Spectrum Sensing Algorithms for Cognitive Radio Applications

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- Introduction
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- Spectrum Sensing Methods For Cognitive Radio
- Spectrum Sensing In Current Wireless Standards
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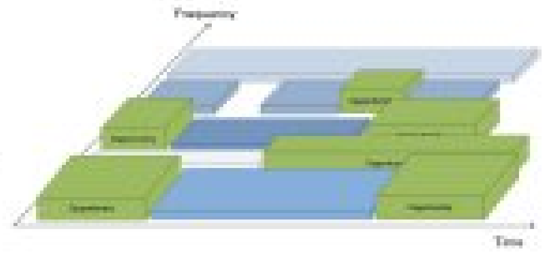
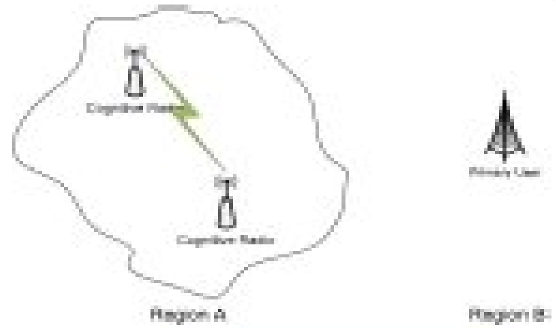
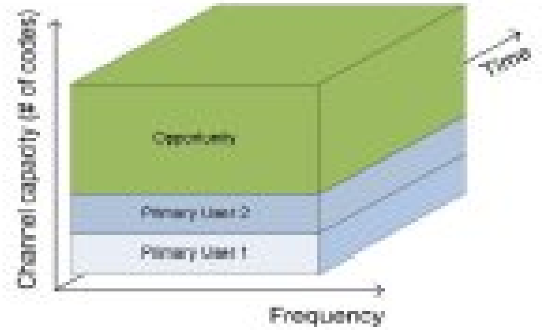
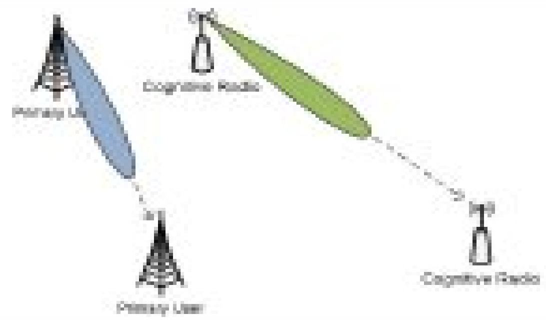
Definition :

- definition adopted by Federal Communications Commission (FCC): "*Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets.*"

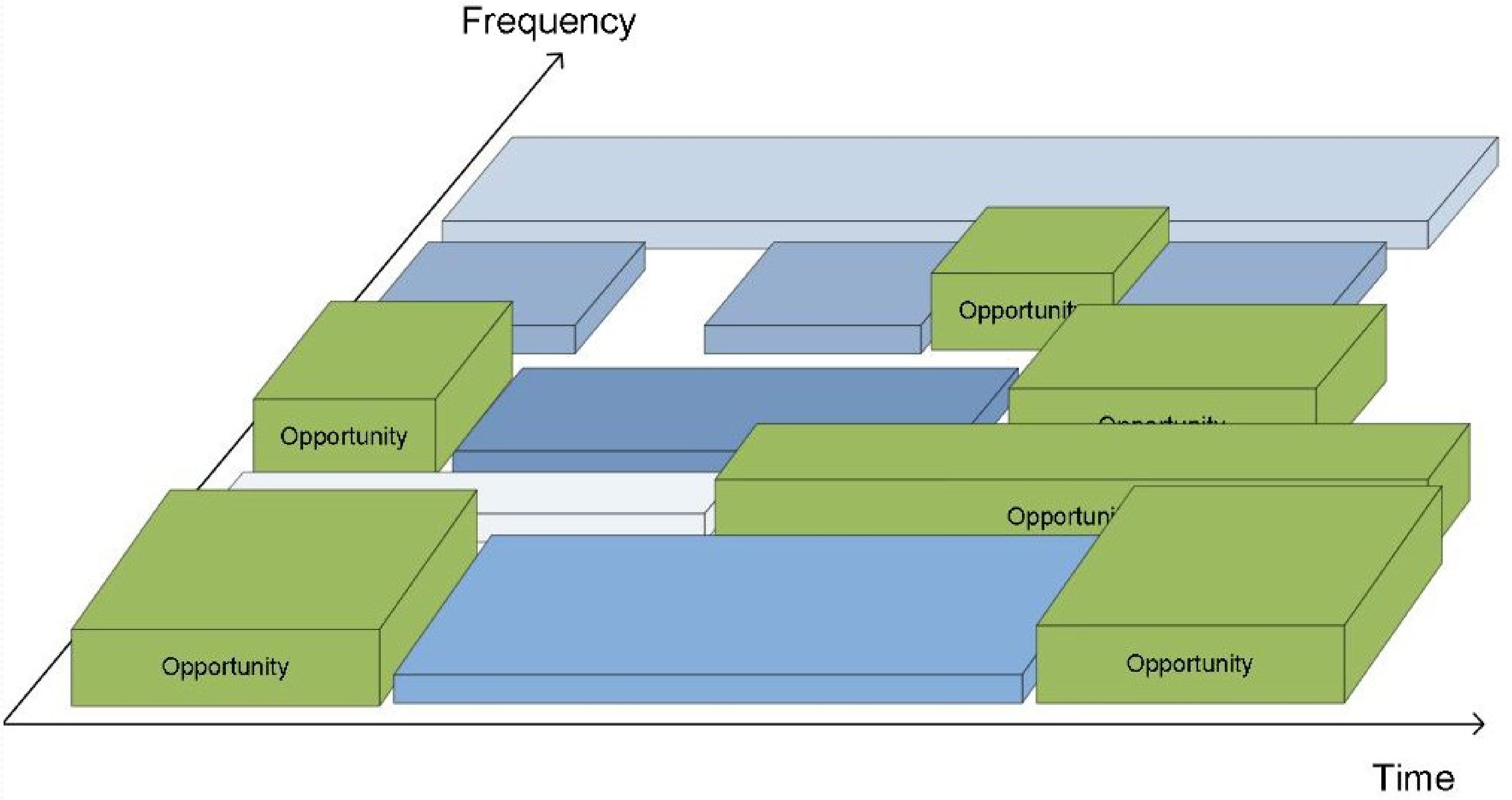
Multi-Dimensional Spectrum Awareness

- Spectrum Opportunity : *a band of frequencies that are not being used by the primary user of that band at a particular time in a particular geographic area*
- Other Dimensions :
- Code Dimension
- Angle Dimension

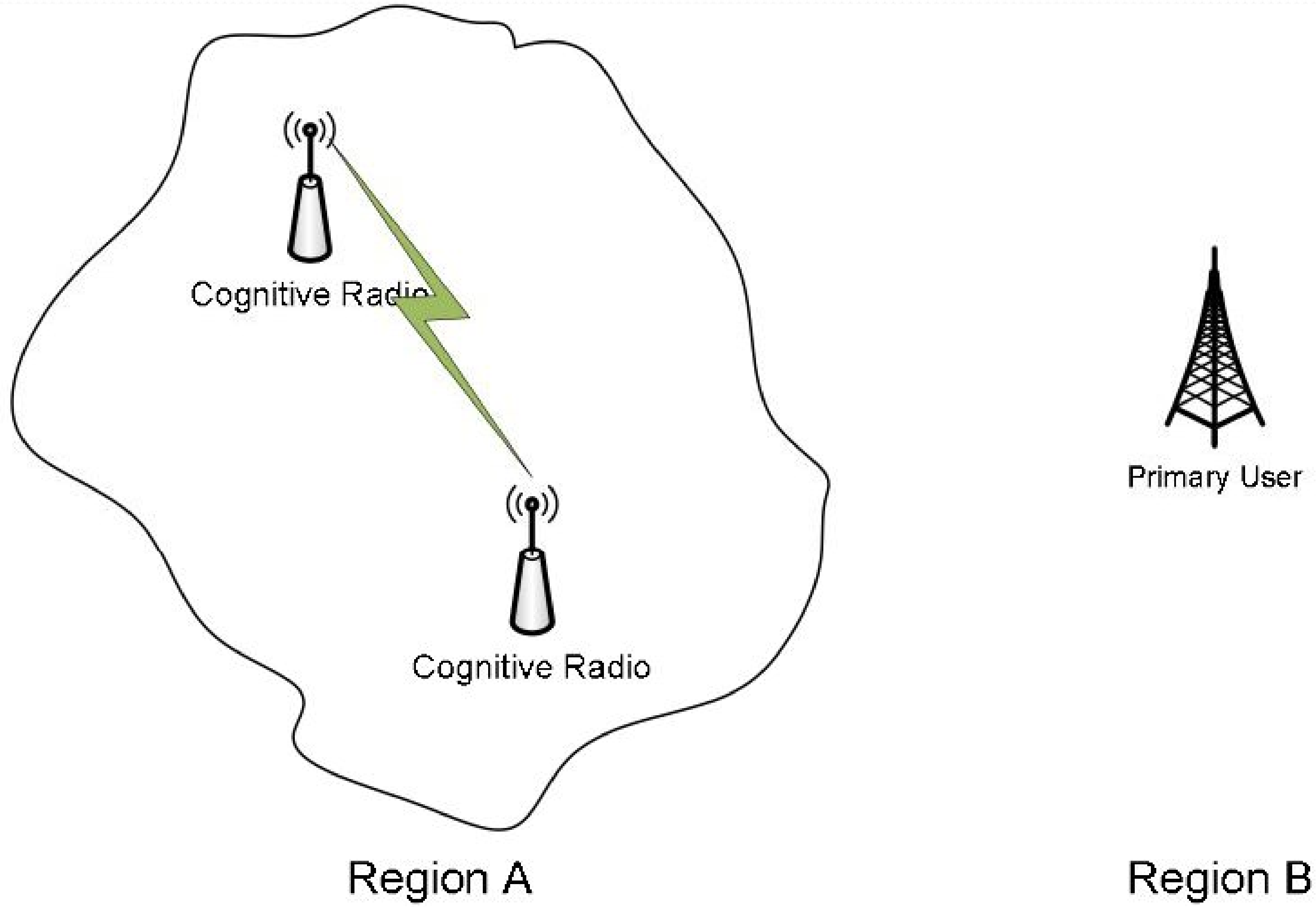
TABLE I
MULTI-DIMENSIONAL RADIO SPECTRUM SPACE AND TRANSMISSION OPPORTUNITIES

Dimension	What needs to be sensed?	Comments	Illustrations
Frequency	Opportunity in the frequency domain.	Availability in part of the frequency spectrum. The available spectrum is divided into narrower chunks of bands. Spectrum opportunity in this dimension means that all the bands are not used simultaneously at the same time, *i.e.* some bands might be available for opportunistic usage.	
Time	Opportunity of a specific band in time.	This involves the availability of a specific part of the spectrum in time. In other words, the band is not continuously used. There will be times where it will be available for opportunistic usage.	
Geographical space	Location (latitude, longitude, and elevation) and distance of primary users.	The spectrum can be available in some parts of the geographical area while it is occupied in some other parts at a given time. This takes advantage of the propagation loss (path loss) in space. These measurements can be avoided by simply looking at the interference level. No interference means no primary user transmission in a local area. However, one needs to be careful because of hidden terminal problem.	
Code	The spreading code, time hopping (TH), or frequency hopping (FH) sequences used by the primary users. Also, the timing information is needed so that secondary users can synchronize their transmissions w.r.t. primary users. The synchronization estimation can be avoided with long and random code usage. However, partial interference in this case is unavoidable.	The spectrum over a wideband might be used at a given time through spread spectrum or frequency hopping. This does not mean that there is no availability over this band. Simultaneous transmission without interfering with primary users would be possible in code domain with an orthogonal code with respect to codes that primary users are using. This requires the opportunity in code domain, *i.e.* not only detecting the usage of the spectrum, but also determining the used codes, and possibly multipath parameters as well.	
Angle	Directions of primary users' beam (azimuth and elevation angle) and locations of primary users.	Along with the knowledge of the location/position or direction of primary users, spectrum opportunities in angle dimension can be created. For example, if a primary user is transmitting in a specific direction, the secondary user can transmit in other directions without creating interference on the primary user.	

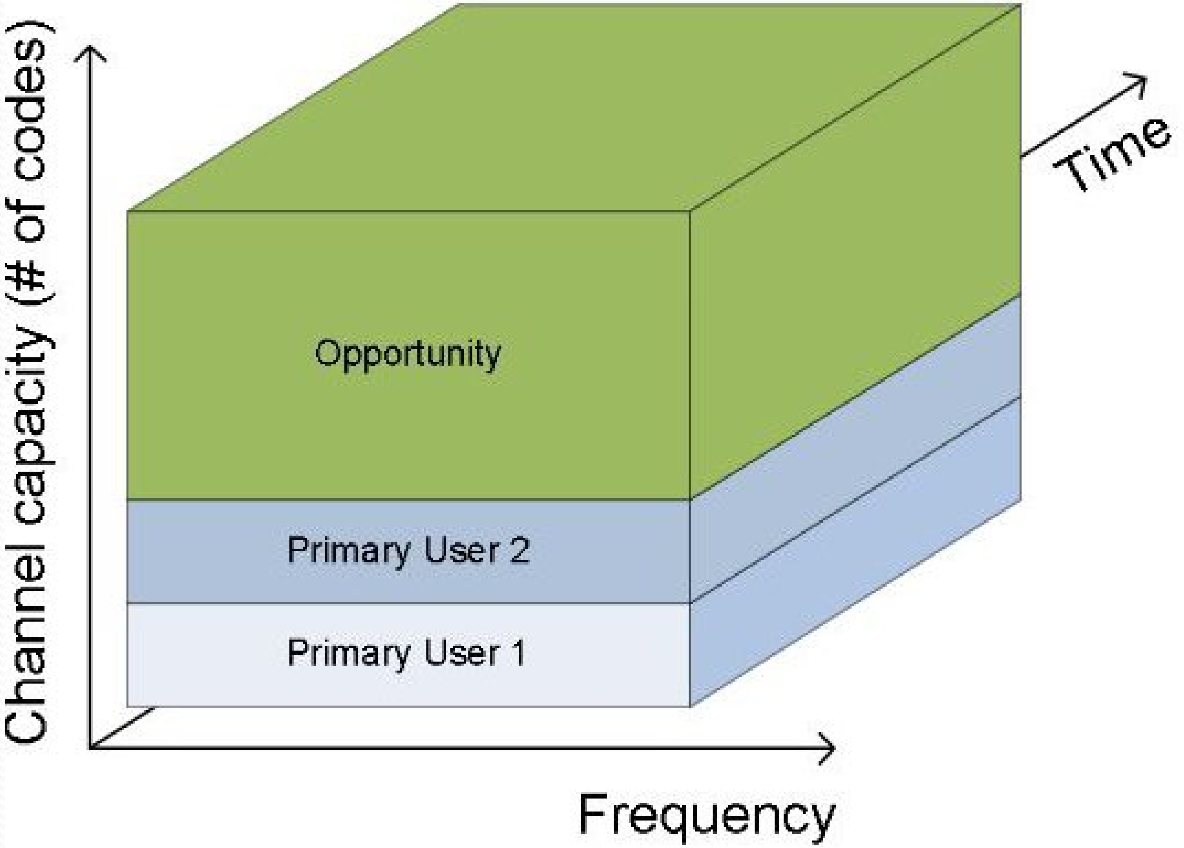
Frequency and Time Dimension



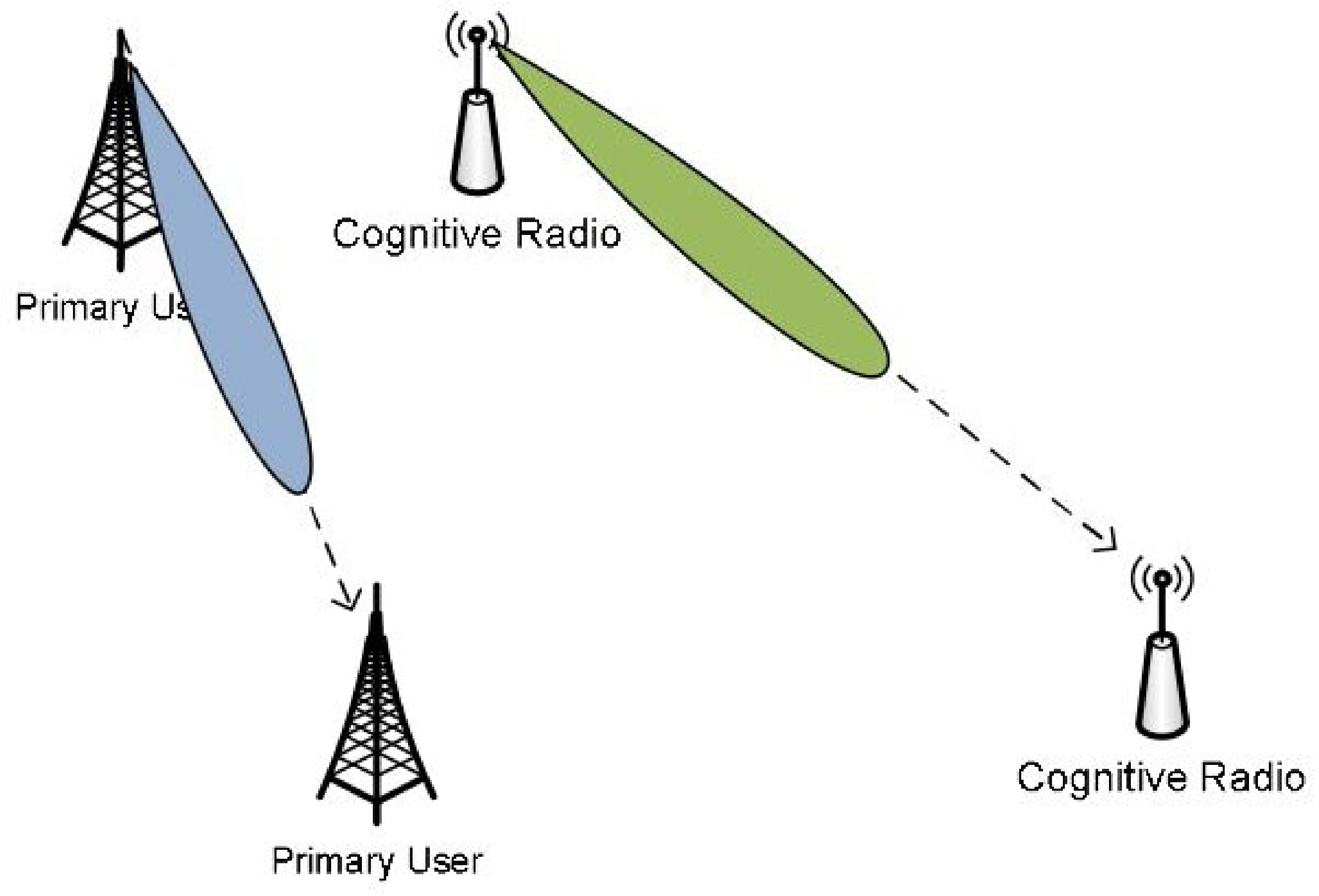
Geographical Space Angle



Code Dimension



Angle Dimension



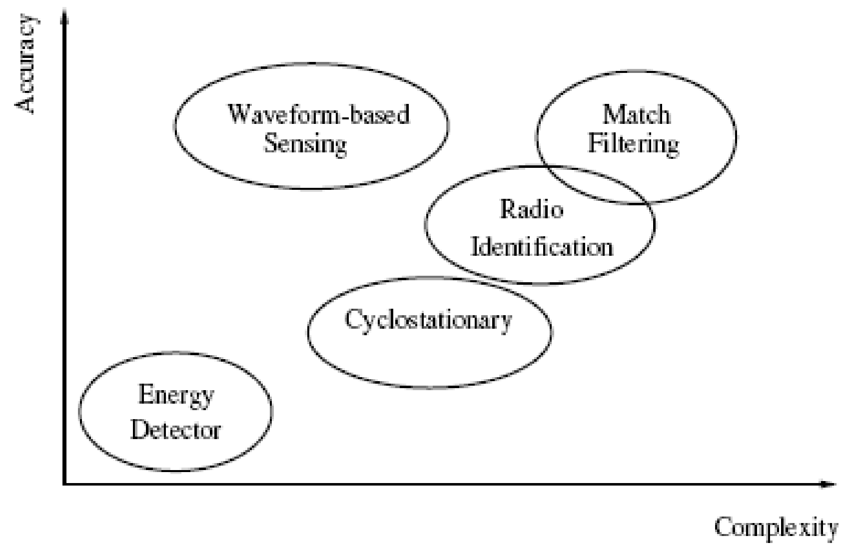
Challenges

- *Hardware Requirements*
- *Hidden Primary User Problem*
- *Detecting Spread Spectrum Primary Users*
- *Sensing Duration and Frequency*
- *Decision Fusion in Cooperative Sensing*
- *Security*

Spectrum Sensing Methods For Cognitive Radio

- *Energy Detector Based Sensing*
- *Waveform-Based Sensing*
- *Cyclostationarity-Based Sensing*
- *Radio Identification Based Sensing*
- *Matched-Filtering*

Comparison of Various Sensing Methods



- Waveform-based sensing is more robust than energy detector and cyclostationarity based methods because of the coherent processing that comes from using deterministic signal component.
- cyclostationary-based methods perform worse than energy detector based sensing methods when the noise is stationary.

- While selecting a sensing method, some tradeoffs should be considered. The characteristics of primary users are the main factor in selecting a method. Cyclostationary features contained in the waveform, existence of regularly transmitted pilots, and timing/frequency characteristics are all important.
- Other factors include required accuracy, sensing duration requirements, computational complexity, and network requirements.

Other Sensing Methods

- *Centralized Sensing*
- *Distributed Sensing*
- *External Sensing*

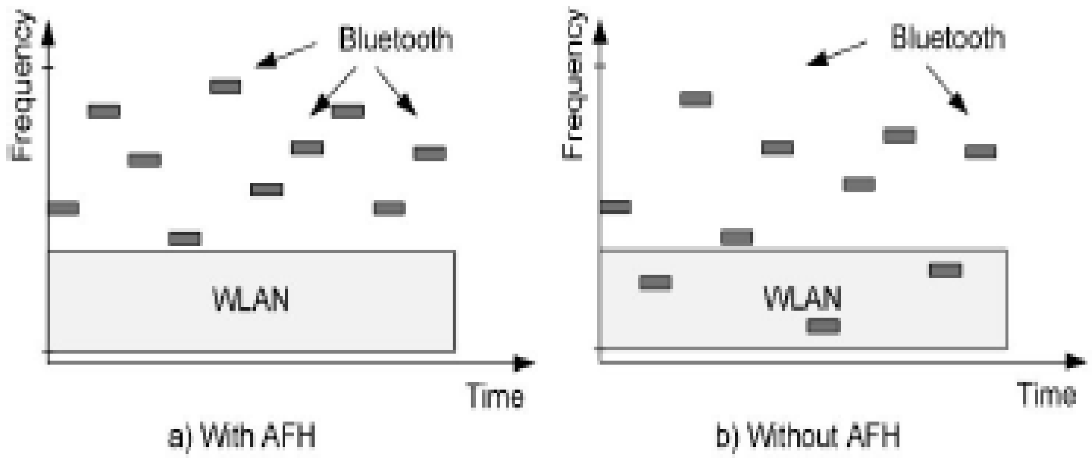
Spectrum Sensing In Current Wireless Standards

- *IEEE 802.11k*
- A proposed extension to IEEE 802.11 specification is IEEE 802.11k which defines several types of measurements. It also creates and updates a radio neighborhood map and report. Some of the measurements include channel load report, noise histogram report and station statistic report.
- The noise histogram report provides methods to measure interference levels that display all non-802.11 energy on channel as received by the subscriber unit.

- AP collects channel information from each mobile unit and makes its own measurements. This data is then used by the AP to regulate access to a given channel.
- The sensing (or measurement) information is used to improve the traffic distribution within a network as well.
- WLAN devices usually connect to the AP that has the strongest signal level. Sometimes, such an arrangement might not be optimum and can cause overloading on one AP and underutilization of others.
- In 802.11k, when an AP with the strongest signal power is loaded to its full capacity, new subscriber units are assigned to one of the underutilized APs. Despite the fact that the received signal level is weaker, the overall system throughput is better thanks to more efficient utilization of network resources.

Bluetooth

- A new feature, namely adaptive frequency hopping (AFH),is introduced to the Bluetooth standard to reduce interference between wireless technologies sharing the 2.4GHz unlicensed radio spectrum.
- In this band, IEEE 802.11b/g devices, cordless telephones, and microwave ovens use the same wireless frequencies as Bluetooth.
- AFH identifies the transmissions in the industrial, scientific and medical (ISM) band and avoids their frequencies.



- Bluetooth transmission with and without adaptive frequency hopping(AFH). AFH prevents collusions between WLAN and Bluetooth transmissions.

- AFH requires a sensing algorithm for determining whether there are other devices present in the ISM band and whether or not to avoid them.

- The sensing algorithm is based on statistics gathered to determine which channels are occupied and which channels are empty

- Channel statistics can be packet-error rate, BER, received signal strength indicator (RSSI), carrier to-interference-plus-noise ratio (CINR) or other metrics.

IEEE 802.22

- IEEE 802.22 standard is known as *cognitive radio standard* because of the cognitive features it contains.
- One of the most distinctive features of the IEEE 802.22 standard is its spectrum sensing requirement.
- IEEE 802.22 based wireless regional area network (WRAN) devices sense TV channels and identify transmission opportunities. The functional requirements of the standard require at least 90% probability of detection and at most 10% probability of false alarm for TV signals with -116 dBm power level or above.

- The sensing is envisioned to be based on two stages: fast and fine sensing .In the fast sensing stage, a coarse sensing algorithm is employed, *e.g.* energy detector. The fine sensing stage is initiated based on the fast sensing results.
- Fine sensing involves a more detailed sensing where more powerful methods are used. Several techniques that have been proposed and included in the draft standard include energy detection, waveform-based sensing (PN511 or PN63 sequence detection and/or segment sync detection), cyclostationary feature detection, and matched filtering.

- A base station (BS) can distribute the sensing load among subscriber stations (SSs).The results are returned to the BS which uses these results for managing the transmissions.
- Another approach for managing the spectrum in IEEE 802.22 devices is based on a centralized method for available spectrum discovery. The BSs would be equipped with a global positioning system (GPS) receiver which would allow its position to be reported. The location information would then be used to obtain the information about available TV channels through a central server.

- For low-power devices operating in the TV bands, *e.g.* wireless microphone and wireless camera, external sensing is proposed as an alternative technique. These devices periodically transmit beacons with a higher power level. These beacons are monitored by IEEE 802.22 devices to detect the presence of such low-power devices which are otherwise difficult to detect due to the low-power transmission.

conclusions

- Spectrum is a very valuable resource in wireless communication systems, and it has been a focal point for research and development efforts over the last several decades.
- Cognitive radio, which is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage, has become an exciting and promising concept.
- One of the important elements of cognitive radio is sensing the available spectrum opportunities. the spectrum opportunity and spectrum sensing concepts are re-evaluated by considering different dimensions of the spectrum space.
- The new interpretation of spectrum space creates new opportunities and challenges for spectrum sensing while solving some of the traditional problems.

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Thank You
Any Question?