

Review of PHY and LINK layer research challenges of cognitive radio networks for dynamic spectrum access

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Outline

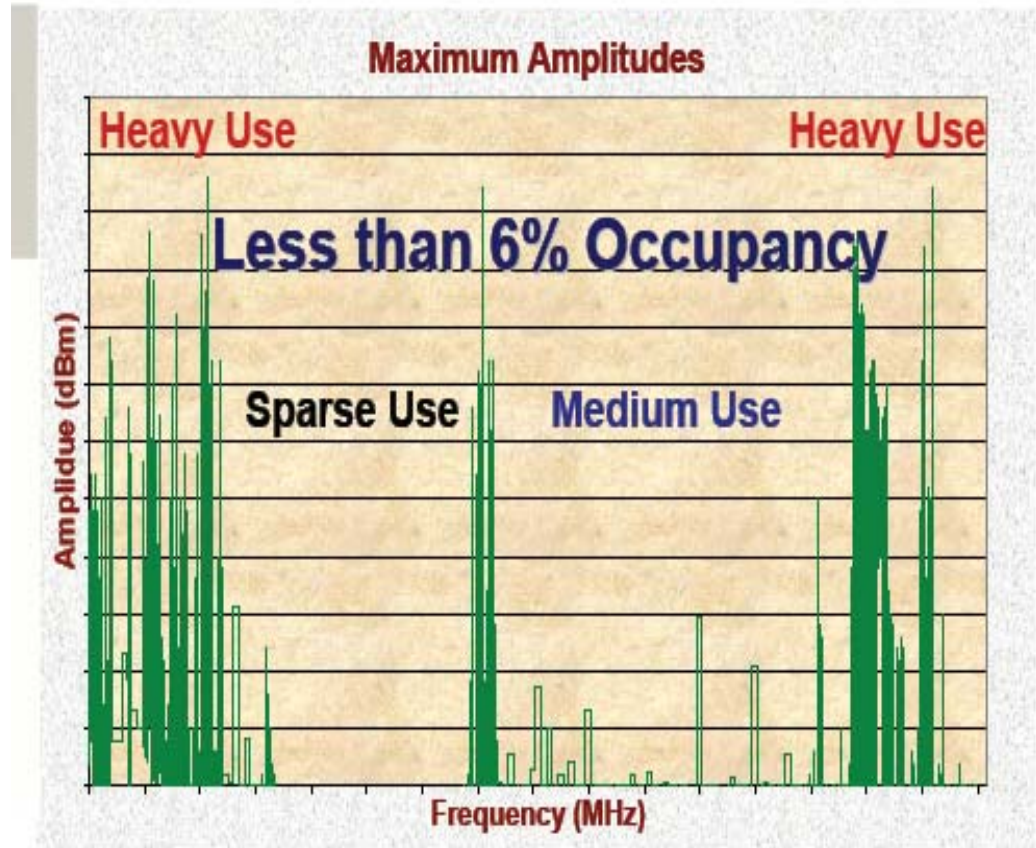
- **Motivation**
- **Terminologies in cognitive radio**
- **Network Architecture of Cognitive Radio Network**
- **Network Protocol Stack of Cognitive Radio**
- **PHY layers functions and open research questions**
- **Link Layer functions and open research questions**
- **Recent Development and our current work**

Motivation

- **Static Allocation of Spectrum is inefficient**
Spectrum regulation: Slow and expensive process that cannot keep up with technology
- **Spectrum allocation rules can encourage innovation & efficiency**
Free markets for spectrum, new services, etc
- **Evidence of WLAN spectrum congestion in unlicensed band**
Unlicensed system need to scale and manage user "QoS"
- **Density of wireless devices will continue to increase**
10x with home gadgets, 100x with sensors/ubiquitous computing
- **Interoperability between different radio standards**
Programmable radio can form cooperating networks across different PHYs

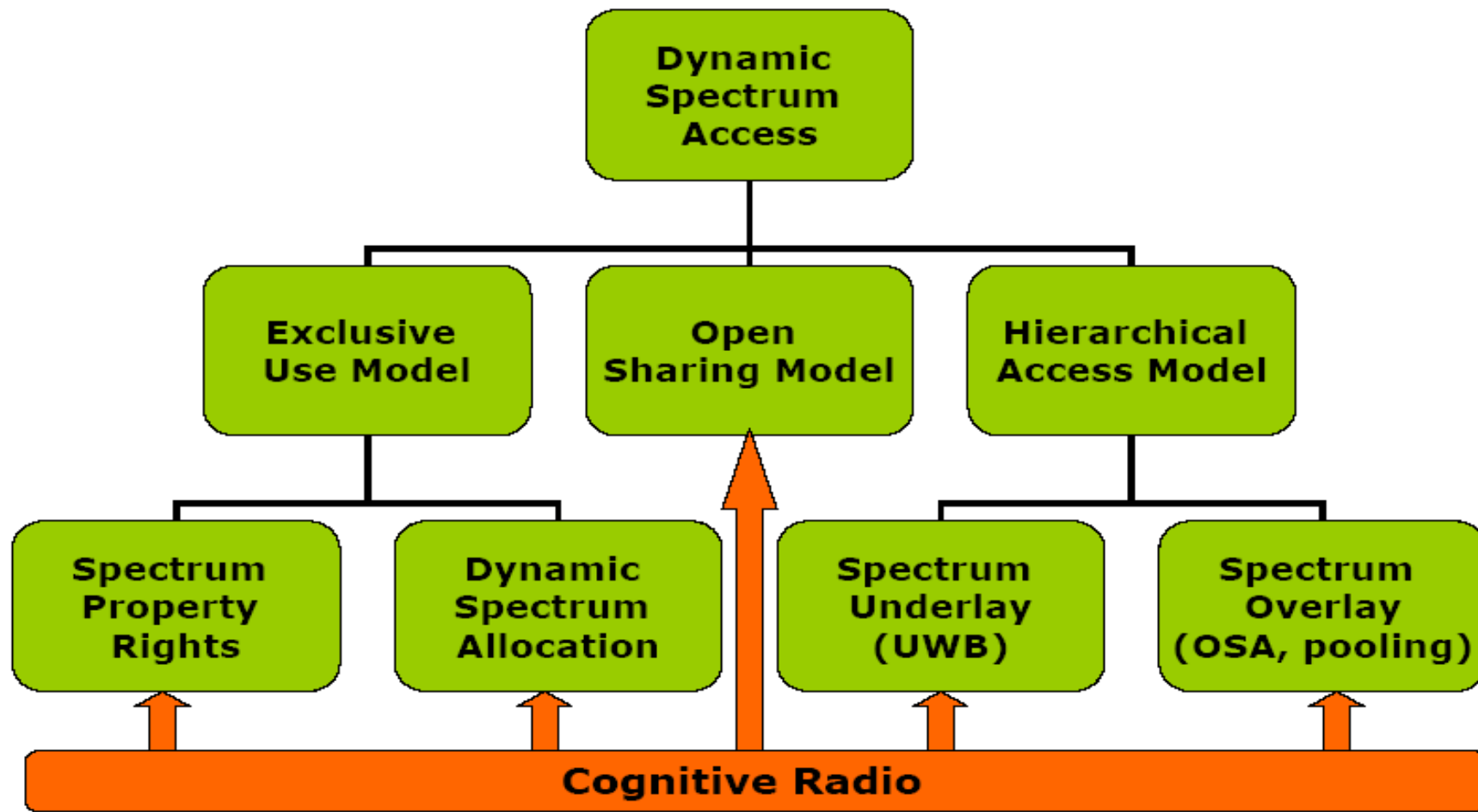
Motivation-Signal strength distribution over a large portion of spectrum

- FCC measurement shows occupancy of 700 MHz spectrum (below 1 GHz) is less than 6% Occupancy
- Besides, in fairness to FCC, traditional fixed spectrum allocation is complex



Signal strength distribution
over a large portion of spectrum
(From FCC)

Motivation- Various Dynamic Spectrum Access based on Cognitive Radio

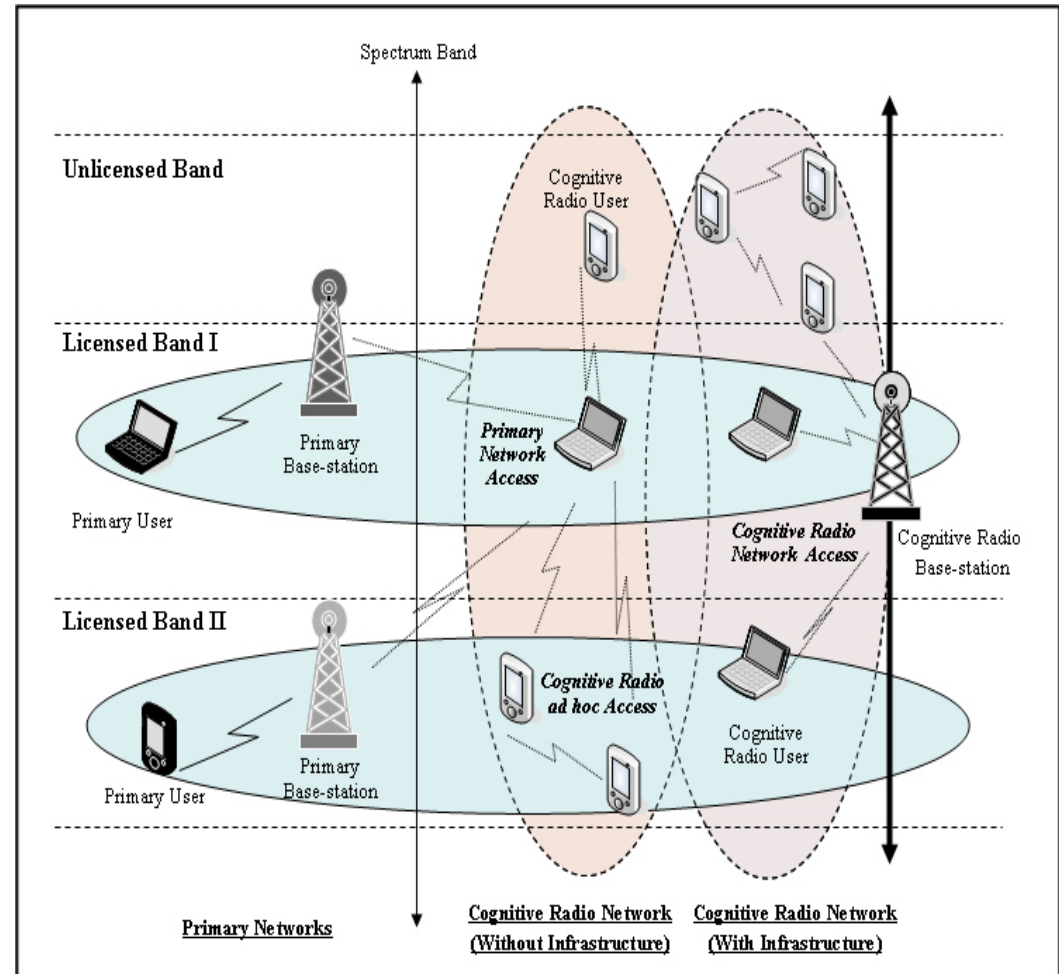


Terminologies in cognitive radio networks

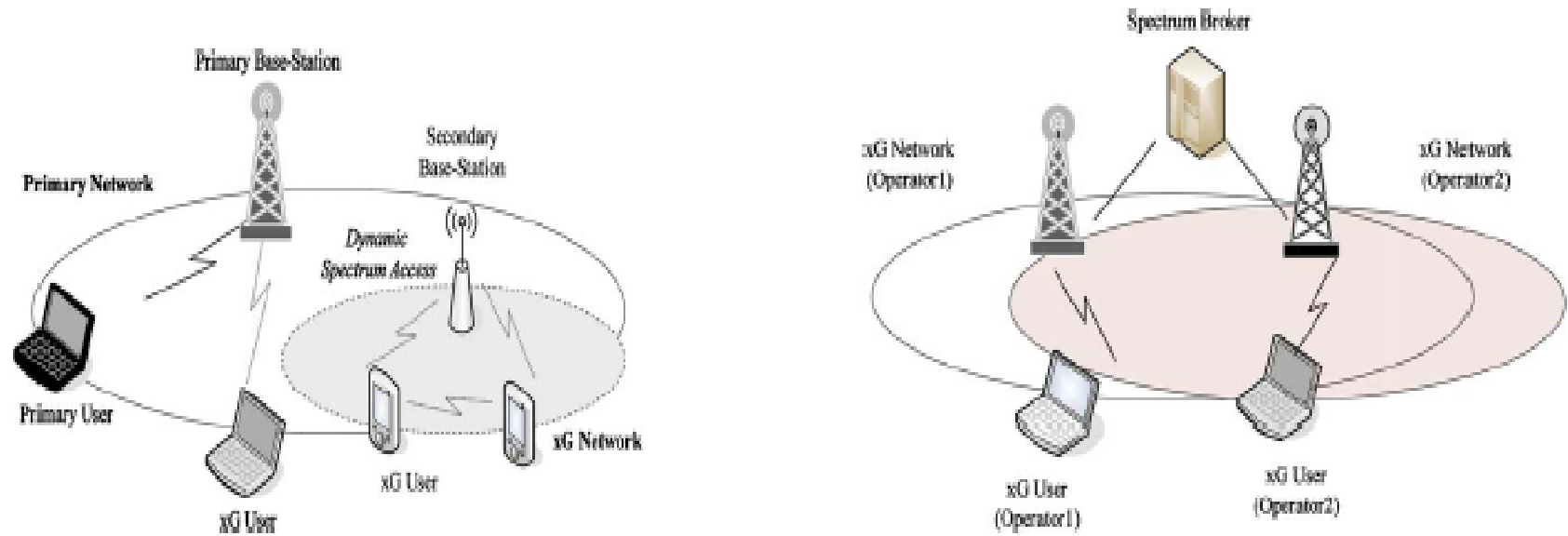
- **Cognitive Radio:**
real-time environment awareness and re-configurability
- **Primary node:** entity that legally owns licensed band
- **Secondary node:** entity that use licensed band opportunistically
- **Spectrum Opportunity:** un-used licensed band (temporally or geographically)
- **Spectrum Usage Policy:** determine how a particular band can be used and define rules of constraining the accesses to this spectrum
- **Interference:** Secondary node to Primary node; Primary node to Secondary node; Secondary node to Secondary node.
- **Primary Network**
- **Secondary Network**

Cognitive Radio Network Architecture

- Primary node access licensed spectrum through primary base station
- Secondary node access licensed Spectrum through primary base station
- Secondary node access both licensed and unlicensed spectrum through secondary base station
- Secondary node access both licensed and unlicensed spectrum through ad-hoc networks

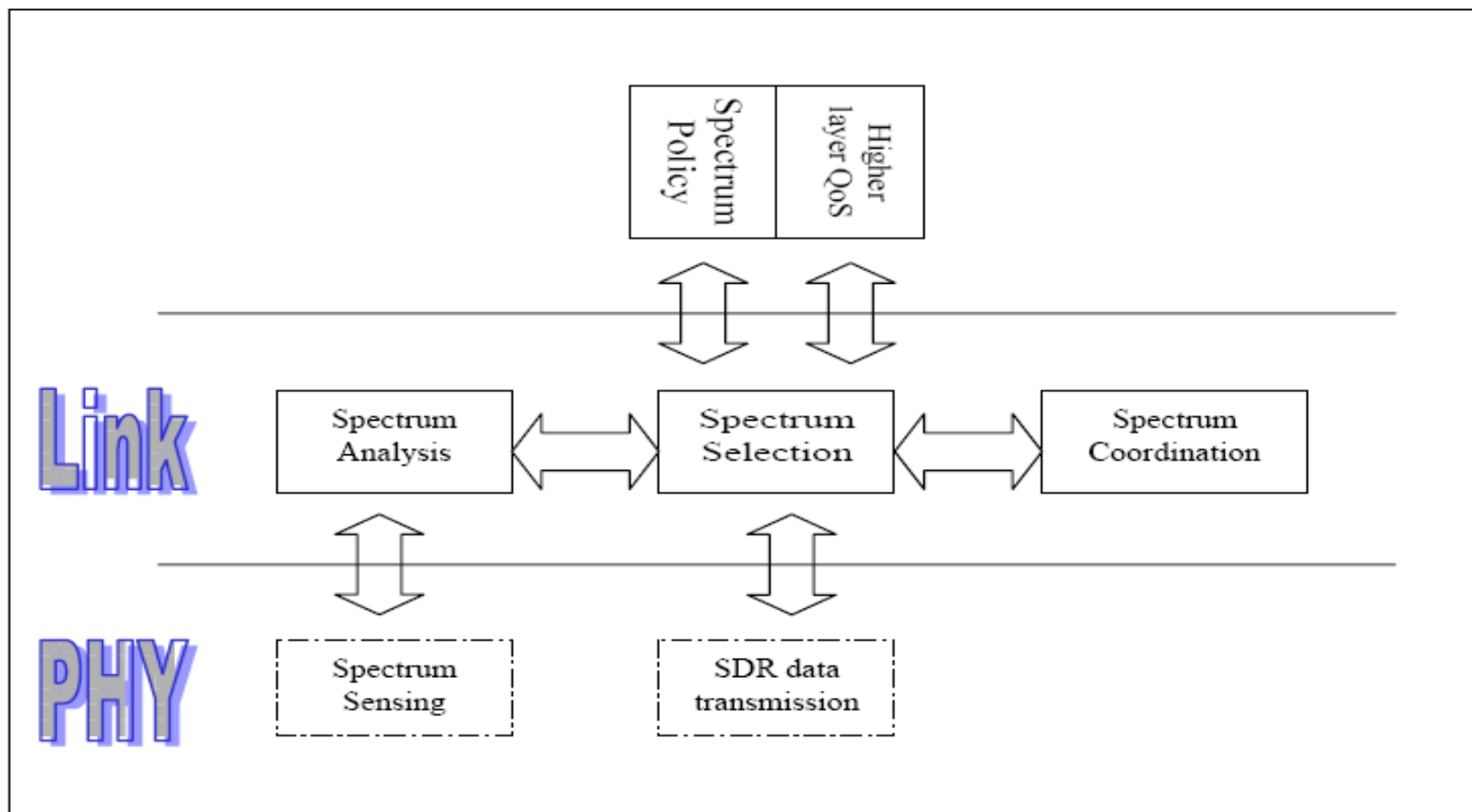


De-composed Cognitive Radio Network architecture



- Figure(left): co-existence of primary and secondary network
- Figure(right): co-existence two secondary networks

Network Protocol Stack of secondary node



PHY layer functions

• Spectrum Sensing

sense the environment over all available degrees of freedom (time, frequency and space) to identify spectrum opportunities.

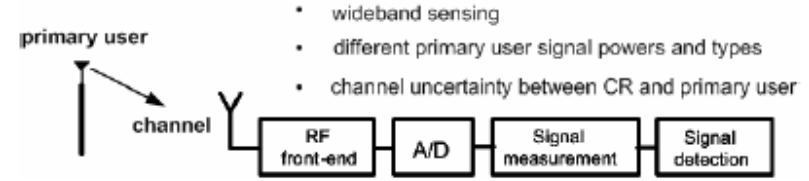
1. Wideband sensing RF Front-End (simultaneous sensing over several GHz, requires high speed and resolution A/D)

2. Spectrum Detection methods (transmitter detection VS receiver detection; cooperative detection VS non-cooperative detection)

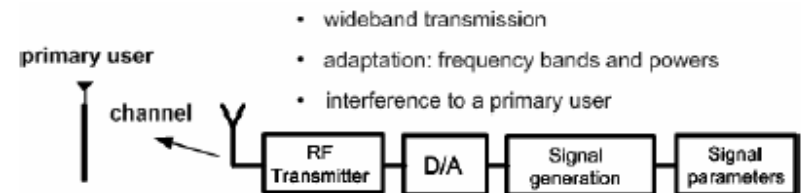
3. Spectrum Sensing Architecture (co-located VS separate sensor network)

• Data transmission

since spectrum opportunities may spread over a wide frequency range with variable bandwidths and band separation. Possible use OFDM

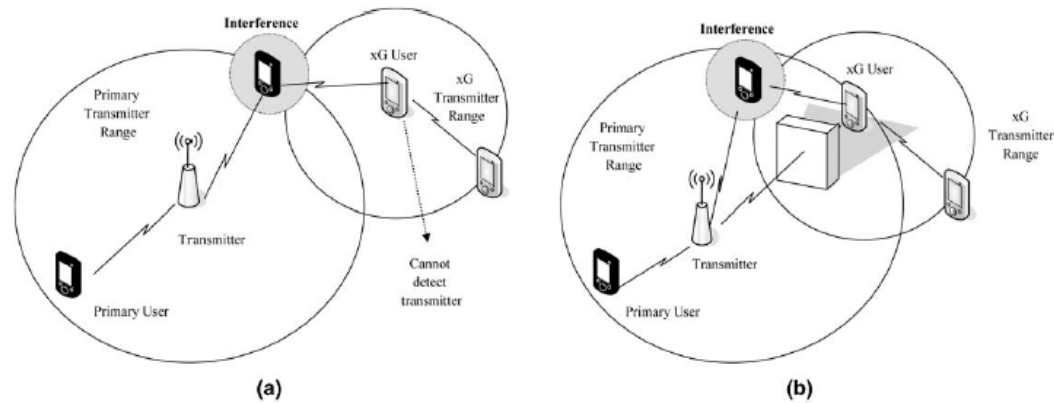


(a) Cognitive radio receiver



(b) Cognitive radio transmitter

Open research questions of PHY layer



- Interference based receiver detection (multi-channel hidden node problem)
- Cooperative Sensing (reduce detection uncertainty, via common control channel)
- Interference model of multiple secondary node signals (differentiate multiple secondary node signals and primary node signal)
- OFDM based spectrum detection

Link layer functions

- **Spectrum Analysis**
Spectrum Opportunity Classification in real time
(Interference level, Path loss, Spectrum Holding etc)
- **Spectrum Selection**
Select spectrum band according to QoS requirement
,Spectrum usage policy and spectrum characteristics.
- **Spectrum coordination**
Inter-Network Spectrum coordination and Intra-network
Spectrum Coordination

Spectrum Selection

- Reactive Spectrum Selection

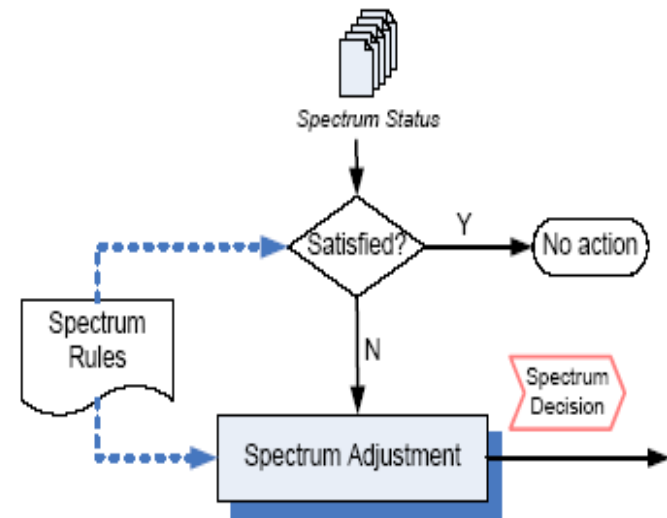
It is a “sense and avoid” approach to impulsively reconfigure spectrum usage without estimating the future spectrum usage dynamics

- Proactive Spectrum Selection

It is a predict and avoid approach. Utilize past observations of spectrum usage dynamics to build predictive model for future spectrum availability.

- Spectrum re-selection

when the quality of current spectrum degrades a lot Or Primary node reclaim the spectrum



- Read in spectrum status (from spectrum analysis)
- Check against spectrum rules and User QoS requirement
- If yes, no re-selection is needed
- If no, new spectrum is selected until both spectrum rules and User QoS is satisfied

Open research questions

- **Spectrum Selection Model.**

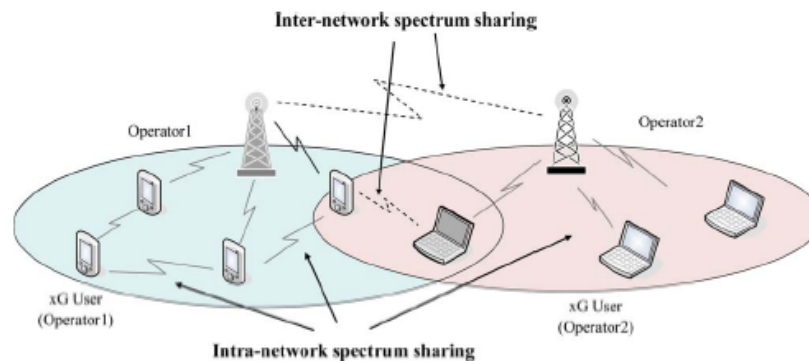
SNR is not sufficient to characterize spectrum opportunities. Other parameters (e.g. Holding time, interference, Path loss) are required to characterize the spectrum quality. A comprehensive selection mode combining different spectrum characterization parameters

- **Multiple Spectrum Band Spectrum Selection**

Since multiple spectrum bands are preferred to be used simultaneously used for transmissions (better mitigate the primary nodes re-claim spectrum), multi-Carrier Modulation schemes are suitable for cognitive radio data transmissions. However, no multiple band spectrum selection is yet proposed.

Spectrum coordination

- **Inter-network Spectrum Coordination:**
spectrum sharing among multiple secondary networks
(centralized VS decentralized, Cooperative VS Non-cooperative
Overlay Access VS underlay access)
- **Intra-network Spectrum Coordination:**
Spectrum sharing among primary and secondary network



Intra-Network Spectrum Coordination

- **Decentralized spectrum coordination VS centralized one.**
secondary ad-hoc network where secondary node cannot directly exchange control information.
secondary nodes are controlled by an central entity and control information are exchanged via the central entity.
- **Cooperative VS Non-cooperative**
secondary nodes act somewhat selfishness by exchanging control info with neighbours. Individual node may occasionally sacrifice local performance to improve the system utility.

cooperative coordination may heavily stress the resource constrained network such as battery limited sensor network. In this case, non-cooperative could be better suitable, as each secondary node act independently only by local observations or spectrum usage rules.
- **Overlay VS Underlay**
FDMA/TDMA/CDMA VS UWB

open research questions of spectrum coordination

- **Common Control Channel (CCC)**

Transmitter-Receiver handshake, cooperative sensing may requires a CCC for initial signalling .

However, several challenges:

- where do we implement it: static or dynamic
- scalability: not scalable with the node density and traffic. In case of dynamic CCC, it may also cause scalability problems with respect to local CCC discover
- security: a simple jamming attack to CCC could disrupt the whole network

- **Heterogeneous transmission ranges**

different frequency band may have different frequency dependent pass loss, thus the same transmission power may translate into different transmission range.

impact to MAC protocol design. Routing decision. TCP timeout.

Recent Developments of cognitive radio for DSA

- JSAC Special Issue, April, 2007.
- Communications Magazine, May, 2007
- Wireless Comm. Magazine, June, 2007
- JSAC, 2008.
- JSTSP, 2008.
- DySPAN 2005, 2007
- CrownCom 2006, 2007
- CogNet 2007, CWNet 2007
- ...

Our research focuses

- Spectrum Coordination Function- Multi-channel MAC protocols for intra-network spectrum sharing
 - dynamic CCC
 - QoS support for secondary network
- Security and Malicious behaviour detection in both dynamic spectrum sharing and cooperative sensing

Thank you for the attention 😊