Spectrum Management in Cognitive Radio Networks

Jul 14,2010

Instructor: professor m.j omidi

By : Mozhdeh Mola & Zahra Alavikia

Contents

- Overview: Cognitive Radio
- Spectrum Sensing
- Spectrum Decision
- Spectrum Sharing
- Spectrum Mobility
- Conclusions
- Reference

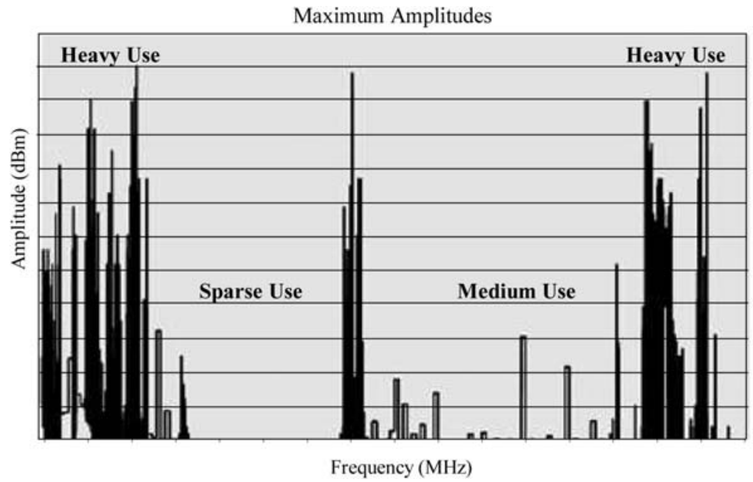
Cognitive Radio

COGNITIVE RADIO

- Current Wireless Networks

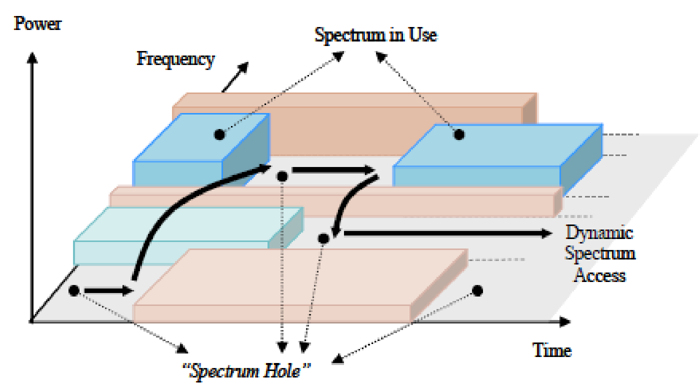
– Static spectrum assignment:

- Spectrum scarcity
- Inefficient use of assigned spectrum bands(temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%.)



COGNITIVE RADIO

- CR capabilities:
  - Dynamic Spectrum Access to exploit the existing wireless spectrum opportunistically
  - Uses white space
  - Vacates spectrum To avoid interference



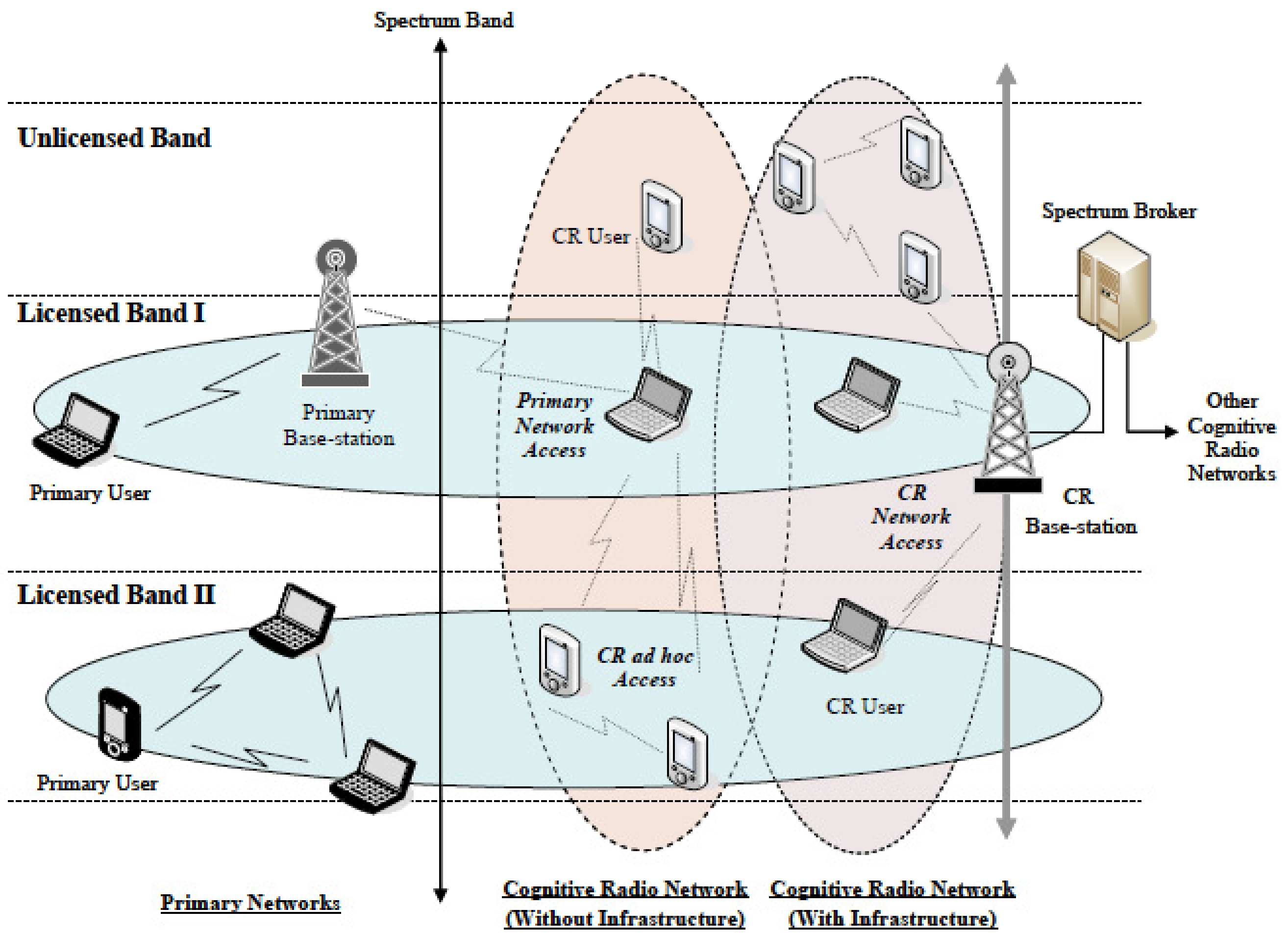
Cognitive Radio

- Definition:

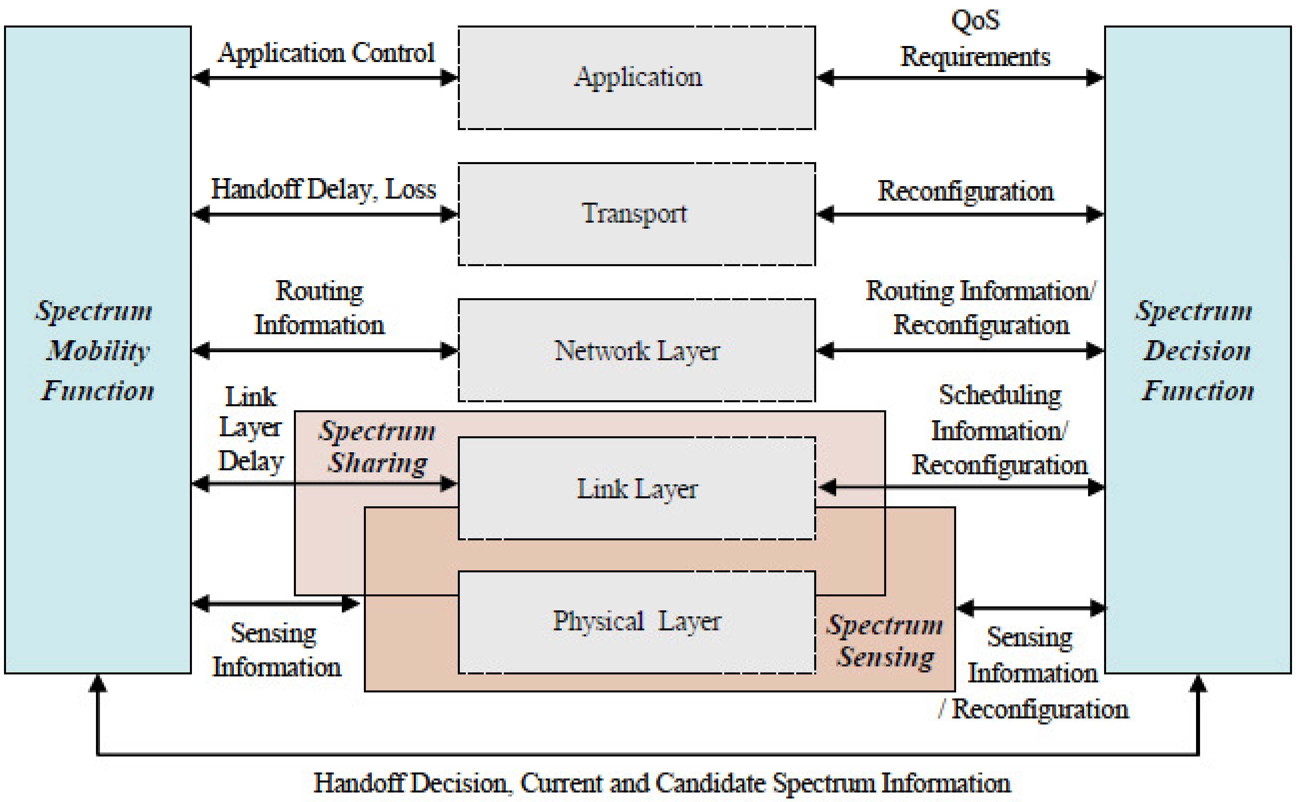
- Cognitive Capability
  - Ability of the radio technology to capture or sense the information from its radio environment

- Reconfigurability
  - To be dynamically programmed according to the radio environment

Cognitive Radio Network Architecture



Cognitive Radio Network Communication Functionalities



Spectrum Sensing

SPECTRUM SENSING

- Definition:

– Ability to be aware of and sensitive to the changes in its surrounding

- In-Band Spectrum Sensing

– Detect the spectrum band during the transmission and detects the presence of PUs so as to avoid interference

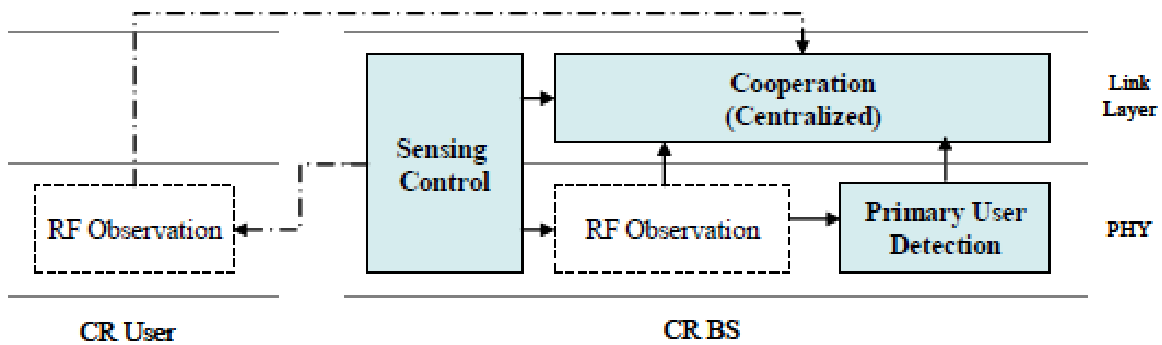
- Out-of-band Spectrum Sensing

– Finds available spectrum holes over a wide frequency range for their transmission

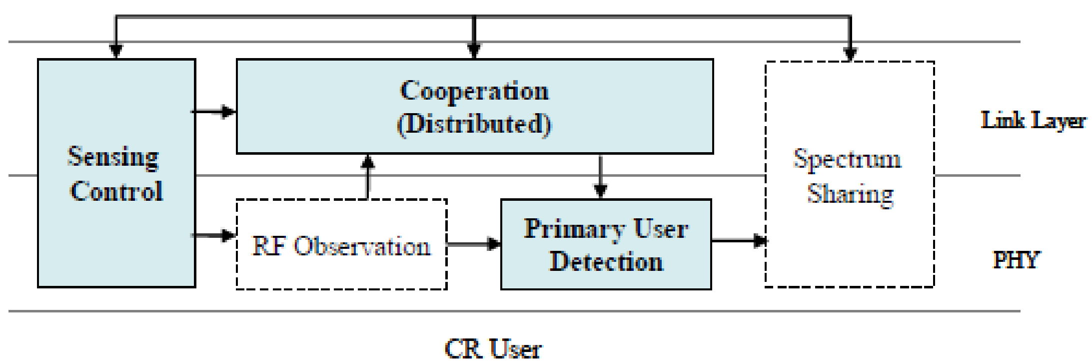
SPECTRUM SENSING

- Functionalities

- Infra Structure-Based Network



- Ad Hoc Network

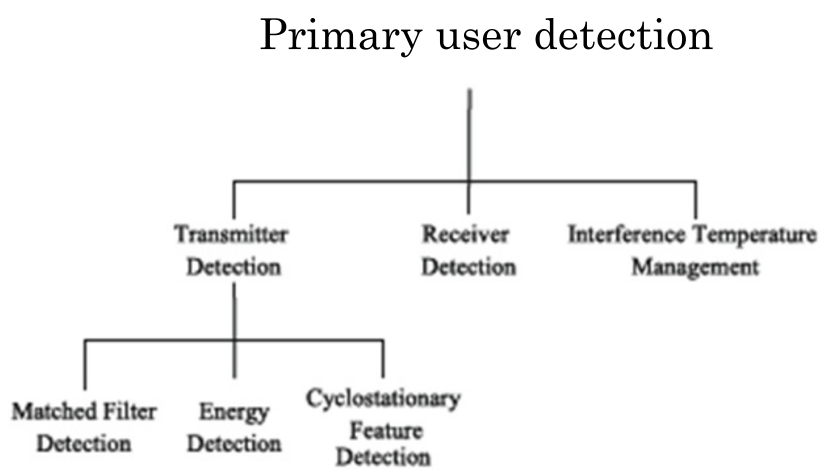


PRIMARY USER DETECTION

- Definition:

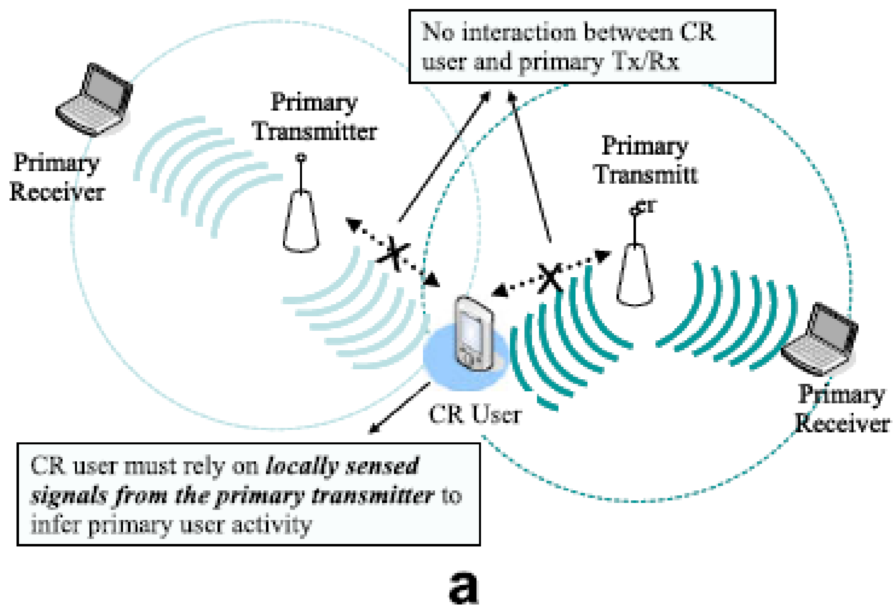
– PU detection is a capability to determine the presence of PU transmissions through the location observation of a CR user and identify the current spectrum availability.

- Classification



TRANSMITTER DETECTION

- Transmitter Detection Technique
  - Matched Filter
  - Energy Detection
  - Feature Detection



TRANSMITTER DETECTION

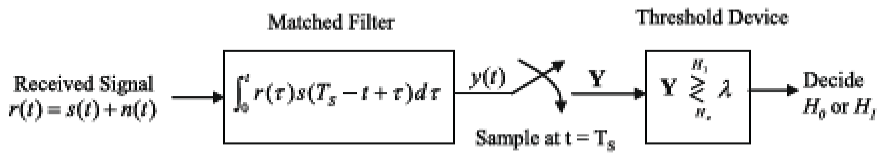
- Matched Filter Detection

✓ Fast sensing time

x priori knowledge of the characteristics of the PU signal

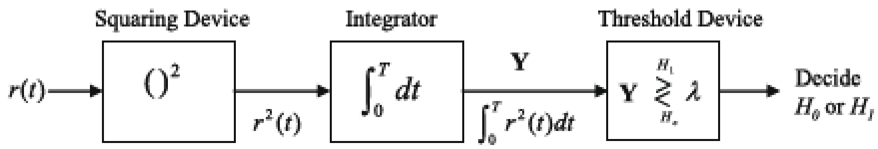
x Necessitates the synchronization between the PU transmitter and the CR user

x Need to have different multiple matched filters dedicated to each type of the PU signal, which increases the implementation cost and complexity



TRANSMITTER DETECTION

- Energy Detection
- ✓ Simple to implement
- x suffers from longer detection time compared to the matched filter detection
- x Its performance is susceptible to uncertainty in noise power
- x cannot differentiate signal types



Transmitter Detection

- Feature Detection

✓ Robustness to the uncertainty in noise power

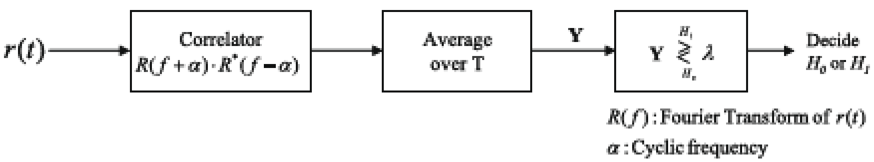
✓ It can distinguish the signals from different networks

✓ Independently operation of those of its neighbors without synchronization

x It is computationally complex

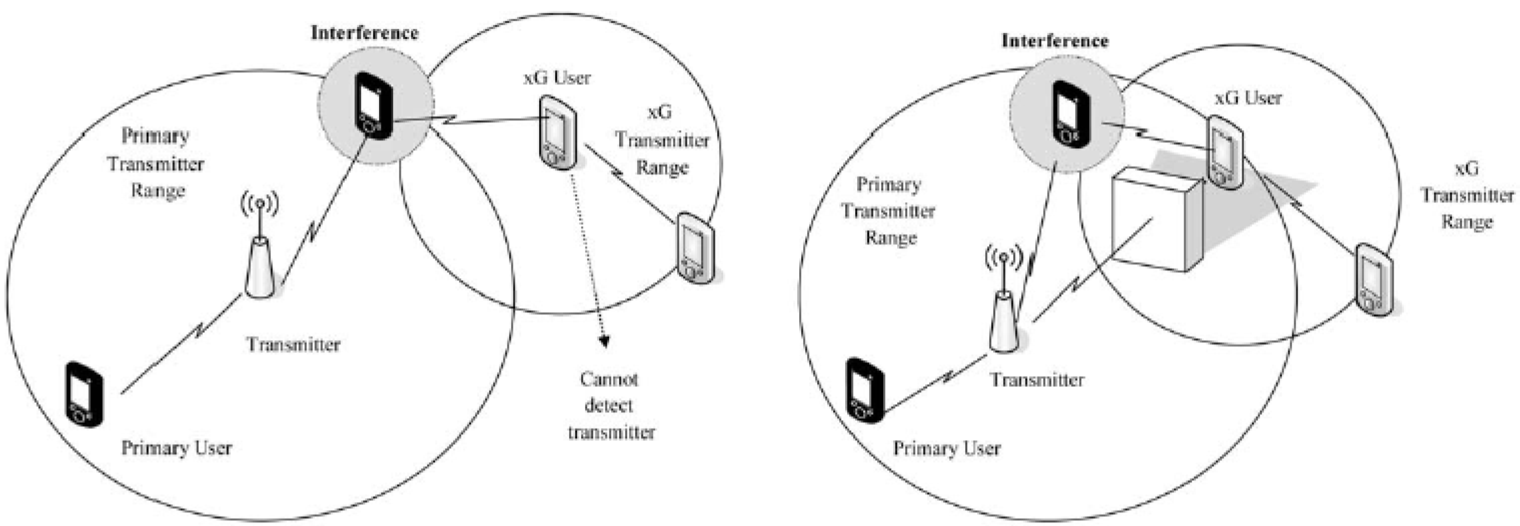
x Requires significantly long sensing time

x Needs a priori knowledge of target signal characteristics

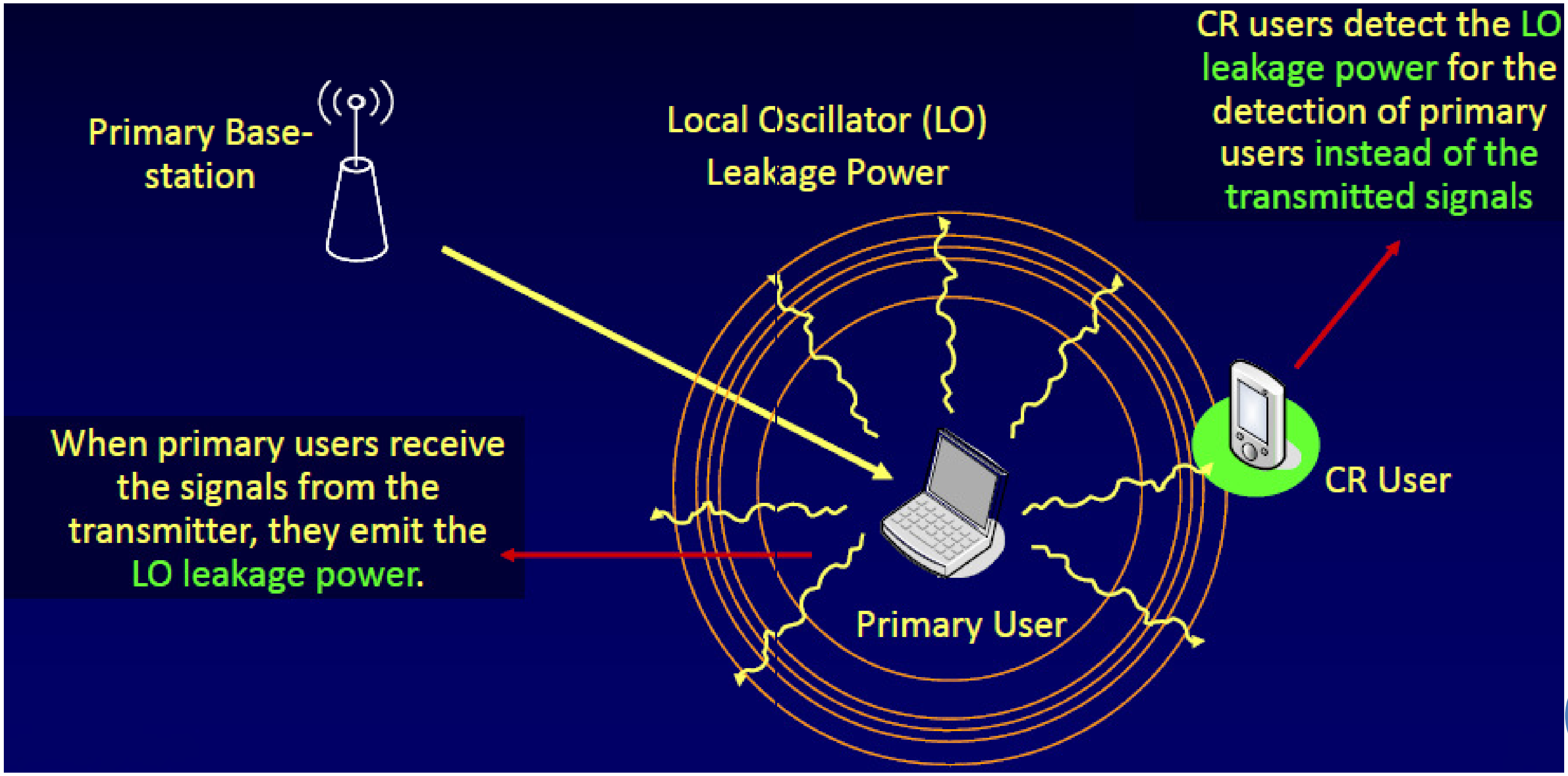


RECEIVER DETECTION

- Limitation of the Transmitter Detection



RECEIVER DETECTION



COOPERATION

- The sensing information from other users is required for more accurate detection to be notified the presence of primary user

– The observed information in each CR user is sent to base-station or exchanged with its neighbors, and spectrum availability is determined accordingly.

- Cooperation improve accuracy significantly

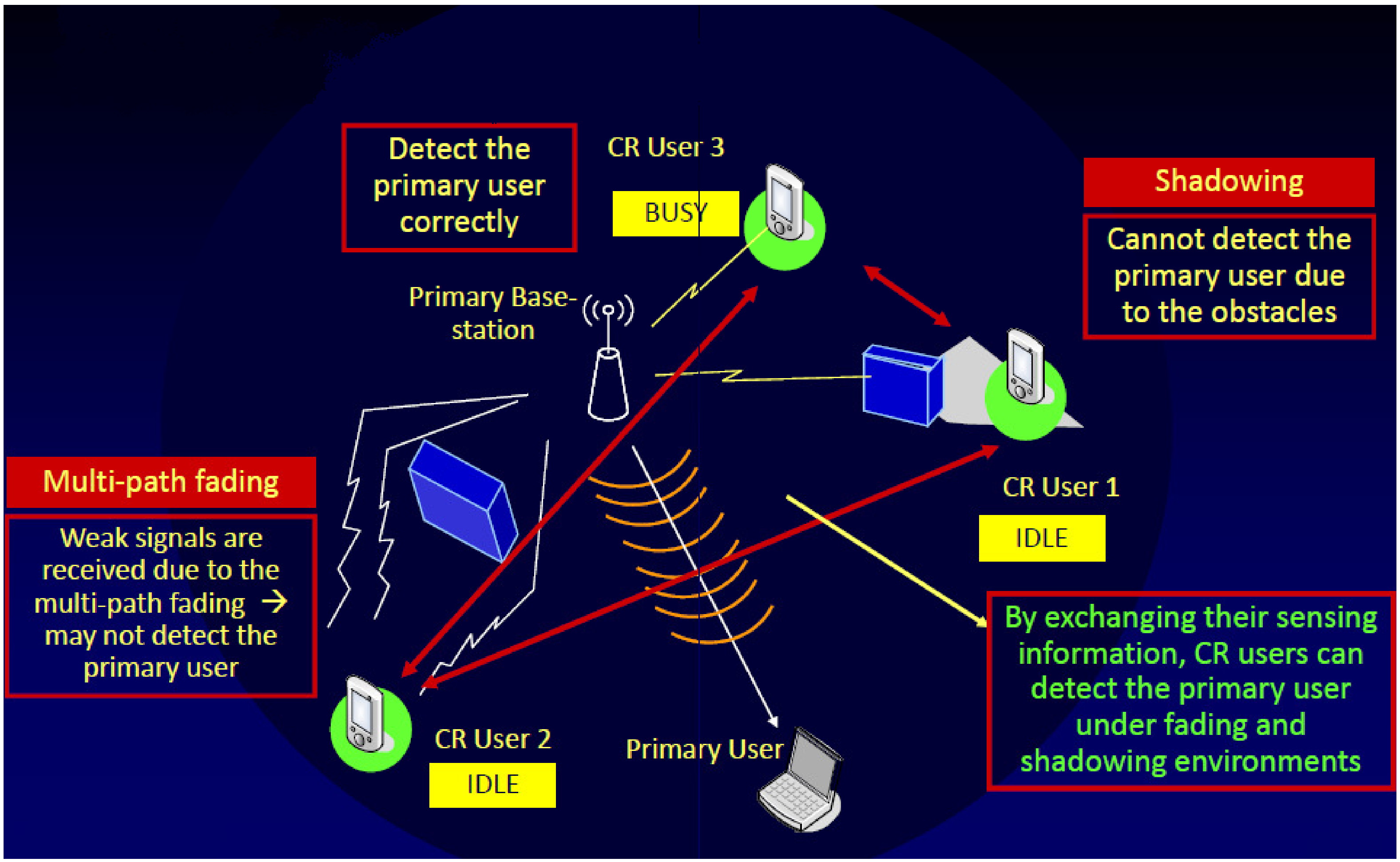
COOPERATION

- Cooperation improve:

  - Multipath fading: received signals may be weak due to multipath fading
  - Shadowing effect : CR users may not detect PU transmitters due to shadowing effect
  - Receiver uncertainty: the PU receiver may not be in the observation range of CR user.

- Cooperation improves these problems

COOPERATIVE DETECTION



SENSING CONTROL

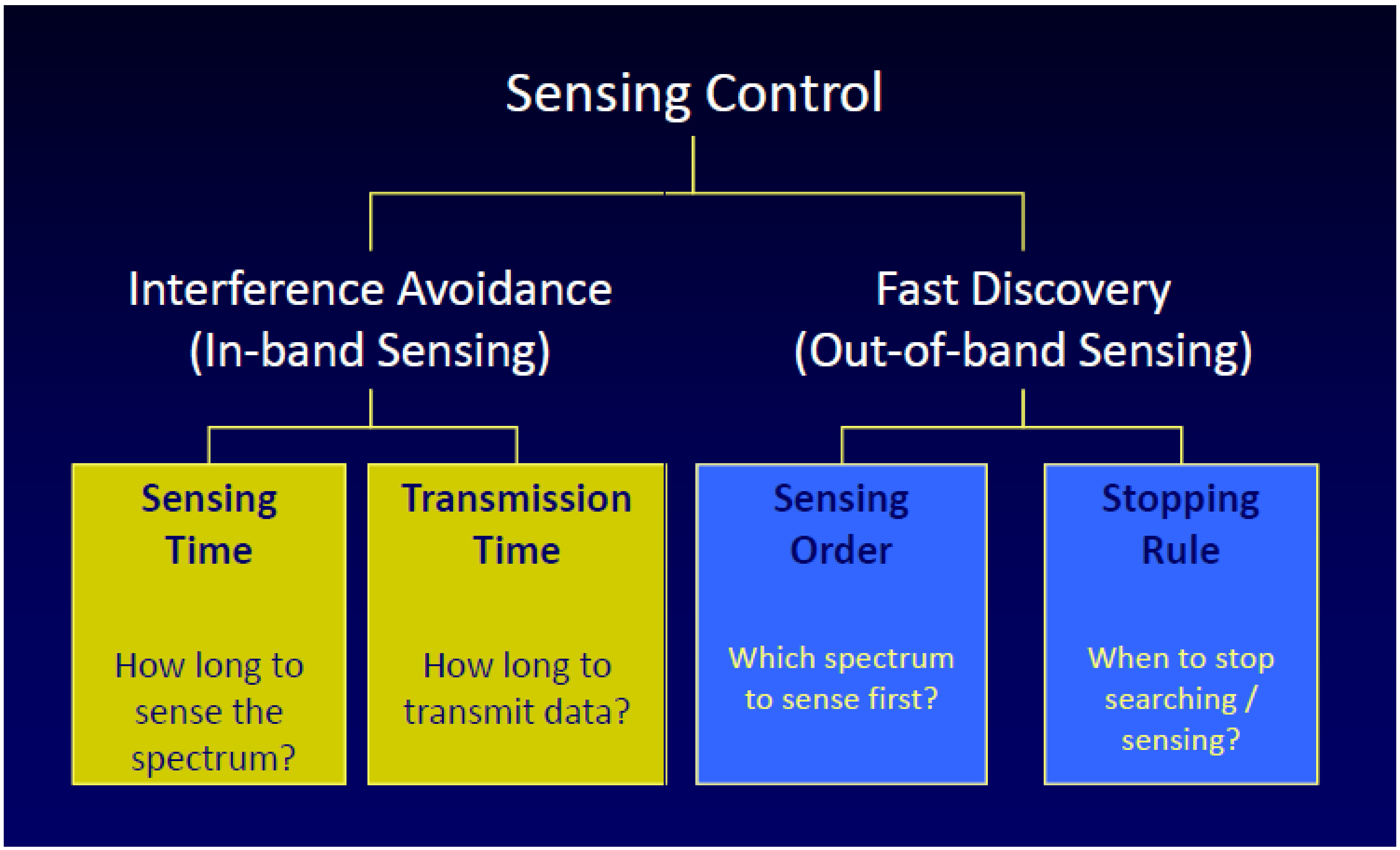
- Definition:

– To control and coordinate CR user for efficient sensing

- In-band sensing
  - How long and How frequently a CR user should sense the spectrum and how long to transmit.
- Out-of-band sensing
  - How quickly a CR user can find the available spectrum band over a wide frequency range.

Sensing control

- **Classification**



SPECTRUM SENSING CHALLENGES

- Limitation on Cooperation Sensing

- To enable cooperation among CR user a common control channel is required , but it is hard to identify an acceptable channel over large portions of network because of wide available spectrum.

- Lack of control channel results in incomplete topology information and interference.

Spectrum Sensing Challenges

- Optimization of Cooperative Sensing
- Cooperation sensing
- ✓ Improve detection accuracy
- x Network traffic
- x Higher latency in collecting sensing information
- x Channel contention
- x Packet retransmission

❖ The CR network are required to consider these factors to find an optimal operating point.

Spectrum Sensing Challenges

- Support for Asynchronous Sensing
- With the energy detection, CR user cannot distinguish the transmission of SUs and PUs, and can detect only the presence of transmission.

- it may detect the transmissions of other CR users as well as PUs during its sensing period and causes false alarm.
- Leads to a decrease in spectrum opportunities.

How to coordinate the sensing operation of each CR user to reduce these false alarms?

Spectrum Decision

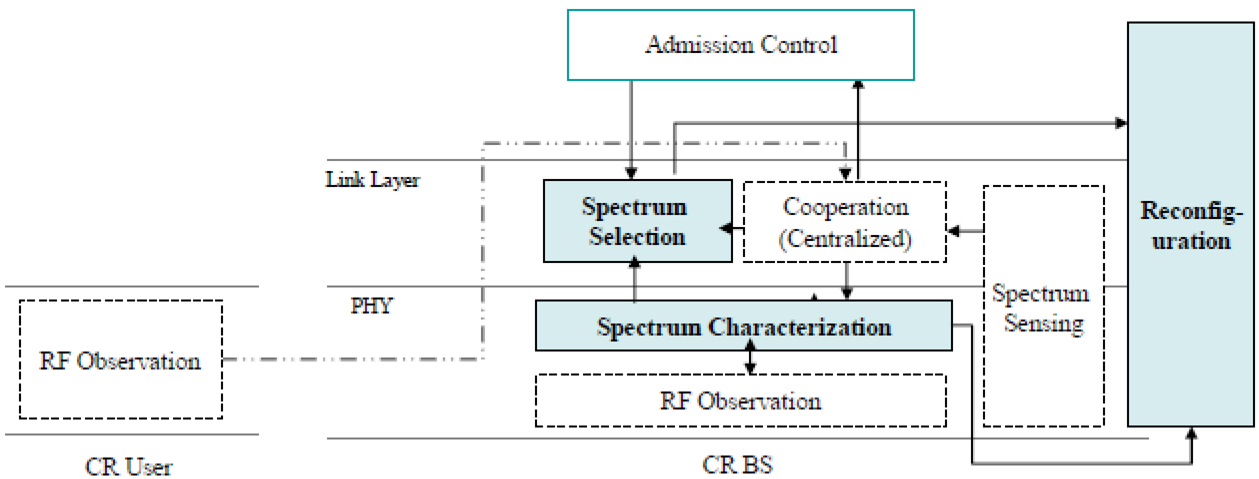
SPECTRUM DECISION

- Definition
- Capabilities to decide on the best spectrum bands among the available bands according to QoS requirement

- Decision Events
- 1) In the beginning of the transmission
- 2) Quality degradation of the current transmission.
- 3) Primary user appearance

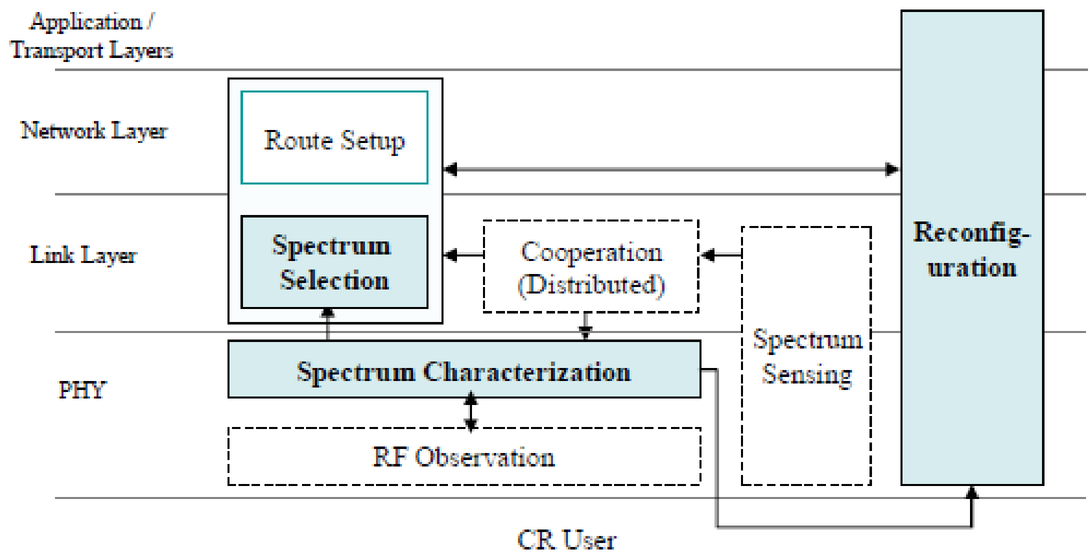
SPECTRUM DECISION

- Functionalities
- Infrastructure-based CR Network



SPECTRUM DECISION

- Functionalities
  - CR Ad Hoc Network



SPECTRUM CHARACTERIZATION

- Through RF observation, CR users determine not only the characteristics of each available spectrum but also its PU activity model

- Radio environment
  - received signal strength
  - Interference
  - Number of existing users
  - Path loss
- PU activities
  - Statistic behavior of primary network

SPECTRUM SELECTION

- According to the spectrum characterization, CR users allocate the best spectrum band to provide QoS.

- Joint spectrum and routing decision method is necessary for CR ad hoc networks.
  - Because available spectrum bands in CR networks differ from one hop to the other.

Spectrum Selection

- Single Spectrum Decision
  - CR users may not have a reliable communication channel for a long time.
  - CR users may experience temporary disconnections during the spectrum handoff

- Multi Spectrum Decision
  - ✓ CR user select multiple non-contiguous spectrum bands simultaneously for the transmission.

Multi Spectrum Decision

- ✓ High data throughput
- ✓ Even if a primary user appears in one of the current spectrum bands, the rest of connection continue their transmissions.
- ✓ Transmission in multiple spectrum bands allows lower power to be used in each spectrum band

- ➢ less interference with PUs is caused

RECONFIGURATION

- Definition

– After spectrum selection, CR users reconfigure their communication parameters adaptively based on:

- application requirements
- spectrum characteristics.

- Hardware/PHY Layer Reconfiguration
  - RF front-end, communication hardware, modulation type,…
- Protocol Reconfiguration
  - Communication protocols for different layers of the network stack must adapt to the channel parameters of the operating Frequency.

Spectrum Decision Challenges

- PU Activity Modeling
- A two-state ON–OFF model based on Poisson arrival has been widely used in the PU activity modeling.
- It cannot capture the diverse characteristics of all existing primary networks.
- This inaccurate model leads to an adverse influence on performance of CR networks resulting in either lower spectrum access opportunities or higher interference to the primary networks.
- Requiring more practical PU activity models .

Spectrum Decision Challenges

- Joint spectrum decision and reconfiguration framework

– According to reconfigurable transmission parameters, these spectrum characteristics change significantly.

– Sometimes, with only reconfiguration, CR users can maintain the quality of the current session.

Spectrum Sharing

Spectrum Sharing

- Definition

– The capability to maintain the QoS of CR users without causing interference to the Pus by coordinating the multiple access of users as well as allocating communication resources adaptively to the changes of radio environment

- Performed in the middle of transmission session and within the spectrum band

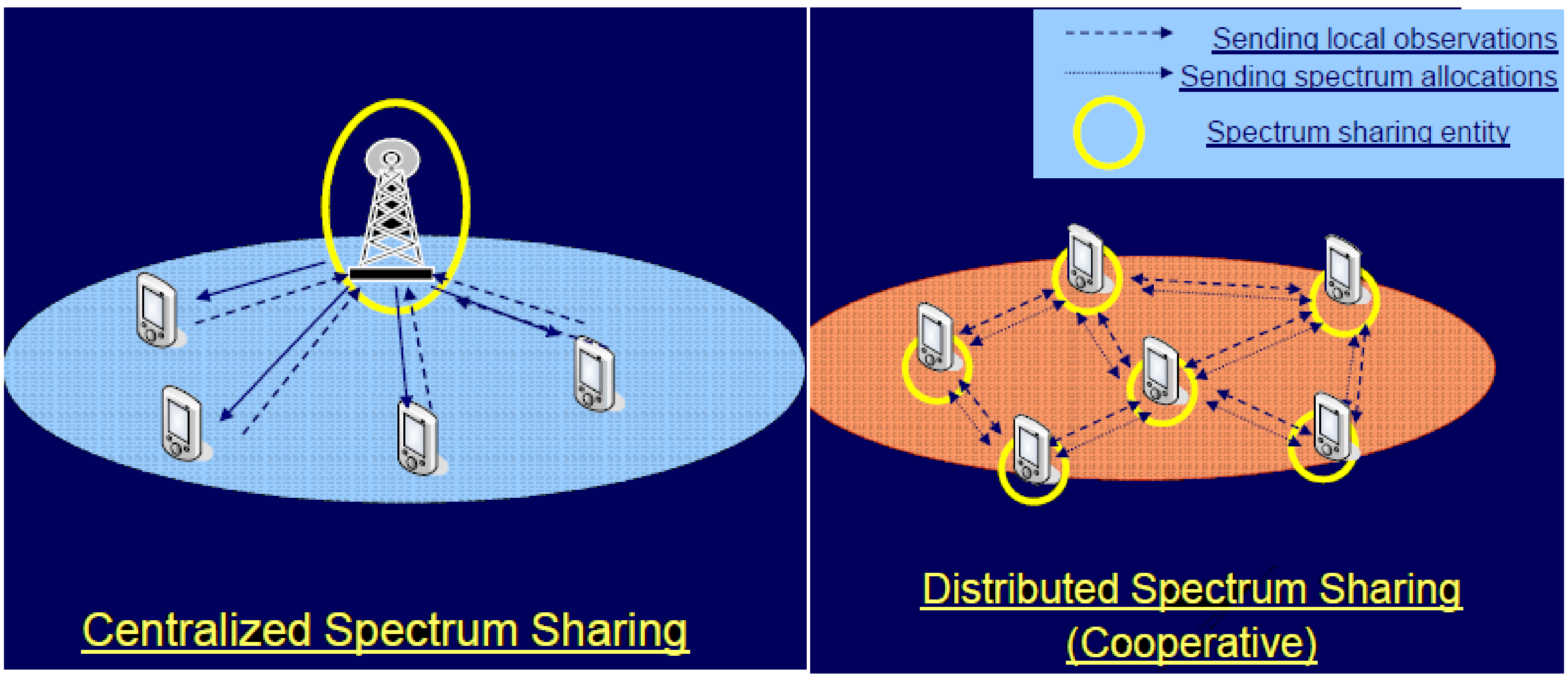
Spectrum Sharing

- Classification
- Intra-Network Spectrum Sharing
  – Spectrum sharing inside a CR network
  - Cooperative
  - Non-cooperative
  – Coordinates multiple accesses among CR users

- Inter-Network Spectrum Sharing
  – Spectrum sharing among multiple coexisting CR networks.
  - Centralized
  - Distributed

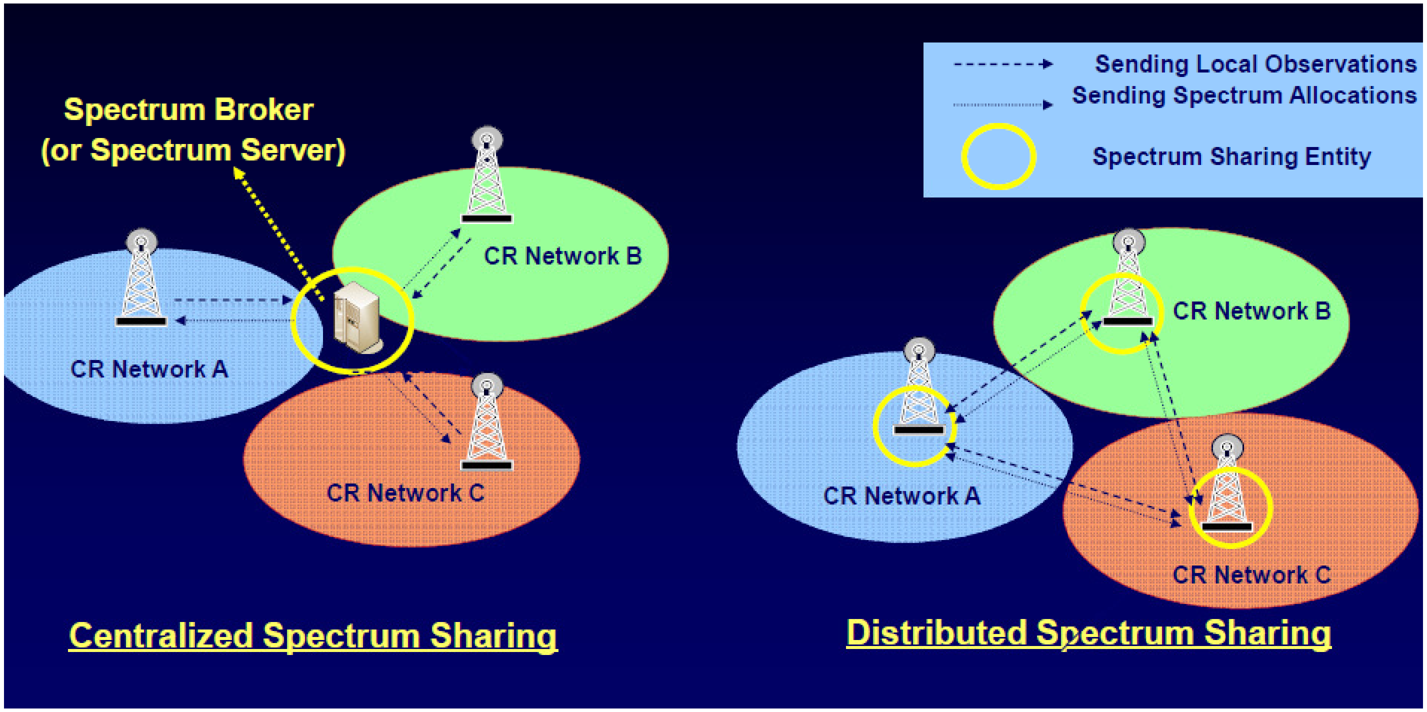
SPECTRUM SHARING

- Intra-Network Spectrum Sharing



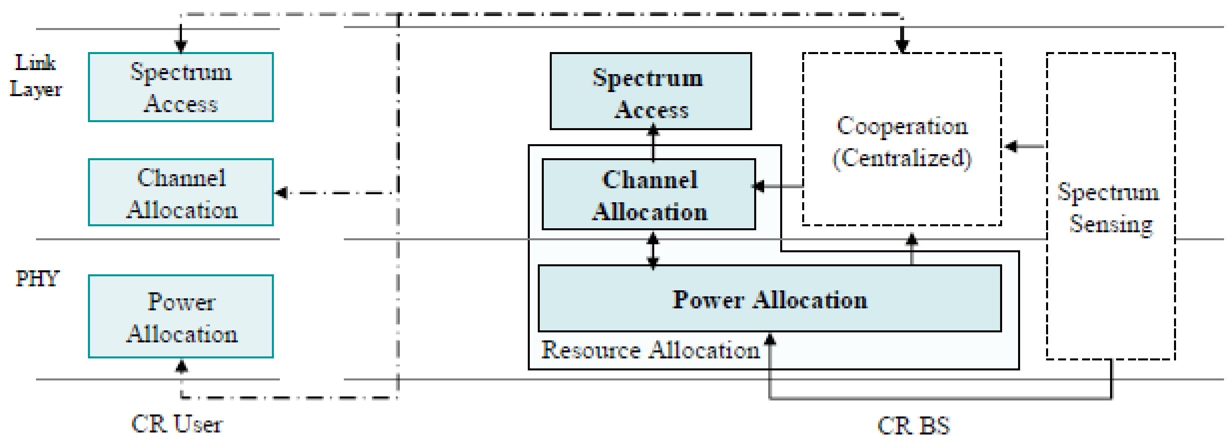
Spectrum Sharing

- Inter-Network Spectrum Sharing



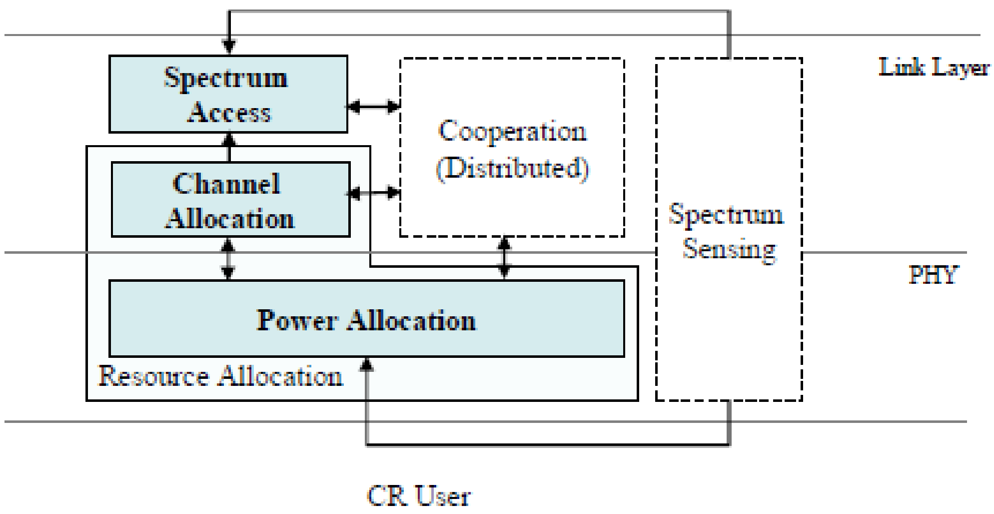
Spectrum Sharing

- Functionalities
  - Infrastructure-based Network



Spectrum Sharing

- Functionalities
- CR Ad Hoc Network



Resource Allocation

- Based on local observation, CR user need to perform channel selection and power allocation while choosing the best channel constrained by interference to other CRs and PUs.

- In power allocation, the CR user needs to adjust its transmission power by considering co-channel interference.

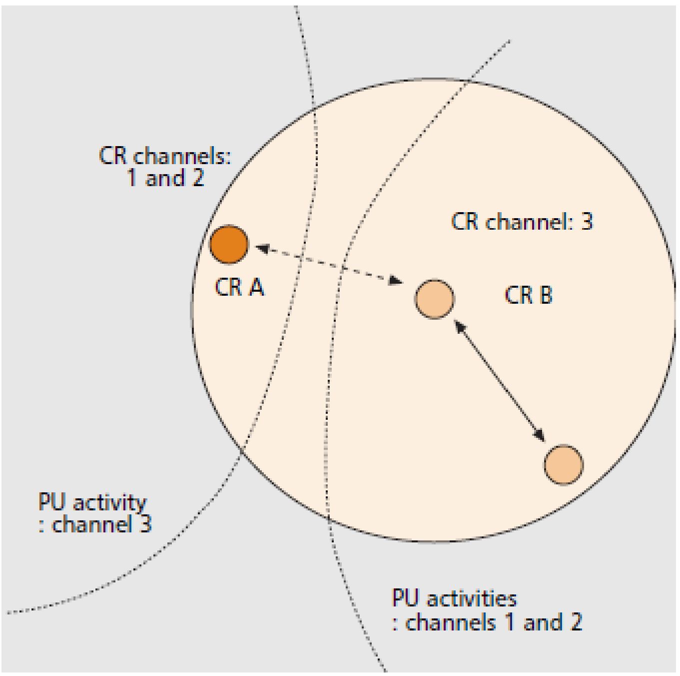
Spectrum Access

- Since there may be multiple CR users trying to access the spectrum , this access should also be coordinated in order to prevent multiple users colliding in overlapping portions of the spectrum

- In CRAHNs
- Instead of periodic sensing, CR ad hoc user may adopt the aperiodic or on-demand sensing.
- on-demand sensing triggered by only spectrum sharing operations .
- When the CR user wants to transmit or is asked its spectrum availability by neighbor users

Spectrum Sharing Challenges

- Topology Discovery



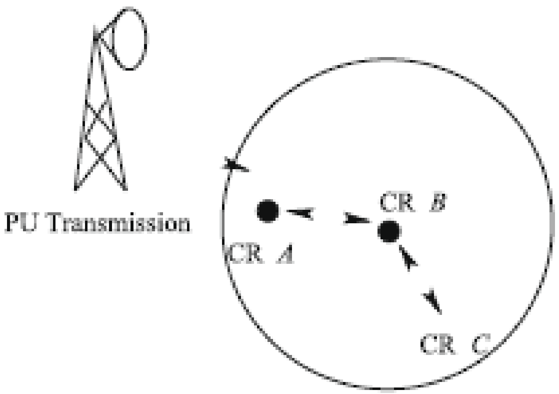
- The use of non-uniform channels by different CR users makes topology discovery difficult.

– CR users A and B experience different PU activity in their respective coverages areas and thus may only be allowed to transmit on mutually exclusive channels.

– Makes it difficult to send out periodic beacons informing the nodes within transmission range of their information for networking.

SPECTRUM SHARING CHALLENGES

- Spectrum access and coordination



- In classical ad hoc networks, the request to send (RTS) and clear to send (CTS) mechanism is used to signal control of the channel.

- A fresh set of RTS-CTS exchange may need to be undertaken in the new channel to enforce a silence zone among the neighboring CR users in the new spectrum.

SPECTRUM MOBILITY

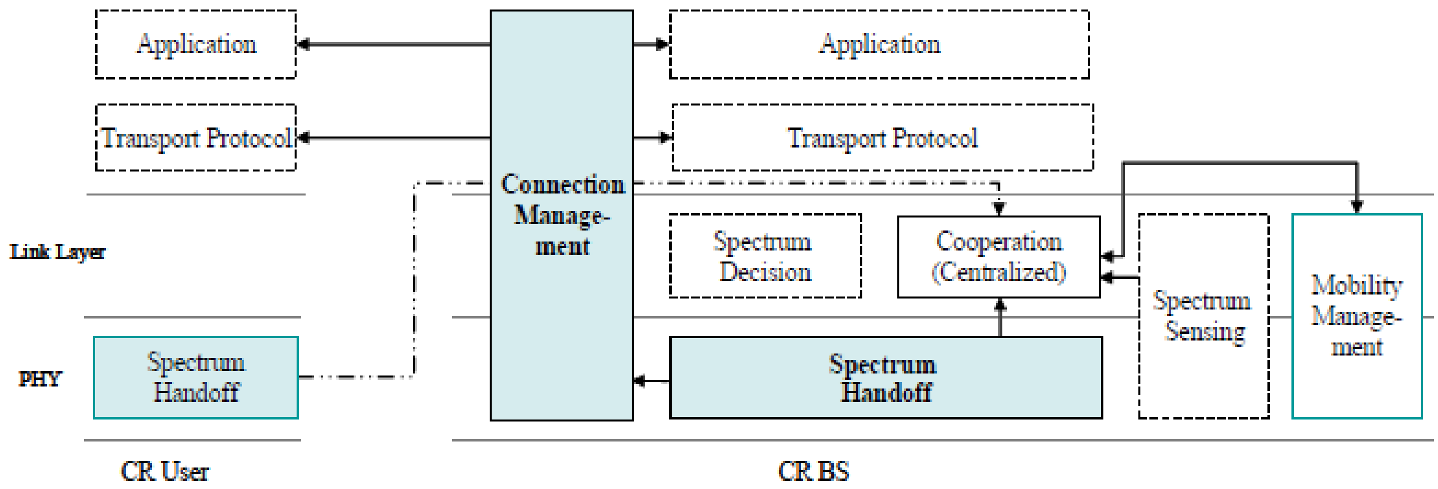
SPECTRUM MOBILITY

- Definition
  - If the specific portion of the spectrum in use is required by a PU, the communication needs to be continued in another vacant portion of the spectrum . this is called spectrum mobility.

- Mobility Events when
  - PU is detected
  - CR user loses its connection due to mobility of users.
  - Current spectrum band can not provide the QoS requirement.

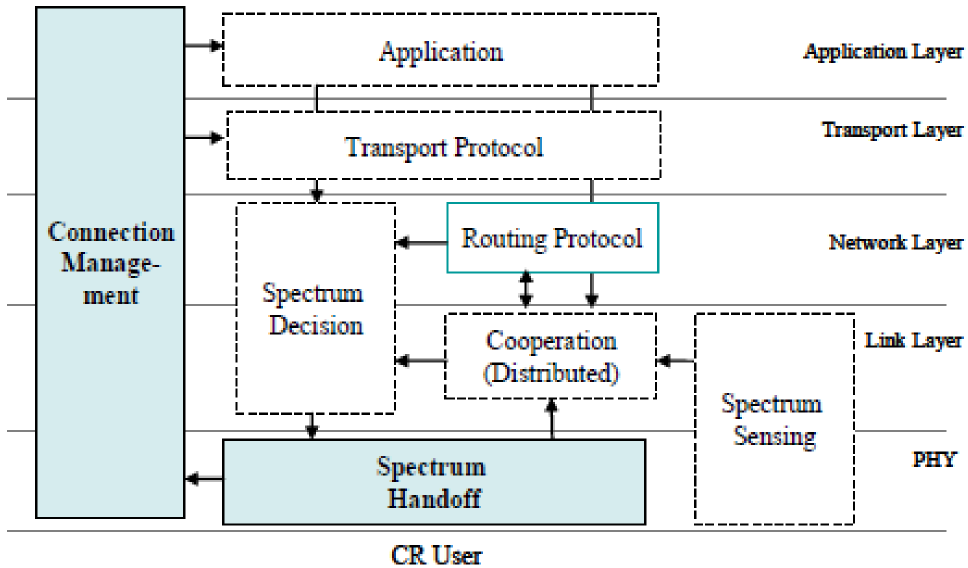
Spectrum Mobility

- Functionalities
  - Infrastructure-based Network



Spectrum Mobility

- Functionalities
- CR Ad Hoc Networks



SPECTRUM MOBILITY

- Spectrum Handoff

– The CR user switches the spectrum band physically and reconfigure the communications parameters for an RF front-end

- Connection Management

– The objective of a connection management function is to sustain the QoS of the ongoing transmission or minimize its quality degradation during spectrum switching by interacting with each layering protocol.

HANDOFF TYPES

- Reactive spectrum handoff

– CR user perform spectrum switching after detecting link failure Due to spectrum mobility.

x Requires immediate spectrum switching without any preparation time, resulting in significant quality degradation in on-going transmissions.

- Proactive spectrum handoff

– CR user predict future activity in the current link and determine a new spectrum while maintaining the current transmission.

✓ The spectrum switching is faster

x requires more complex algorithms.

Switching Delay

- Spectrum handoff delay is dependent on:

– The network protocols may require modifications on the operation parameters, which may cause protocol reconfiguration delay.

– The actual switching time determined by the RF front-end reconfiguration.

– Out-of-band sensing and route recovery times to find the new spectrum and route

Spectrum Mobility Challenge

- Switching Delay Management

– Ones, the best available spectrum is selected, the challenge is to design new mobility and management approaches to reduce delay and loss during spectrum hand off

– The switching delay is closely related not only hardware, such as an RF front-end, but also to algorithm development for spectrums sensing, spectrums decision, MAC, and routing.

- It is desirable to design spectrum mobility in a cross-layer approach.
  - Reduce the operational overhead among each functionalities
  - Achieve a faster switching time.

Spectrum Mobility Challenge

- Flexible Spectrum Handoff Framework
  - The decision on switching strategy needs to be made adaptive to the types of applications and mobility events.

[Mobility Events]

– According to the mobility events, a spectrum switching time will change.

– Since a PU activity region is typically larger than the transmission range of CR users, multiple hops may be influenced by spectrum mobility events at the same time, which makes the recovery time much longer .

CONCLUSIONS

- CR Networks
  - The limited available spectrum and the inefficiency in spectrum usage necessitate a new communication paradigm to use the existing wireless spectrum opportunistically.

- The Spectrum Management Framework consists of
  - Spectrum Sensing: determine which portions of the spectrum is available and detect the presence of licensed users when a user operates in a licensed band
  - Spectrum Decision: choosing the best spectrum among the available options
  - Spectrum Sharing: coordinate access to the spectrum with other users
  - Spectrum Mobility: vacate the channel when a licensed user is detected

REFERENCE

[1] I. F. Akyildiz, W.-Y. Lee, and K. Chowdhury, "*Spectrum management in cognitive radio Ad Hoc networks,"* IEEE Network • July/August 2009

[2] I. F. Akyildiz *et al.*, "*NeXt Generation/Dynamic Spectrum Access/Cognitive Radio Wireless Networks: A Survey*", *Comp. Networks J.*, vol. 50, Sept . 2006, pp. 2127–2159.

[3] I. F. Akyildiz, W.-Y. Lee, and K. Chowdhury, "*CRAHNs: Cognitive Radio AdHoc Networks,"* Ad Hoc Net. J., vol. 7, no. 5, July 2009

[4] FCC, "*Spectrum Policy Task Force Report*," ET docket no. 02- 135, Nov. 2002

[5] Won Yeol Lee*,"SPECTRUM MANAGEMENT IN COGNITIVE RADIO WIRELESS NETWORKS,"* PhD Thesis, Georgia Institute of Technology, August 2009

[6] Akyildiz, I. F., Lee, W.-Y., Vuran, M. C., and Mohanty, S., "A survey on spectrum management in cognitive radio networks," *IEEE Communications Magazine*, vol. 46, pp. 40{48, April 2008.

[7] Won- Yeol Lee " Spectrum Management in Cognitive Radio Networks" May 20, 2010, KT (Korea Telecom), Central R&D Laboratory , presentation

Q&A