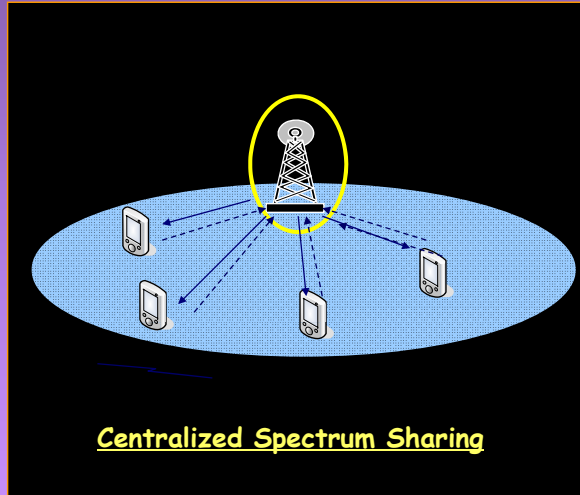
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Intra-Network Spectrum Sharing



Centralized Spectrum Sharing

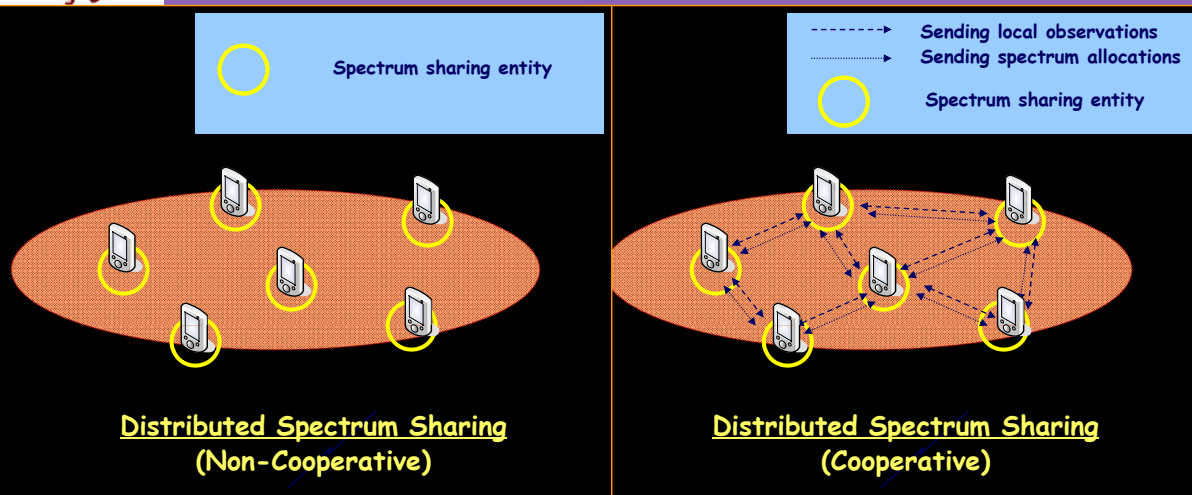
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Intra-Network Spectrum Sharing



Distributed Spectrum Sharing (Non-Cooperative)

Distributed Spectrum Sharing (Cooperative)

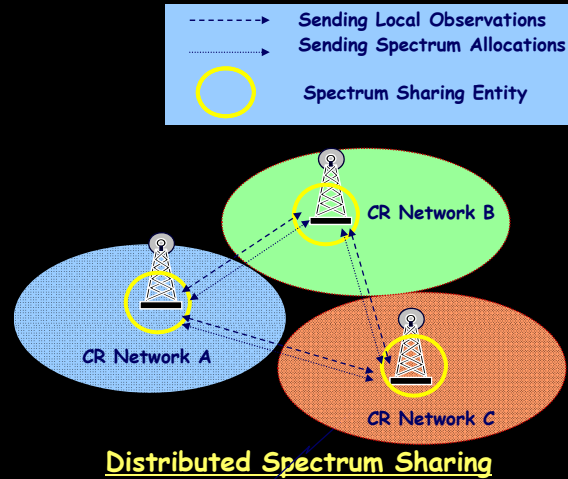
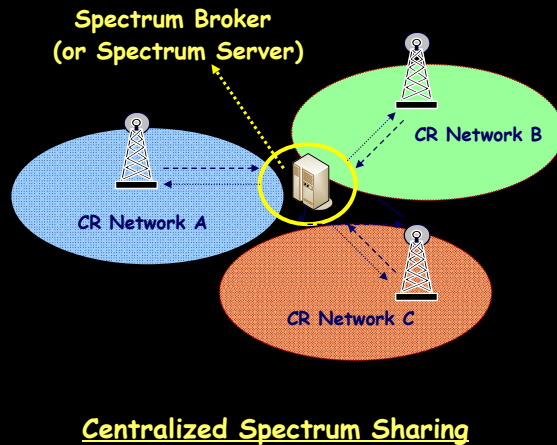
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Inter-Network Spectrum Sharing



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Why Game Theory?

[Spectrum Sharing in CR networks]

- CR users have a common interest to have the spectrum resources as much as possible.
- However, CR users have competing interests to maximize their own share of the spectrum resources. *i.e., the activity of one CR user can impact the activities of the others*
- Also CR user's rational decisions require anticipating rivals' responses

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Why Game Theory?

- Provides an efficient distributed spectrum sharing scheme.
- Provides the well-defined equilibrium criteria for the spectrum sharing problem to measure the optimality in various network scenarios.

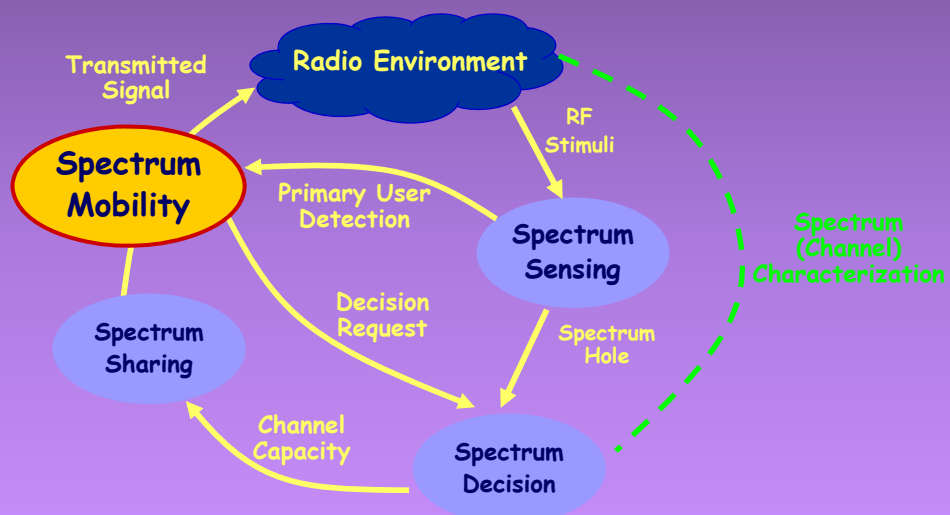
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Spectrum Mobility



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Spectrum Mobility/Handoff

- "Get the Best Available Channel" concept
- CR radio can capture the best available channel
- Spectrum Mobility/Handoff (a new type of handoff) is defined as the process when a CR user (SU) changes its frequency of operation
- When channel conditions become worse or a primary user (PU) appears, spectrum handoff happens

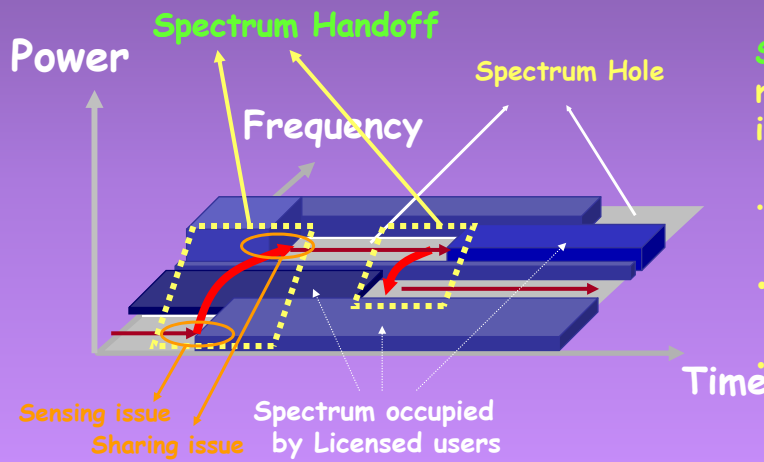


Handoff Process

Traditional Handoff	Spectrum Handoff
A MN detects its link quality deterioration	PU Detection (Sensing issue) PU Notification
The MN scans neighbor BSs/APs to get their knowledge	Out-of-band sensing to find new channel (Sensing issue)
The MN selects one BS/AP	Channel selection (Spectrum decision)
The MN connects to the new BS/AP to resume communications	Channel Switching (Hardware issue) Resume Communication (Sharing and routing issue)



Spectrum Handoff Example



Spectrum handoff is a multi-step process, it includes:

- Primary User Detection (Sensing issue)
- Channel Switching (Hardware issue)
- Resume Communication (Sharing issue)

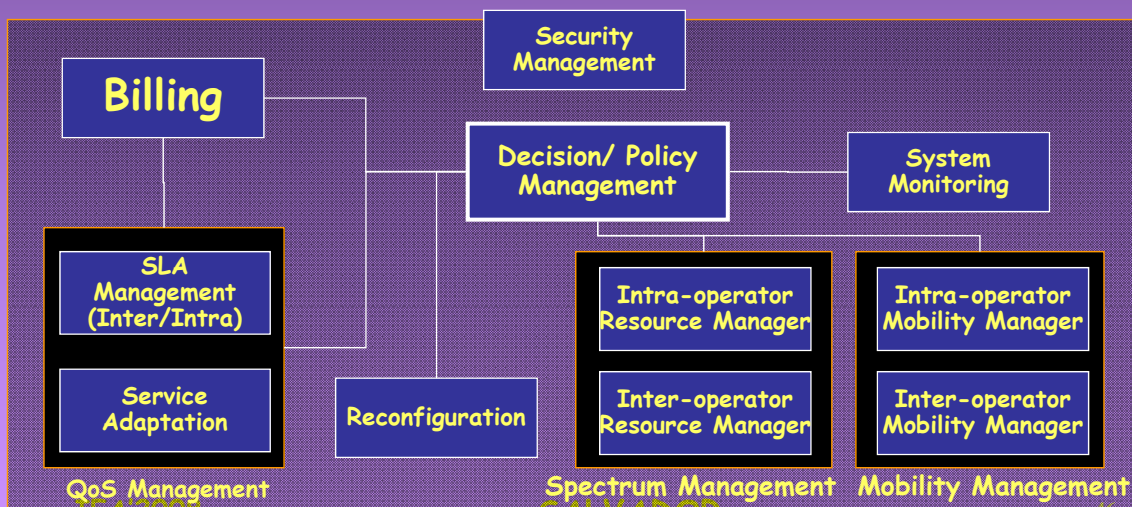
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Proposal for a CR Network Management Framework



QoS Management
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Spectrum Management
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Mobility Management



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RESEARCH CHALLENGES

- Cognitive Radio Design
- Spectrum Sensing Algorithms
- Spectrum Sharing Algorithms
- Spectrum Mobility (Spectrum Handoff Solutions)
- Routing Algorithms
- Transport Layer Solutions
- Network Management (Operation, Maintenance, Billing)

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Cognitive Radio Network Standards

- IEEE 802.22 (**Wireless Regional Area Networks**)
(Cognitive Radio for TV Bands/Channels) (2004)
- IEEE P1900 (2005)

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