Cooperative Spectrum Sensing in Cognitive Radio

Outline:

✓ Introduction
✓ Local Spectrum Sensing
✓ Cooperation in Cognitive Radio
✓ Considerations and Future Works
Introduction

- Spectrum is a limited natural resource, it is divided into:
  - licensed band
  - unlicensed band
- Measurements indicate that many portion of the licensed spectrum are underutilized in space and time
- In recent years, dramatic increase in the demand for radio spectrum, lead the need for a spectrum policy reform

Development of Cognitive Radio concept:

- cognitive users are secondary users in primary licensed users’ networks
- cognitive users have to create virtually unlicensed bands
- cognitive users use primary user’s time-space unused spectrum resources on a non-interfering base
Local Spectrum Sensing

Fundamental task:
A secondary user has to monitor licensed bands and opportunistically transmit whenever no primary signal is detected.

Detection on the basis of local sensing measurements
Three possible approaches:
1. Matched Filter
2. Feature detector
3. Energy detector
Detection Approaches (ref. [1])

**Matched Filter:**
- Optimal way for signal detection
- Maximizes the SNR
- Less time to achieve high processing gains thanks to coherency

**Drawbacks:**
- Due to coherency a CR node needs an a priori knowledge of primary signal
- CR node needs a dedicated receiver for every primary user class

**Feature Detector:**
- Exploits periodicity of cyclostationary processes derived from signal’s modulation
- Spectral Correlation Function to better detect desired signal at low SNR

**Drawbacks:**
- Complex processing
- Knowledge of signal characteristics

**Energy Detector (widely utilised):**
- Sub-optimal non coherent detection
- Simple technique

**Drawbacks:**
- No differentiation among primary signal, noise and interference
- Threshold is highly susceptible to changing level of noise and interference
Limitations on local sensing

Secondary node don’t know measurement of communication link between primary transmitter and receiver:

- Hidden terminal problem

Complex wireless environment:

- Fading
- Shadowing

Complexity in revelation of primary activity:

- $P_{fa}$: low spectrum utilisation
- $P_{m}$: increased interference to primary
Cooperation in Cognitive Radio

A network of CR Nodes scattered in different places exploits **space diversity** to improve probability of detection and spectrum utilization.

**Schemes:**

1) Cooperative Transmission
   1a) Cooperative Transmission between secondary users
   1b) Cognitive Relay

2) Cooperative Spectrum Sensing
1) Cooperative Transmission

Starting point:
In wireless networks diversity is a method for directly combating the effects of fading.
Temporal, frequency and spatial diversity as well-known forms of diversity.

Idea:
Use of cooperative spatial diversity in secondary networks to coexist with primary networks.
Secondary node (relay) forwards the transmission of a primary or secondary node (source) according to the selected approach.
1a) Cooperative Transmission between secondary users (ref. [2],[3])

**Two users cognitive radio network**

U1 and U2 operate in a fixed TDMA mode for sending data to a common receiver.

- TS1: U1 transmits to the common receiver (ordinary link).
- TS2: U2 relay (Amplify-and-forward mode) transmission of TS1 to the common receiver (relay link).
  - U1 listens to the eventual presence of the primary also thanks to its relaying transmission (relay link).

In presence of the primary the bands must be vacated as soon as possible.
The first user to detect the presence of the primary informs the others through the common receiver.
1a) Cooperative Transmission between secondary users (ref. [2],[3])

**Advantages:** respect to a Non Cooperative scenario (each user detect the primary activity indipendently)
- Increased overall detection probability
- Reduced overall detection time
  - agility gain through cooperation

**Extended case:** Multiuser Network

**Issue:** a direct application of previous solution with more than two users leads to great computational complexity

**Solution:** grouping nodes in pairs.
- nodes divided in two groups: weak and strong
- weak nodes search for a relay node

**Drawbacks:**
- scalability problems for pairing scheme in real scenarios with not symmetric distributions of nodes (see mobility)
- consider overhead for signal processing and data load.
1b) Cognitive Relay (ref. [4], [5])

**Internetwork cooperation:**

A secondary user has the possibility to relay the traffic of a primary transmitter towards the intended destination.

- The primary increases its throughput and diminishes its transmission time.
- This leads to more transmission opportunities for the secondary enhancing the throughput.
1b) Cognitive Relay (ref. [4],[5])

Model:
-the secondary accepts primary’s packets not correctly received to the intended destination (ACK/NACK).

-when an idle slot is detected (through local spectrum sensing) the secondary transmits a packet from one of its queues according to a scheduling probability.

Advantages:
-relevant secondary throughput gains respect to a no relaying scheme

Drawbaks:
-secondary has to know primary transmissions
-increased overhead and energy consumption (charge of secondary and primary traffic)
2) Cooperative Spectrum Sensing
(ref. [6],[7],[8],[9])

Trivial solution:
- each CR node performs independent spectrum measurement
- each decision is forwarded to a Common Receiver
- the Common Receiver decides on the presence of the primary
  using a Decision Fusion Rule

Drawback:
also the reporting channel
between CR node and Common
Receiver suffers fading and shadowing
2) Cooperative Spectrum Sensing
(ref. [6],[7],[8],[9])

**Cluster-Based solution:**
- all CR node are clustered into a few groups
- a cluster head is chosen in each cluster according to the highest SNR of the reporting channel
- the sensing results of each CR node are reported to its cluster head which will make a preliminary cooperative decision.
- each cluster head reports its decision to the Common Receiver
- the Common Receiver performs the final decision.

**Advantages:**
- diversity gains proportional to the number of nodes per cluster
- lower energy consumption thanks to inter cluster information exchange
Considerations and future works

Desidered characteristics for a cognitive network:

- Limited overhead for cooperative messaging
- Limited energy consumption for CR nodes
- Scalability

Cooperative Spectrum Sensing scheme fulfils in the best way this characteristics

This model exploits as starting point the scenario developed by IEEE 802.22 group:

Development of a Wireless Regional Area Network for unlicensed access to TV spectrum on a non-interfering basis
Considerations and future works
(ref. [10])

All cooperative scheme however has to face some challenges:
- delay between sensing and decision
- complexity and large dynamic range requirement for wideband spectrum sensing

New techniques inspired by introducing the concepts of multiple access in cooperative scheme could solve the addressed problems.

Time Division CSS
Frequency Division CSS
Considerations and future works

**TD-CSS** (ref. [10])

- Nodes divided into groups (N > D/I)
- Each group in turn detect the presence of primary user, I (I < D)
  is the interval of subsequent detection
- Information is exchanged at the end of each cooperative detection
  time D in order to maintain synchronization and detection order

**Advantages:**
- Fast response time

**Issues:**
- Trade-off of diversity and communication range
- Narrow Target Bandwidth
Considerations and future works

FD-CSS (ref. [10])

- Nodes divided into geometric groups (nodes close together)
- Different groups are assigned to different frequency bands \((W = B/N)\) through a coordinator on the basis of the local channel conditions
- When a group detects the primary, all users are informed that this frequency band is occupied.

**Advantages:**
- Wide Target Bandwidth
- Faster spectrum sensing by increasing \(N\)

**Issues:**
- Slow response time
- Limits with deep fading in many detecting bands
Considerations and future works

Developments:

- Consider the Cluster-Based Cooperative Spectrum Sensing
- Study eventual benefits from introducing TD-CSS or FD-CSS
- Study effects of mobility
- Possibility of introducing UWB technology
References

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