Spectrum Sharing in Cognitive Radio Networks

By: H.Feizresan

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Spectrum sharing in cognitive radio networks

- Steps of spectrum sharing in cognitive radio networks
- Spectrum sharing techniques
- Inter-network spectrum sharing
- Intra-network spectrum sharing
- Spectrum sharing challenges

Steps of spectrum sharing in cognitive radio networks

- Spectrum sensing

When an CR node aims to transmit packets, it first needs to be aware of the spectrum usage around its vicinity

- Spectrum allocation

Based on the spectrum availability, the node can then allocate a channel

- Spectrum access

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

Steps of spectrum sharing in cognitive radio networks

- Transmitter-receiver handshake

  Once a portion of the spectrum is determined for communication, the receiver of this communication should also be indicated about the selected spectrum

- Spectrum mobility

  If the specific portion of the spectrum in use is required by a licensed user, the communication needs to be continued in another vacant portion.

Spectrum sharing techniques

Architecture assumption

- Centralized spectrum sharing

  A centralized entity controls the spectrum allocation and access procedures

- Distributed spectrum sharing

  Each node is responsible for the spectrum allocation and access is based on local or possibly global policies

Spectrum sharing techniques

Spectrum allocation behavior

- Cooperative spectrum sharing

  Consider the effect of the node's communication on other nodes

  The interference measurements of each node are shared among other nodes

- Non-cooperative spectrum sharing

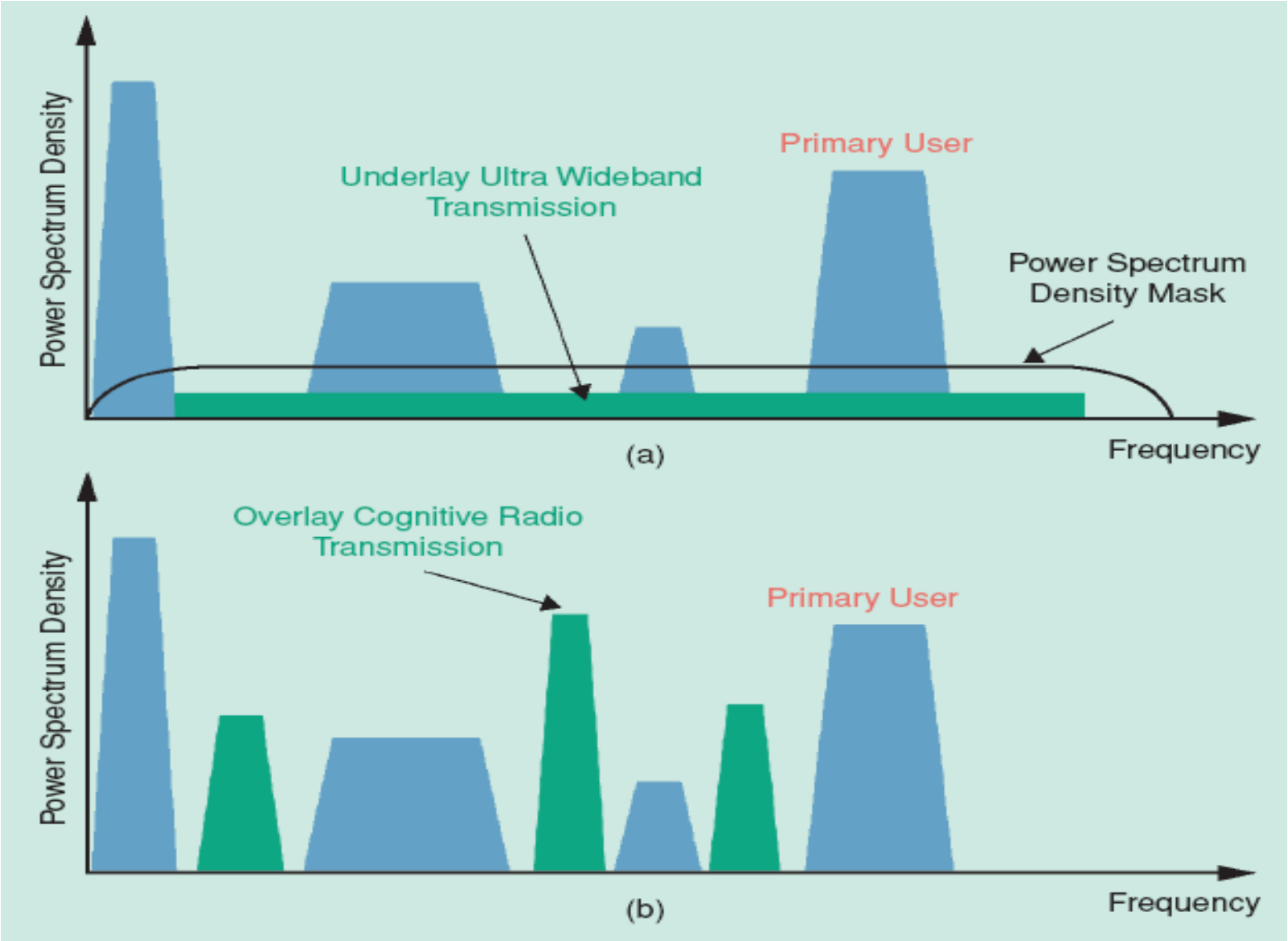
  Consider only the node at hand

Spectrum sharing techniques

Spectrum access technique

- Overlay spectrum sharing
  - A node accesses the network using a portion of the spectrum that has not been used by licensed users
  - Cognitive Radio
- Underlay spectrum sharing
  - Requires sophisticated spread spectrum techniques
  - UWB

Spectrum sharing techniques



Requirement for hybrid techniques

- Cooperative settings result in higher utilization of the spectrum as well as fairness
- The cost of cooperation due to frequent information exchange among users
- An overlay technique focuses on the holes in the spectrum
- Dynamic spreading techniques are required for underlay techniques for interference free operation between primary and secondary systems

Hybrid techniques

- Inter-network spectrum sharing
  - Centralized inter-network spectrum sharing
  - Distributed inter-network spectrum sharing

- Intra-network spectrum sharing
  - Cooperative intra-network spectrum sharing
  - Non-cooperative intra-network spectrum sharing

Centralized inter-network spectrum sharing

Common spectrum coordination channel (CSCC) protocol

- The coexistence is maintained through the coordination of nodes with each other by broadcasting CSCC messages
- CSCC etiquette protocol improves throughput by 35–160% via both frequency and power adaptation

Distributed inter-network spectrum sharing

Distributed QoS based dynamic channel reservation (D-QDCR) scheme:

- A base station (BSs) of a WISP competes with its interferer BSs according to the QoS requirements of its users to allocate a portion of the spectrum
- The control and data channels are separated
- The basic unit for channel allocation in D-QDCR is called Q-frames
- The competition between BSs are performed according to the priority of each BS depending on a BSs data volume and QoS requirement

Cooperative intra-network spectrum sharing

Dynamic spectrum access protocol (DSAP)

- Enables a central entity to lease spectrum to users in a limited geographical region
- DSAP consists of clients, DSAP server, and relays that relay information between server and clients that are not in the direct range of the server
- Global view of the network can be constructed at the server
- By exploiting cooperative and distributed sensing, DSAP servers construct a RadioMap
- This map is used for channel assignments which are leased to clients for a limited amount of time

Non-cooperative intra-network spectrum sharing

An opportunistic spectrum management scheme

- Users allocate channels based on their observations of interference patterns and neighbors
- users allocate channels based on their observations instead of collaborating with other users
- In case more than one node chooses the same channel in close proximity, random access techniques are used to resolve the contention

Spectrum Sharing Using Different Weighting Factors

- Cognitive radio users select spectrum resources to use based on the weights assigned to the spectral resources. resources with higher weights are considered
- The concept of ‘weight’ is a number assigned to a resource, and the number reflects the importance of the resource to a certain CR user.
- Basic rule: the CR users always choose the spectrum with the highest weight to communicate, and the weights of the resource for these users will be modified based on the assessment of the degree of success. In other words, CR users are learning from the interaction between themselves and the environment.

Spectrum Sharing Using Different Weighting Factors

- Initially, all CR users have equal access to the entire available spectrum pool. After each activation, the weight of the successfully used spectrum for a user is increased by a certain weighting factor. When the attempt fails, the weight is reduced

- The CR users are a set of transmitting-receiving pairs of nodes, denoted as U, uniformly distributed in a square area, and all the pairs Ui $\in$ U are spatially fixed.

Spectrum Sharing Using Different Weighting Factors

Steps of set up a communication link from its transmitter Txi to the intended receiver Rxi:

- Spectrum selection
  - Choose spectrum with the highest weight
  - Picks up a channel randomly if all resources have same priority
- Spectrum sensing
  - Ui senses the interference level on Ck
  - If the interference level I of Ck is below the interference threshold Ithr, Ui is activated
  - Otherwise if I > Ithr , the weight of Ck for Ui is decreased by a punishment weighting factor and Ui returns back to step 1.

Spectrum Sharing Using Different Weighting Factors

- SINR measuring

  The SINR at Rxi can be expressed as:

$$SINR = \frac{S_i}{\sum_{j=1, j \neq i}^{n} I_{ji} + N}$$

- Porpuse: maintain the communication quality of channels
  - If the SINR of the activated pair Ui is greater than the threshold (SINRi>SINRthr), Ui successfully uses the spectrum and the weight of Ui for Ck will be increased by a weighting factor f
  - If SINRi<SINRthr, Ui is blocked by the channel and the weight is updated with a punishment weighting factor.

Spectrum Sharing Using Different Weighting Factors

- N(Ui)<Nmax

If N(Ui)>Nmax, and Ui is still searching for an unoccupied resource, it is blocked and waits for the next activation

Reinforcement learning

Reinforcement learning is a computational approach to learn how to map situations to actions

- the reward function to determine the weights of the resource

$$W_t = f_1 \cdot W_{t-1} + f_2$$

- Choosing an appropriate value for f is the main issue

Reinforcement learning

SCHEMES	f_1		f_2	
	Reward	**Punish ment**	**Reward**	**Punish ment**
Mild Punishment Scheme	1	1	1	-1
Harsh Punishment Scheme	1	0	1	0
Discounted Scheme	1	0.5	1	0

Spectrum sharing challenges

- Common control channel
- Dynamic radio range

Common control channel(CCC)

- Many spectrum sharing solutions, either centralized or distributed, assume a CCC for spectrum sharing
- CCC facilitates many spectrum sharing functionalities
  - Transmitter receiver handshake
  - Communication with a central entity
  - Sensing information exchange

❖ **Implementation of a fixed CCC is infeasible in CR networks**

Dynamic radio range

- Radio range changes with operating frequency due to attenuation variation
- In CR networks, where a large portion of the wireless spectrum is considered, the neighbors of a node ma change as the operating frequency changes

Conclusion

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Thanks