An Overview of Spectrum Sensing Techniques in Wireless Sensor Networks

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Outlines

- Overview and introduction of CR
- Cognitive Cycle
- Wireless Sensor Networks
- Spectrum sensing techniques
- Conclusion

RF Spectrum Utilization

- Spectrum is potentially scarce resource
- Static spectrum allocation
- –underutilization
- –overcrowding

FCC 2002 Report

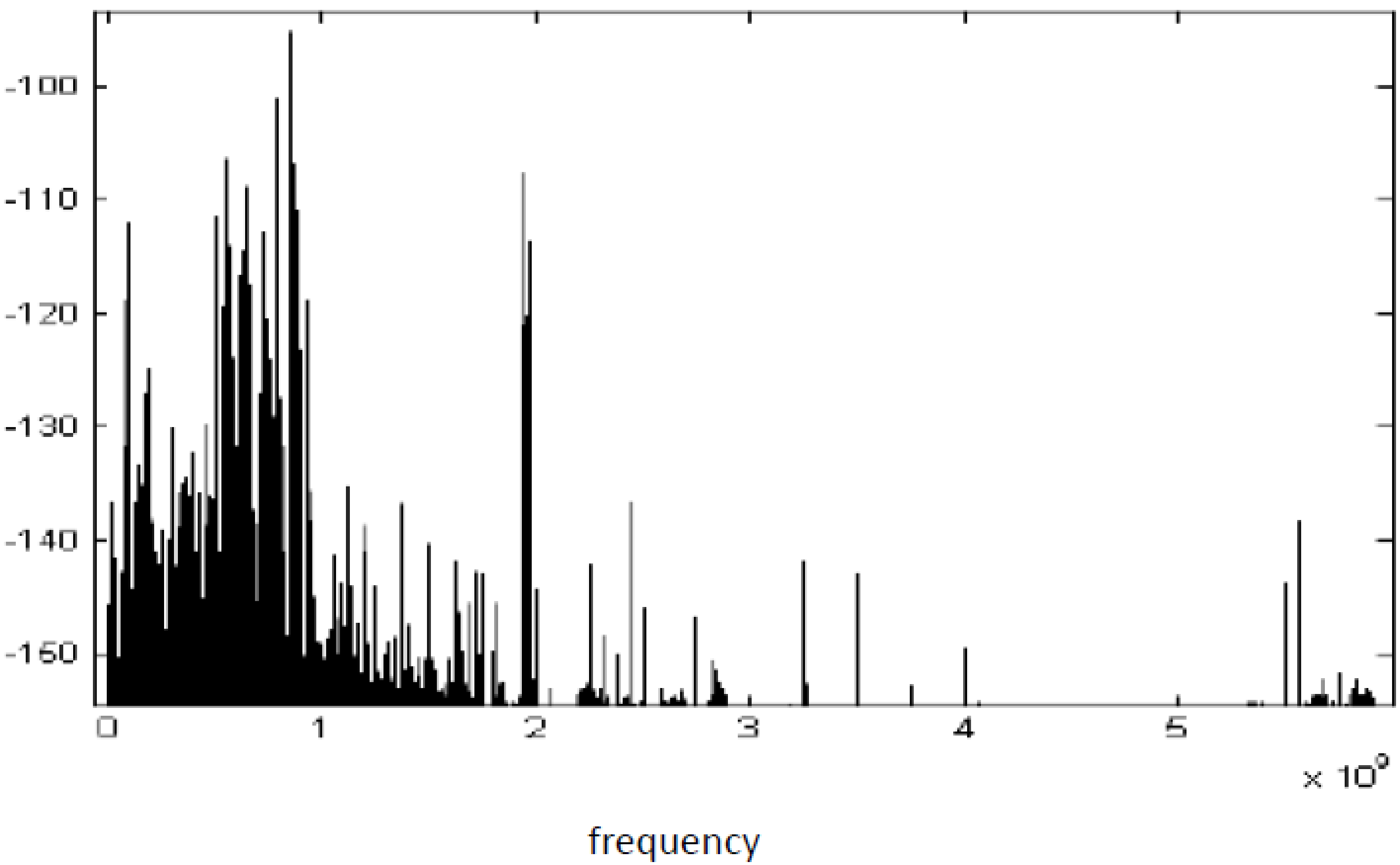
- Allocated spectrum usage 15% - 85%
- Licensed Bands are underused most of the time
- There is significant inefficient spectrum utilization than the actual spectrum scarcity due to the legacy system and the rules imposed by FCC
- Most of the allotted channels are not in use most of the time
- Some are partially occupied while others are heavily used.

FCC Report 2002

- Report recommends certain rules and regulations for the efficient use of radio spectrum
- FCC is interested about the use of holes by unlicensed users(802.16).
- FCC allows the use of TV bands by unlicensensed user without creating interference to the licensed user .
- Unlicensed user will vacate the spectrum when licensed user want to transmit.
- Dynamic approach for spectrum sensing and access.

Spectrum Utilization

Licensed bands are underutilization most of the time



Wireless Sensor Networks

- WSN are very simple, cheaper, easy to implement
- WSN made by set of sensors which are interconnected with the help of wireless communication network.
- The wireless sensor nodes are short range devices.
- The sensor nodes can monitor the physical conditions, collect the data and route this data
- Environment monitoring, home automation, fire detection, wild life tracking and health care are done by WSN.
- The wireless sensor networks are flexible and they can form self-organizing networks.
- WSN have two mode of operation, data collection and data routing.
- The main requirement of a WSN is energy efficient communication because of the limited power supplied by the battery.

Wireless Sensor Networks (continue)

- The computations and communication protocols used in WSN need to be energy efficient.
- The WSN uses fixed spectrum assignment policy, this limits the performance in terms of computation power, bandwidth and QoS.
- The WSN are operated in unlicensed band so the possibility of interference is increased due to the presence of other devices
- The performance degradation is expected due to the rapid growth of new wireless applications. For example, the IEEE 802.11 network can degrade the performance of the Zig BEE/802.15.4 network.
- competitiveness is increasing and a research emphasis is required to address the problem of coexistence and dynamic parameter adaptation in the changing physical environment
- The routing, Fusion of information with fault tolerance, security, scalability and deployment of the networks are common design issues

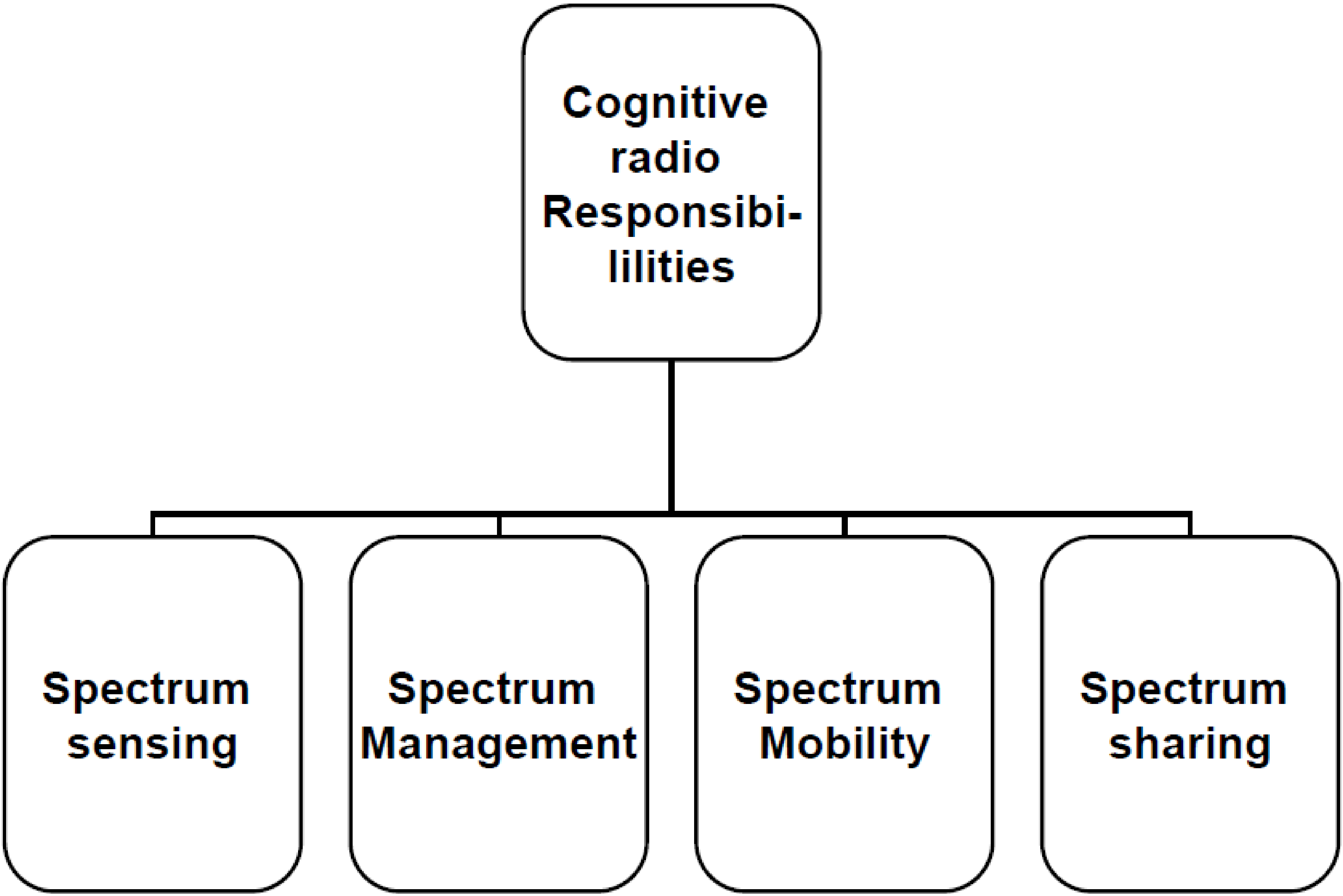
Wireless Sensor Networks (continue)

- The rapid growth and deployment of the new wireless nodes in unlicensed bands is creating the spectrum scarcity.
- It is increasing the interference and can create the disastrous situation.
- The possible solution to these problems is the cross discipline research in the fields of cognitive radio technology and WSN.
- The sensing and identification of the spectrum hole is the first task performed for the dynamic spectrum management in cognitive wireless sensor networks (CWSN).
- Dynamic spectrum sharing (DSS) and Dynamic spectrum access (DSA) are also popular research areas depending on spectrum sensing.
- Sensor nodes consist of different components for example power unit, processing unit, sensing unit, communication unit

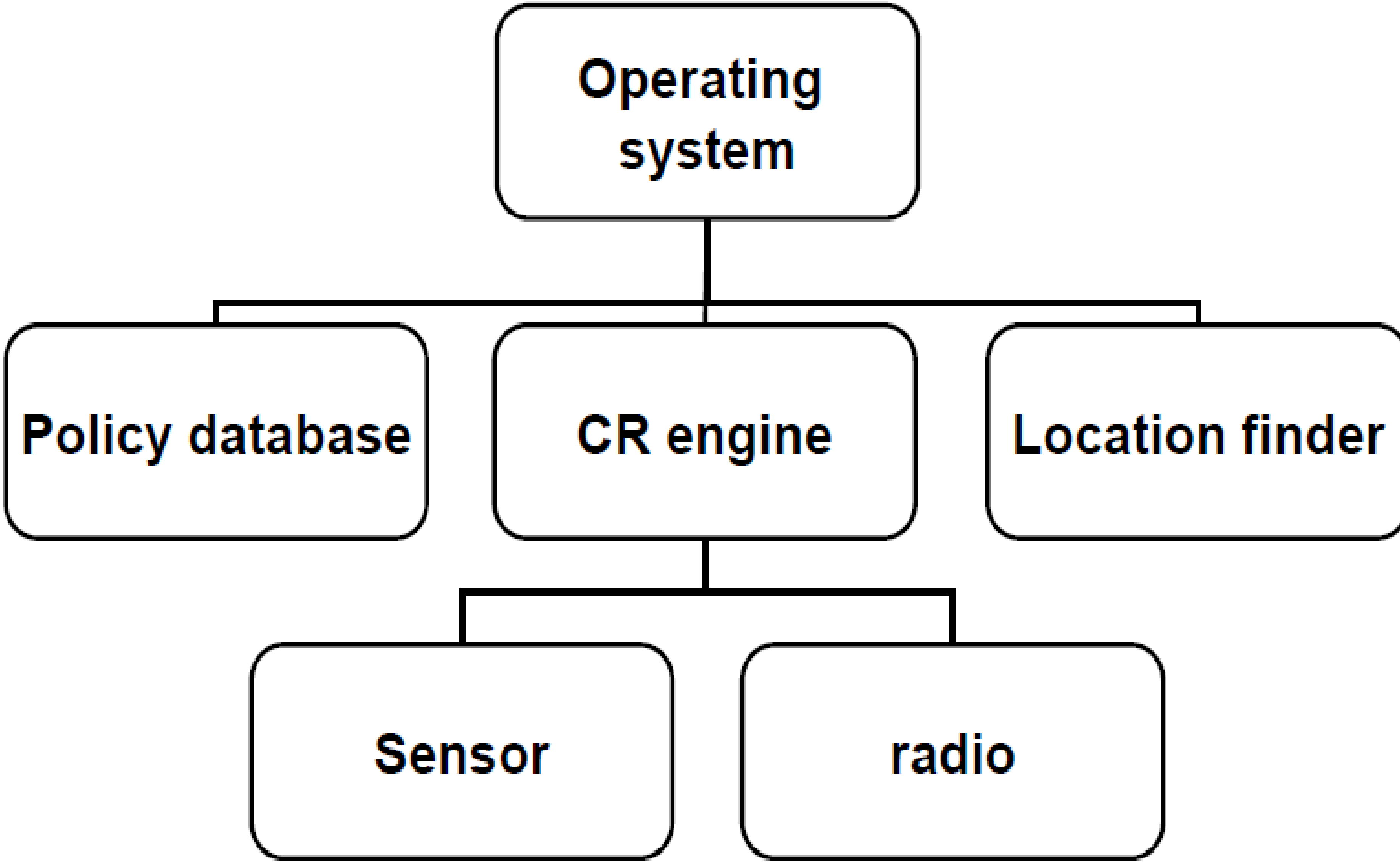
Cognitive Radio

- **Intelligent: can sense the environment & learn to adapt [Mitola'2000]**
- **CR is a self-aware, context aware spectrum-agile ,Next generation radio.**
- **can change its parameters according to changing communication environment to ensure the QOS**
- **Can dynamically share underutilized spectrum**
- **Spectrum sensing is one of the key enablers for the success of cognitive radio (CR).**
- **CR must ensure that the primary user will not experience undue interference.**
- **Radio system senses its operational electromagnetic environment and dynamically and autonomously adjusts its radio operating parameters.**
- **Operated in opportunistic ,greedy manner.**
- **Spectrum sensing Cognitive Radio (only frequency spectrum) is considered**
- **CR can be designed for both licensed or unlicensed bands**
- **CR are working according to Cognitive cycle.**

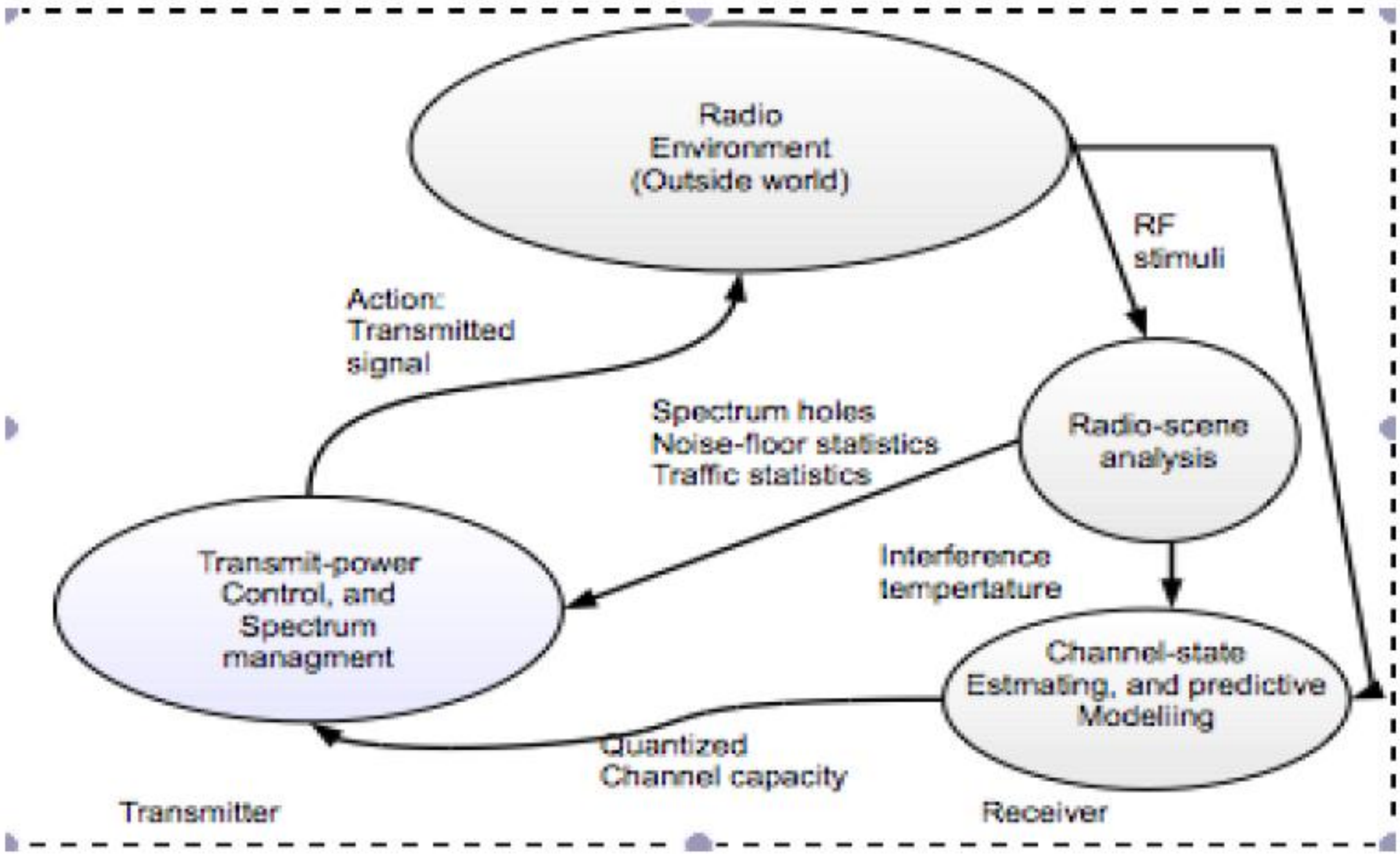
Main Features of CR



The main components of CR



Cognitive Cycle



Spectrum Hole

- Licensed users are known as Primary users
- Unlicensed users are known as the cognitive users
- Primary users have the spectrum usage priority
- Cognitive user can use the free bands in an opportunistic, greedy way
- Multidimensional regions within frequency, time, space are spectrum hole
- Spectrum hole represent the potential opportunities for non interfering(safe)
- FCC allowed the Cognitive users to access the ultrahigh frequency (UHF) TV bands in a dynamic way (802.22 standard)

Cognitive wireless Sensor Networks

- IN CR and CWSN the sensing is performed to collect the information from the Communication environment about spectrum occupancy and environmental parameters.
- CWSN are dealing with the cognition in all layers.
- The merging of CR and WSN (CWSN) technologies enables the network to dynamically sense the availability of spectrum holes
- It increases the spectrum efficiency and can operate with more available bandwidth.
- The dynamically changing transmission parameters can improve the Quality of Service (QOS) wide variety of data rates, and throughput.
- CWSN can dynamically adapt the different modulation schemes, power, constellation schemes, operating frequency, pulse shape, symbol rate, coding scheme.
- The CWSN can be operated in lower frequency ranges which normally have a better transmission range.
- Fewer nodes can cover a specific area

CWSN Architecture

- Cognitive wireless sensor networks consist on several tiny sensors.
- sensors have “limited battery energy”.
- CWSN have a cognitive module which is responsible for the dynamic spectrum sensing and adaptation of the parameters.
- The cognitive module is controlled by Cognitive engine.
- The cognitive engine enables the sensor nodes to achieve the context awareness and intelligence.
- The cognitive engine can help in routing, localization, scheduling and routing in the WSN.
- The CWSN nodes can have the spectrum sensing ability.
- The spectrum sensing process helps in the detection of spectrum holes.
- The modified version of the 802.15.4 protocol (Zig Bee) is a possible best option for Physical and MAC layers of CWSN.

Spectrum Sensing In CWSN

- The dynamic spectrum sensing and adaptation is a main difference between WSN and CWSN.
- The spectrum sensing is possible in centralized or distributed way.
- In centralized spectrum sensing scheme, one network coordinator is responsible for the spectrum sensing and spectrum scheduling tasks.
- centralized spectrum sensing needs a separate control channel.
- control channel broadcasts channel switch command which dictates the nodes to change their Tx /Rx frequencies
- Some licensed or Industrial, Scientific, Medical (ISM) band can be used for this purpose.
- This technique is energy efficient but there is a chance that if the control channel is faded due to any reason then whole network will be in a chaos

Distributed Spectrum Sensing

- In distributed scheme, each node is cognitive.
- Each Node have the ability to sense the communication environment by itself.
- Nodes share this information with each other and then decides to adapt the best available channel.
- This scheme has less chances of the fading.
- Due to distributed nature it has high computational complexity and need more complex hardware.
- As the sensor nodes are battery powered, therefore, the distributed spectrum sensing scheme is not feasible with respect to energy consumption.
- It is a better option to have few specialized and dedicated nodes in a network which can sense the environment.
- There is a trade-off between accuracy and time required for spectrum sensing

Spectrum Sensing in CWSN

- The spectrum sensing can be over a narrow or wide frequency band.
- efficient and interference free transmission is the main task of spectrum sensing
- The spectrum sensing can be done in an individual or cooperative manner.
- Due to power constraint, CWSN needs an energy efficient and computationally less complex technique.
- This technique lies in time or frequency domain.
- The high energy budget, spectrum sensing techniques are not used in CWSN

Spectrum Sensing (continue)

- The spectrum sensing is used to detect the empty frequency bands (spectrum holes).
- The spectrum resources are limited; therefore the spectrum sensing will help us improve the efficiency of wireless sensor networks.
- The spectrum sensing (signal detection) is a simple binary hypothesis problem.
- One hypothesis is known as null hypothesis and it is represented by H_0
- The other hypothesis is known as alternative hypothesis and it represented by H_1

The Problem

H_o=x[n] =w[n] n=0,1,2,…………,N-1

H_1=x[n] =s[n] +w[n] n=0,1, 2,…………,N-1

s[n]: zero-mean Gaussian process with known covariance

W[n]: white Gaussian noise (WGN) with $\mathcal{N}(0, \sigma^2)$ independent of s[n]

Types of Spectrum Sensing in CWSN

- The spectrum sensing in CWSN can be subdivided in Blind sensing and the other is signal-specific sensing.
- **Blind Spectrum sensing**
- *Energy Detectors*
- *Eigenvalue-based Spectrum sensing*

Energy detection based spectrum sensing

- Non-optimal way of detection
- non coherent detection technique, so no prior knowledge about primary signal is required
- Not good for noise buried signals
- Performance is not good for fading channels.
- Psd based spectrum sensing
- Welch periodogram based spectrum sensing.
- Pfa Vs Pd presents the detector
- O(1/SNR)^2 samples required for optimal detection.

Energy Based Detection

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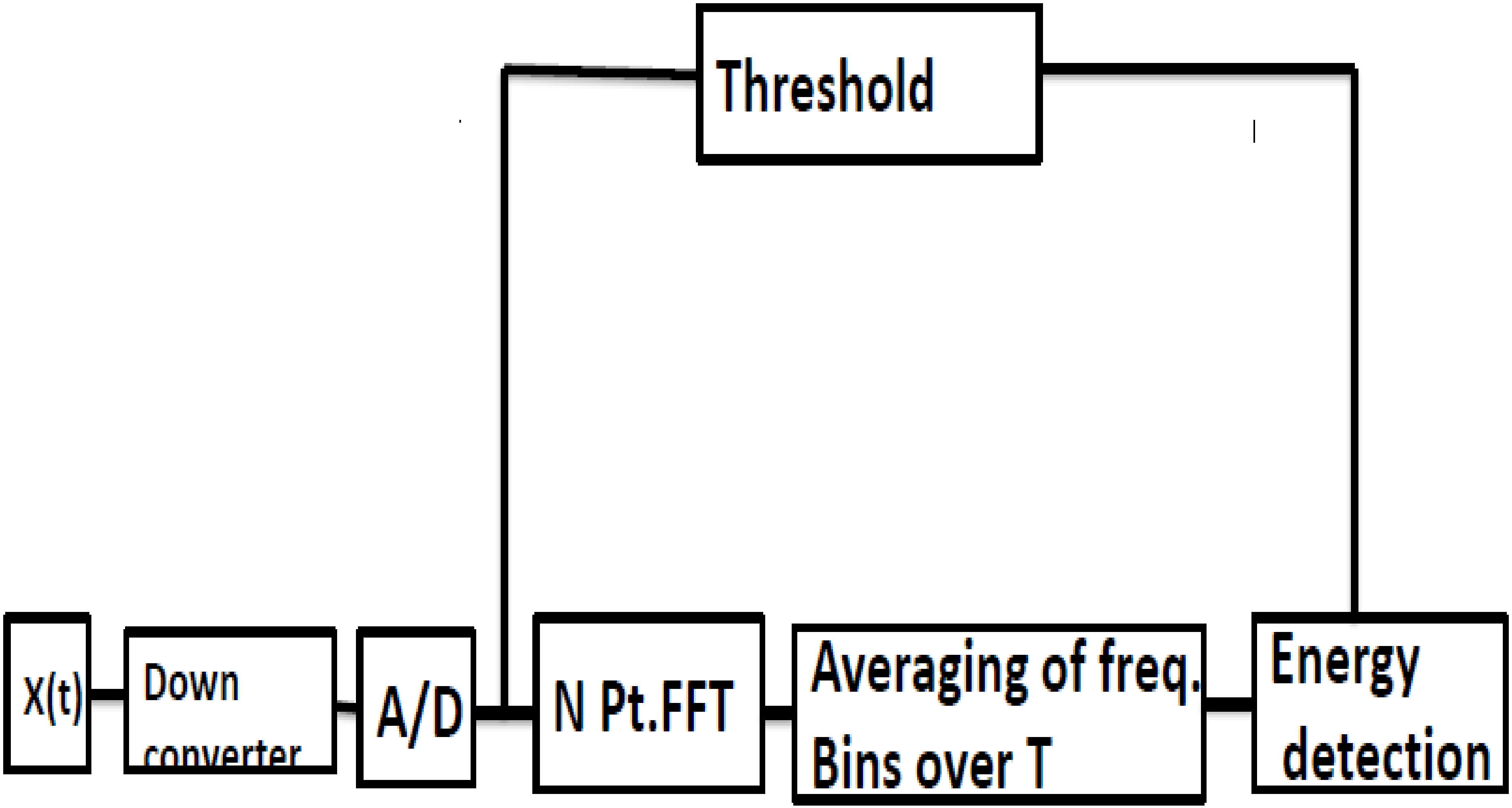
- Performance is not good for fading channels.
- PSD based spectrum sensing
- Welch periodogram based spectrum sensing.
- Pfa Vs Pd presents the detector
- (1/SNR)^2 samples required for optimal detection.

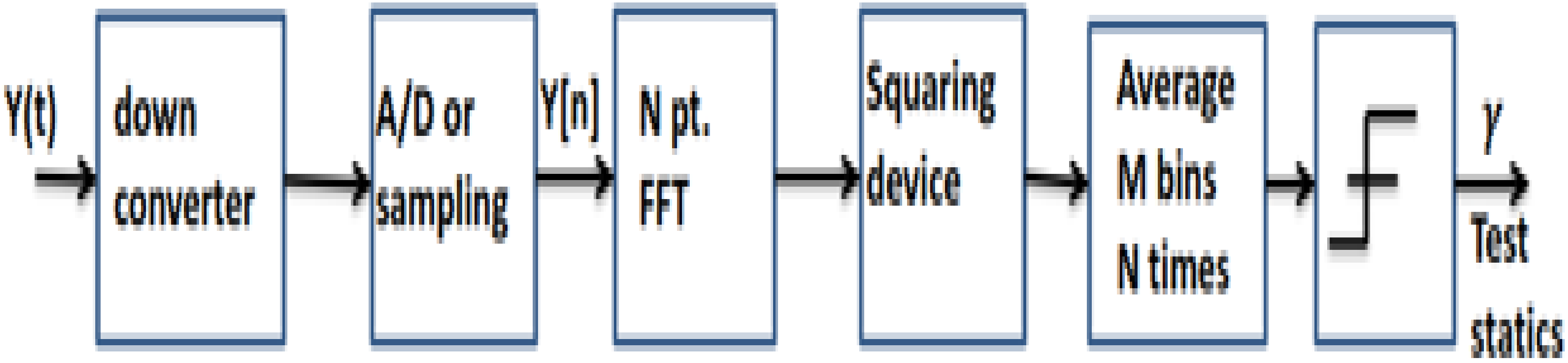
continue

- Output of band pass filter with bandwidth W is squared and integrated over the observation interval T.
- output of the integrator is compared with a threshold to detect whether the primary signal is present or not.
- In frequency domain
- averaging bins of a Fast Fourier Transform.
- the processing gain is proportional to FFT size N and the averaging time T.
- Increase in the size of FFT improves the frequency resolution
- freq. resolution is helpful in detecting narrowband signals.
- The reduction of the averaging time improves the SNR by reducing the noise power.)

Energy Detection (continued)

Block diagrm





Y(t)
down
converter
A/D or
sampling
Y[n]
N pt.
FFT
Squaring
device
Average
M bins
N times
γ
Test
statics

Eigen Value based Spectrum Sensing

- Eigenvalue based spectrum sensing technique uses the Eigen-values of the correlation matrix of the received signals.
- The Eigen-value based spectrum sensing is subdivided in to two categories. One type operates on the basis of minimum and maximum eigenvalues of the sample covariance matrix of the received signals. It compares the maximum Eigen-values and minimum Eigen-values with the threshold value.
- The threshold value at the required probability of false alarm is set by using random matrix theory

Eigen Value Based Spectrum Sensing (continued

- In the second method, the energy of the minimum eigenvalue is compared with the threshold.
- These signal detection techniques are computationally more complex as compared to the energy detectors
- The performance of eigenvalue detector is independent of noise uncertainty.
- These techniques are based on generalized likelihood ratio test (GLRT).

Signal Specific Spectrum Sensing Techniques

- These techniques utilize the features of the specific signal for the spectrum sensing. They are
- *FFT-based Carrier sensing*
- *Multi-taper Spectrum Estimator (MTSE)*
- *Signature sensing for Advanced Television Systems Committee (ATSC) Signal Identification*
- *PLL-based ATSC pilot sensing*
- *Higher order statistics sensing (HOSs)*
- Covariance-based spectrum sensing
- *Correlation based spectrum sensing*
- *SVM Based spectrum sensing*

FFT Based Spectrum Sensing

- used for the estimation of the power spectral density (PSD) .
- PSD is estimated with the help of discrete Fourier transform (DFT).
- The averaging of periodogram sequence helps in improving the SNR of the estimated signals.
- This technique is computationally less complex [32].
- can be used for the detection of analog and digital signals.
- more susceptible for fading because due to useage of narrow band signals.
- Shows worst performance in case of fading channels

Multi-taper Spectrum Estimator (MTSE)

- used for the leakage reduction and for improvement of variance of the estimated power.
- multiple orthogonal prototype filters are used.
- A set of Slepian vectors is used to represent the last N samples after receiving and collecting the data.
- For finite no of samples, the maximum concentration of the Fourier transform (FT) of the Slepian vectors lies in a bandwidth $f_c - w$ to $f_c + w$.
- good spectrum sensing technique for small sample size and its performance is poor for large sample sizes due to high computational complexity

Signature sensing for Advanced Television Systems Committee (ATSC)

- specific signal signatures are used for the detection of primary signals
- The sequence of segments is contained by data fields of ATSC signals
- ATSC every field has 313 segments, the first segment is used for synchronization
- It contains one PN511 sequence and three PN63 sequence
- The PN sequence is used as a signature for the spectrum sensing of ATSC signal
- The test statistic is based on the maximum absolute value of the correlator output. The correlator gives the result in 24.2ms

PLL-based ATSC pilot sensing

- In the ATSC pilot frequency is tracked with the help of two frequency tracking blocks.
- digital version of Phase lock loop (PLL) using Costas loop is used in this technique.
- The tracking frequency used to initialize the trackers is close to the expected pilot frequency.
- Trackers are operated at nominal frequencies± 30 KHz.
- The frequency is estimated by the absolute values of the difference between the finally estimated frequencies by both trackers.

PLL-based ATSC pilot sensing

- If the value of the test statistics is greater than threshold value, it will represent the presence of ATSC pilot signal.
- Normally sensing technique requires 50 to 75ms
- results of the PLL based sensing technique highly depends upon the fading characteristics of the channels

Higher order statistics sensing (HOSs)

- mathematical tools which can describe the statistical characteristics of a random process.
- Works according to Gaussian noise statistics principle.
- Matching of the signal statistics with Gaussian distributions is used to decide the presence or absence of the spectrum hole.
- ATSC pilot signal and received signals are converted into DC and baseband signals respectively.
- Both signals are filtered with the help of narrowband filters.
- The 2048 FFT is used to transform the resultant signal into frequency domain signal. T

Higher order statistics sensing (HOSs)

- High-order (more than 2nd order) cumulants and moments of the frequency domain signals are calculated.
- Calculation is done for both imaginary and real parts of the resultant frequency domain signals.
- For noise only case, higher order cumulants will be zero.
- The higher order cumulants and moments can be used to eliminate the influence of Gaussian noise.
- It can perform well in case of excursion and rotation of the constellation diagram.
- If the gaussianity test fails, the decision about the presence of the pilot signal is done.

Covariance-based spectrum sensing

- Similar to eigenvalue-based spectrum sensing technique.
- The sample covariance matrix is calculated.
- In case of white Gaussian noise the covariance matrix becomes diagonal matrix.
- most commonly used test statistics is T = T1 = T2. Here T1 represents the sum of the magnitude of the entire covariance elements matrix and T2 represents the sum of the magnitude of the diagonal elements.
- For the white Gaussian signal T1 and T2 will be equal. In the case of wireless microphone, the signal is not white and hence the test statistics is not closer to one.
- The T1 and T2 are replaced by T3 and T4 respectively .
- The sensitivity of the device is approximately equal to -23dB for the 10ms sensing period.

Correlation based spectrum sensing

- FFT is used to estimate the power spectral density (PSD).
- Measured PSD is compared with the pre-stored PSD of the desired signal.
- Efficient for the signal detection but need more memory
- The presence of the information signal is declared when the test statistics is greater than the pre-stored threshold value.
- it needs a large amount of memory.
- This technique is not useful for spectrum sensing in case of WSN due to memory limitation

Support Vector Machines Based Spectrum Sensing

- **working on the basis of large margin principle and mapping of the data in to a higher dimensional feature space .**
- **SVM tries to minimize the structural risk in higher dimensional feature space to find the low VC Hyper-plane such that the distance between two classes becomes maximum.**
- **Machine uses support vectors for the classification**
- **Techniques is basically nonlinear, empirical technique.**
- **Techniques are based on certain Kernel function.**
- **Kernel function can convert the nonlinear machine into linear detector.**
- **Normally for the signal detection, the Huber loss function is used.**
- **The technique is subdivided into two steps: training and testing.**
- **computationally very complex**
- **Help in the detection of very weak signals .**

Cooperative Spectrum sensing techniques

- Multipath and shadowing degrades the sensing performance.
- The solution of these problems is the cooperative spectrum sensing.
- The probability of deep fades is reduced.
- Some important cooperative spectrum sensing techniques are

    Voting based sensing

    Correlator based sensing

Conclusion and Future Work

- Cognitive radio is a generic term. The intelligent, Self-aware systems are the solution of the future wireless communication problems
- Solution of spectrum sensing is possible by the combination of Statistical signal processing and statistical learning techniques
- Interference can be avoided by the intelligent spectrum sensing and adaptation of the parameters
- CR is the solution of the problems of future Wireless communication devices

Q&A

- Thank you very much