Optimization Technique for Cognitive Radio Network: A Panoramic Survey

G. Kalaimagal, M.S. Vasanthi

Abstract: Cognitive radio technology is a developing technology for upcoming radio communication systems such as Machine to Machine, IoT and Energy conservation system. In this survey paper we have summarized the studies of sensing techniques which maximizes the probability of detection of the presence of primary user (licensed) and minimizes the probability of false alarm. Therefore, the performance of spectrum sensing is measured by the probability of detection and the probability of false alarm. To save energy, higher probability of detection is performed to avoid collision to licensed users. We extend a study of optimization strategies which enhances energy conservation per bit, with objective of reducing the total error in cognitive radio sensor network. Then we provide explored survey that comprises of Multi-objective optimization algorithms for sensing duration to enhance the throughput of the network. Furthermore, we have consolidated a variety of joint optimization using algorithm which are recommended for the observer to understand from the collected references. Finally, we have discussed the challenges for the CRN to be handled in future work.

Index Terms: optimization techniques, sensing duration, collision, Multi-objective optimization.

I. INTRODUCTION

Due to increase in different communication devices and protocol, the demand of spectrum also increases. So, there is a need of radio spectrum allocation. To exploit the different frequency band without affecting the licensed user, dynamic spectrum technique is proposed to alleviate the demand of spectrum. The sensor which uses the dynamic spectrum access technique called as Cognitive radio. The current technology has wide challenges, such as maximum throughput, reduced power consumptions, delay and lesser interference. The sensor (CR) enhances these performance metrics through identification and communication with the external environment.

Recently many researches are carried out in CR and a different funding agency supports the research work in CR. The agencies are Defense Advanced Research Project Agency (DARPA), National Science Foundation (NSF), National Communications and Information Administration (NTIA) and Federal Communication Commission (FCC) have focused on various applications such as spectrum awareness, Dynamic spectrum access and Spectrum sensing techniques in Cognitive Radio. As wireless communication system uses static spectrum for communication, these fixed channels are used by the primary users which excludes unlicensed user to access those channels even when they are used.

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From this observation, cognitive radios (CR) use spectrum sensing techniques to detect the unused radio spectrum, also known as spectrum holes [2]. Once the CR detects the spectrum hole, secondary user (unlicensed) create a link to access the spectrum/channel unused by primary user (licensed) and it continues to use the hole until the licensed user arrives in the allocated channel [1][2].The unlicensed user has to release the link to prevent interference when the licensed user reappears.

In real-time system, there are two different error occurs during sensing the spectrum. The first type of sensing error is misdetection occurs, when the secondary user is unsuccessful to detect the licensed signal as well as when the sub channel's band is identified to be empty but it is used by the PU. The second type of sensing error is false alarm, which means that when CR recognizes the sub channel band is used but it is unoccupied. The primary function of CR is Spectrum sensing is to identify the presence of licensed user. The purpose of sensing technique is to mitigate the interference between primary and secondary user. Spectrum sensing techniques are categorized into Narrow band and wide band sensing. Fig.1 attributes the types of Spectrum sensing techniques. The Narrow band sensing technique is implemented when CR decides the presence and absence of primary user. The assumptions are taken depending on behavior of primary user as H_0 and H_1. The received signal is expressed in the form of equation using these two assumptions:

y(n) = w(n) ---(1):H_1 /absence of primary user y(n)= x(n)+w(n)--(2) :H_0 /presence of primary user

Where x(n) is the transmitted signal, y(n) represents received signal, w(n) denotes additive white Gaussian noise with zero mean and n indicates sensing duration.

Narrow band sensing techniques are classified as Energy detection, Cyclostationary feature detection, Matched Filter detection and Covariance based detection. Table I summarize the types of different spectrum sensing method and also define the advantages and limitations. Wide band sensing techniques are operates based on Nyquist theorem whereas compressive sensing technique achieves low sampling rate dissimilar to other sensing method. Nyquist based sensing is further divided into wavelet, multiband and filters bank. Blind and non-blind are two types of compressive sensing technique. Generally wideband spectrum sensing, is performed by dividing narrowband in order to increase the sensing time. The prototype and implementation of Narrowband method is simple and has less power consumption and complexity as compared to wideband spectrum sensing.

Another drawback is the frequency occupancy is unknown to the secondary user. Some of the researches are carried out by using narrow band sensing techniques are explained below. In Rajan *et al*.(2016), analyzed the false alarm and detection probability using energy detector and the results proves that QAM modulation technique is the best for the spectrum sensing. Another approach of sensing technique which can be used to detect the modulated signal is the cyclostationary feature and performs in low SNR. Hassaan Bin Ahmad *et al*,(2019) implemented machine learning in feature extraction method using the value of SNR=-15dB to -10dB for OFDM QAM and QPSK signal. The simulation results are compared without machine learning and energy detection technique. From Hassaan's proposed work [38], he has suggested for better sensing performance the combined cyclostationary detection and classifier can be designed.

Some of the authors [5-8] has explained about the matched filter technique for spectrum sensing & differentiated the received signal with pre-allocated and pilot samples captured from the same transmitter. This sensing technique is best suitable for fading channels and low SNR. An updated version of matched filter technique called correlation-based Euclidean distance has been devised to reduce noise. The next approach is the Covariance-Based Detection method [9] which is used to detect the licensed user .The method is based on sample matrix (covariance) of the accepted signal and singular value decomposition (SVD). Then, the ratio between the maximum and minimum eigenvalue are calculated and measured with a threshold to detect the primary user is available or occupied the channel. There are many factors which affects the secondary user in poor detection of spectrum such as different noises, hidden node problem, multi-path fading and shadowing etc.

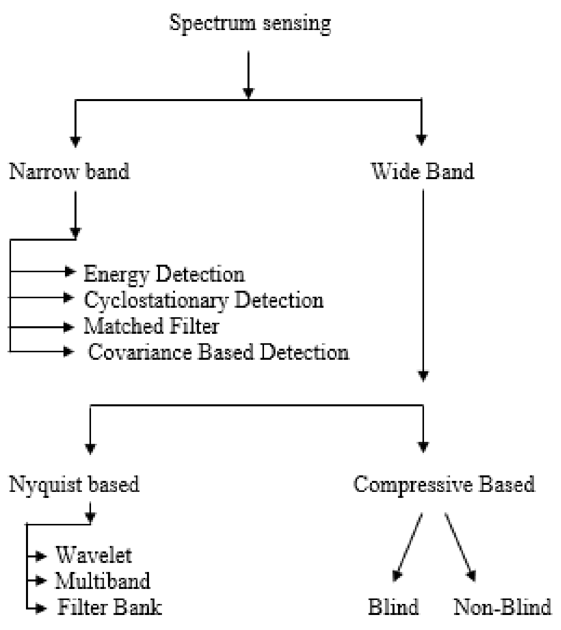

Fig. 1. Classification of different sensing techniques [26].

The organized paper has been focused on narrow band sensing techniques as follows: In Section II, we present the various algorithms used to implement Multi-objective Optimization and in Section III, we have highlighted some of the trade-offs while adapting Multi objective optimization method. Section IV, discussed the literature survey using optimization from the past five years and additional survey papers from different authors has been reviewed in Table II. Section V, deals with future scope. Finally, we conclude the paper in Section VI.

Table I: Narrow band sensing summary

Sensing techniques	Advantages	Disadvantages
1. Energy detection. [17],[18],[19]	-Design and implementation is simple. -Prior knowledge about Primary network not required.	-Noise immunity is less. -can't differentiate between noise and PU signal.
2. Cyclo-stationary feature detection.[22],[23]	-Fast sensing. -Good performance at SNR is low.	-prior knowledge of the primary network is required. -complexity is high.
3. Matched Filter detection.[20],[21]	-processing gain is high. -received SNR maximizes.	-depends on primary network. -synchronization is required.
4. Covariance based detection [24]	-can detect low SNR. -Noise immunity is good.	-Computational complexity is high.

II. MULTI-OBJECTIVE OPTIMIZATION ALGORITHMS (MOOP/MOP)

The optimization algorithms are available in various aspects than the multiple objective functions, but the proper selection of objective function is more important than selection of algorithm. The optimization problem can be handled as single or multiple which depends upon the type of objective. In Single objective optimization method, one objective can be maximized or minimized under the different constraints, where as in multi-objective optimization method multiple objectives are simultaneously optimized.

Based on the choice of multi-objective, the optimization problem can be deal using different techniques. Some of the multi-objective techniques are Min-Max, Pareto Ranking, Goals, Preference, Sub-population, Fuzzy Logic, Artificial neural network, Reinforcement learning and Game theory.

In traditional design, optimization objective is based on the selection of the performance metrics, while the other metrics are taken as the limitation of the optimization problem [10]. Pareto optimization is a mathematical optimization problem which involves more than one objective function to be optimized simultaneously.

Generally, the optimizations are multi-objective in nature. The problems can be implemented in four different ways based on the designer choice on the different objectives. To conduct optimization, a common method is used to combine all the different objectives to a single objective by using weighted sum.

Scalarization method in Multi-objective optimization problem (MOP) develops a optimal or sub-optimal solutions from the single objective optimization problem [12]. Different methods used for Scalarizing such as

- Linear weighted-sum method: -pre-multiplying each performance metric with a weight.
- ε-constraints method: -single objective function is optimized while the remaining as constraints.
- Goal programming-based method: -targets have been assigned to all objectives instead of maximizing.

Other methods such as Nature-Inspired Metaheuristic algorithms, Evolutionary algorithms, Genetic algorithms, Differential Evolution, Artificial Immune system, Imperialist competitive algorithm. The MO evolutionary and Swarm intelligence are optimization algorithms are often used in MOP. Ant colony optimization commonly used algorithm [13], which solves complex and non-linear problems.

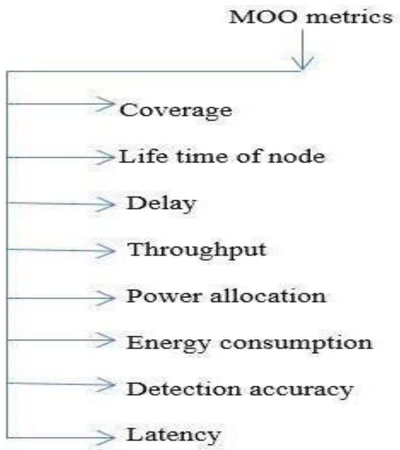

Fig. 2. Types of Multi-objective optimization performance metrics [10].

Multi objective genetic algorithms is a subset of Multi objective evolutionary algorithms, other MOP algorithms which are used to construct an approximate Pareto set are Strength Pareto Evolutionary Algorithms [14] and Nondominated Sorting Genetic Algorithm-II[15].The Researchers computed multi-objective optimization by simultaneously treating multiple objectives to a set of constraints. But this approach is not feasible to reach their respective optima. However, to achieve at single optimal solution is called Pareto optimal. None of the objective functions can be improved without lowering some of the other objective values. Riquelme *et al* [16] surveyed the selection of metrics plays important to develop new algorithms. MOO metrics are selected based on the objective while performing optimization as shown in the Fig. 2.

III. JOINT OPTIMIZATION METHODS

In this subsection, we have focused the survey of joint optimization as well as the MOP techniques. Several related works have been surveyed to increase the Energy efficiency of cognitive radio sensor network which are greatly affected by transmission duration, spectrum sensing duration and

also power allocation associate with them. Multi-objective optimization problem is a nonconvex optimization type, finding a solution is a difficult task. To overcome this difficulty, non- convex optimization problem is converted into convex optimization problem. Consequently, it is important to balance trades-offs effectively during the implementation of MOP techniques, some of them are discussed as follows:

(A) Lifetime Vs Coverage Trade-offs:

Coverage optimization explains the increase in proposition of the observed area comparable to the total area. To achieve longer lifetime of the network, the sensor should operates using as few hops and their energy is used for their own communication, but this result in poor coverage problem. Therefore, different algorithms are used to minimize or maximize the network's coverage area and network lifetime [27].

(B) Latency Vs Energy Trade-offs:

In every hops, reducing the consumption of energy needs transmitting the sensed data over the minimum distance [28]. In order achieve maximum distance between the sources and destination with minimum delay and less number of intermediate forwarders between the nodes is required [29].

This results in unbalance available energy. Therefore, a joint optimization is necessary for the Energy consumption and delay. The energy consumption and sensing time by the secondary user is selected according to the transmission power and capacity rate

(C) Throughput Vs Lifetime Trade-offs:

The performances of the network application rely on the collection of data from each sensor. Furthermore, higher data rate leads in increased sensing, Energy consumptions and also communication cost, as well as in reduced network lifetime [30].The choice of decision threshold is important to enhance the throughput.

IV. OPTIMIZATION STRATEGIES FROM EXISITING LITERATURE SURVEY

The objective of Abbas *et al* (2017) is to decrease the probability of the error with increasing the sensing time Ts. In fact increasing the SNR results in decreasing the error probability. The three values of SNR -6dB,-5dB and-4dB by taking assumptions of N=7 secondary users to plot error probability versus threshold decision using Monte Carlo integration method [35]. He has suggested that the maximum data transmission time and acceptable error probability can achieve by tuning the ratio between transmissions and sensing time. The simulation results are proved for the limited Energy (surplus /deficit) and Time duration in practical collaborative spectrum sensing of secondary users.

Hae Sol Lee *et al* (2018) proposed his work based on the behavior of Primary user traffic patterns in orthogonal frequency division multiple access, whereas secondary user accumulates the traffic pattern information using unsupervised method. In order to overcome the drawbacks in the previous work based on traffic pattern, the decision threshold was framed as high and low. If its greater than threshold the sub channels is identified as busy whereas low, then the sub channels is recognized as idle. As a result the channels suffers energy depletion, which increases the collision between PU and SU, also reduces the transmission efficiency [36].

To improve the energy harvesting and transmission capacity, Hae sol Lee has used Dirichlet process mixture Model (DPMM) to classify three traffic features. In his work he expressed that secondary user senses the sub channel using detection threshold to achieve optimal sensing policy. The result has been expressed in the form of graphs [36] which demonstrate the energy detection threshold versus rate capacity of SU. With the help of threshold optimization, author obtained maximum rate capacity with higher transmit power (P_t) of 0.24W and later P_t =0.26W.

Pratibha [37] employed Secondary user throughput maximization (STM), Energy cost minimization (ECM) and suboptimal policy by maintaining the collision below tolerable value. Her paper explains about the Mean idle duration ($1/\lambda_0$) and busy duration ($1/\lambda_1$) of Primary user with respect to Secondary user throughput (R_s).The author also explains if $1/\lambda_0$ or $1/\lambda_1$ increases or decreases it reflects the spectrum opportunities. The maximum throughput for the larger value of $1/\lambda_1$ =800 with lesser value of $1/\lambda_1$=300, provides more opportunity for the secondary user to energy harvest, while considering the power level of sensing is less than power level of transmission. Another important operation of Cognitive radio sensor network is Spectrum access. There are three different Spectrum accesses-Overlay, Underlay and Interweave. Out of three spectrum accesses, Interweave and Underlay most commonly used in CR network. In overlay process, secondary user access the licensed channel simultaneously with less interference to licensed user. In overlay process, secondary user access the licensed channel simultaneously with less interference to licensed user. The secondary user utilizes the channel of the primary user with in the restricted power in Underlay method, where as in Interweave the secondary user will make use of the channel when the licensed user is inactive. The optimization policy such as sensing duration and power allocation can also be performed in spectrum access, as they are categorized based on white space. Mehmeti *et al* (2018) derived expression in closed form and compared the metrics such as throughput and delay for Underlay and Interweave methods. He has designed the algorithms using these two methods and obtained the result using two dimensional Markov chain and Poisson process approach. Mehmeti achieved some improvement in maximization of throughput and minimization of the delay as compared to realistic simulation [39].The optimization scheme can also be used in Carrier sense multiple access with collision avoidance (CSMA-CA)[40].The author has performed joint optimization in CSMA-CA with an intention of maximize the throughput of the cognitive network, they have experimented the results with hard decision and soft decision rule. In their proposed work through the designed algorithm, they have proved optimal solution is better than sub-optimal solution for different values of SNR= 0dB to -15dB with different samples of N.

V. FUTURE DIRCTIONS

From the review paper based on optimization in narrow band sensing techniques, some of the future directions are presented in the following areas such as Non-orthogonal multiple access (NOMA) can be analyzed along with cognitive concept to achieve better results in spectrum efficiency. As power domain and spatial domain plays major role to reduce the interference in wireless transmission. The Optimization techniques can be designed using simultaneous wireless information and power transfer (SWIPT) with NOMA and also with MIMO and MISO techniques. MOP can also be solved using 3D network.Cooperative communication scheme using clustered model can be implemented along with game theoretical models, random matrix theory and distributed rule regulated which can reduce incurred overhead. Cross layer design can also be experimented with the optimization technique of physical layer and data link layer by proper selection of protocols which helps to reduce packet error rate and maximize throughput.

VI. CONCLUSION

We highlighted the different algorithms used in Optimization techniques and also literature review of joint optimization in narrow band sensing technique. The surveyed paper also provides the discussions of cognitive radio system especially in the Multi-objective optimization and their work .With increasing attention of minimizing harmful interference with high probability of detection and low probability of false alarm can be performed by proper selection of spectrum sensing techniques.

Table II Literature Survey on Joint Optimization

S.No	Authors	Concepts covered	Proposed work	Optimization techniques
1.	Kishong Lee *et.al* [30]	Anon-convex optimization problem has been formulated for increasing energy efficiency to evaluate optimal sensing duration and allocation of power.	Achieved ~56.66% of outage probability with total time frame of 10ms. Power saved of 0.06W with assumption of 12 relays.	Non-linear fractional programming. Iteration methods.

2.	Sang-Jo-Yoo*et. al* [31]	Maximum CRN system utility is achieved with collision free cooperative sensing. Frequency hopping based CRN	Implementation of Frequency hopping in spectrum sensing and no.of hopping channels used is 10.	Genetic algorithm
3.	Avik Banerjee *et.al*[32]	Optimal route selection Reduce the total power consumptions and to enhance the network lifetime.	To reduce the outage probability of SU while maintaining a target primary user cooperate rate.	Bellman-Ford
4.	Hang Hu *et.al* [33]	Optimization problem is classified into two sub problems for energy balance and energy insufficient region.	Joint optimization is performed for the maximization of throughput through sensing duration and power allocation of SU.	Iterative algorithm

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