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Artificial Neural Networks-Based Spectrum Sensing Algorithms for Cognitive Radio Based Disaster Response Networks CR-DRNs

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Abstract

The recent advancements of artificial intelligence techniques and its impact in the context of cognitive radio networks has become immeasurable. Artificial intelligence redefines and empowers the decision making and logical capability of computing machines, one of the most Significant functionalities of artificial intelligence include spectrum sensing and management which is a key function of Cognitive radio Cognitive Radio (CR) networks, these networks empower secondary users to work on licensed spectrum or primary user's spectrum without any interference , the implementation of CR for Disaster Response Networks (DRNs) imposes the necessity of sophisticated and advanced techniques that explore the available spectrum and utilizes it in such a way that guarantees maximum spectrum utilization without any interference with PUs licensed spectrum and provide communication solutions within the 48 or 72 hours following the occurrence of disastrous event, this is the primary concern of Artificial Neural Networks (ANNs) based algorithms that are capable of understanding the environment, learning and adjusting in real time operating parameter according to specific need of unlicensed user, in this study , we highlight the most recent and applicable algorithms of (ANNs) and show how they can be implemented in CR-DRNs to efficiently sense and utilize the spectrum in disaster area where available resources are limited and rapid deployment of a reliable communication system is must.

Key words : Artificial Neural Networks, Disaster response networks, Cognitive radio, smart computing.

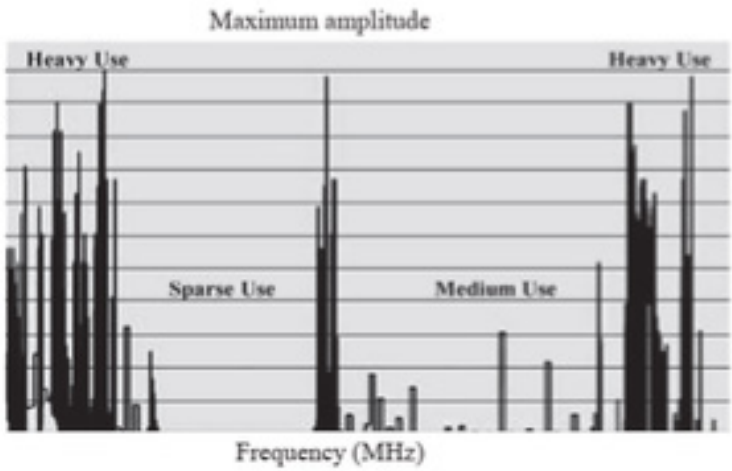
Algoritmos de detección de espectro basados en redes neuronales artificiales para redes cognitivas de respuesta a desastres basadas en radio CR-DRN

Resumen
Los recientes avances de las técnicas de inteligencia artificial y su impacto en el contexto de las redes de radio cognitivas se han vuelto inconmensurables. La inteligencia artificial redefine y potencia la toma de decisiones y la capacidad lógica de las máquinas informáticas, una de las funcionalidades más significativas de la inteligencia artificial incluye la detección y gestión del espectro, que es una función clave de las redes de radio cognitiva (CR), estas redes permiten a los usuarios secundarios trabajar en espectro con licencia o espectro de usuario primario sin ninguna interferencia, la implementación de CR para redes de respuesta ante desastres (DRN) impone la necesidad de técnicas sofisticadas y avanzadas que exploren el espectro disponible y lo utilicen de tal manera que garantice la máxima utilización del espectro sin ningún tipo de interferencia con el espectro con licencia de PU y proporcionar soluciones de comunicación dentro de las 48 o 72 horas posteriores a la ocurrencia de un evento desastroso, esta es la principal preocupación de los algoritmos basados en Redes Neuronales Artificiales (ANN) que son capaces de comprender el entorno, aprender y ajustarse en tiempo real pa operativo de acuerdo con la necesidad específica del usuario sin licencia, en este estudio, destacamos los algoritmos más recientes y aplicables de (ANN) y mostramos cómo se pueden implementar en CR-DRN para detectar y utilizar eficientemente el espectro en el área del desastre donde se encuentran los recursos disponibles. El despliegue limitado y rápido de un sistema de comunicación confiable es imprescindible.
Palabras clave: redes neuronales artificiales, redes de respuesta ante desastres, radio cognitiva, computación inteligente.

1. Introduction

The Federal Communications Commission (FCC) and other communication regulatory agencies and institutes in the world concluded that the large amount of frequency spectrum was still underutilized by existing communication systems and organizations, this conclusion has brought cognitive-radio research to the front specially the recurrent dynamic spectrum access research. Joseph Mitola introduced cognitive radio in 1999 [1]. It was an extremely important and innovative foundation towards wireless communication. The intelligent system behind this approach is known as cognitive radio. It is a self-adjustable and smart radio technique that adapts from environment by deeply observing & then learning process. Mainly this radio used for maximizing the utilization of radio frequency by allowing the unlicensed users (Cognitive users) to opportunistically utilize the white spaces while being not used by licensed or authorized user [2]. The main function of cognitive radio is Spectrum sensing, Spectrum sharing, Spectrum management and Spectrum mobility. Cognitive radio gives belief to upcoming wireless communication system [3]. In this system spectrum sensing is one of the significant features to realize spectrum reuse and improve the spectrum efficiency in cognitive radio networks (CRNs). the implementation of CRNs based on spectrum sensing ability. So the major challenge in cognitive radio is to locate the existence of primary users in an authorized spectrum [4]. The energy detection method is an available fast sensing method, its implementation is easy and its sensing accuracy totally dependent to selection of threshold level [5]. Many spectrums sensing algorithms like cyclo stationary based sensing, adaptive spectrum sensing [6], matched filter and cooperative sensing have been proposed which are described in [7] . Energy detection method was less complex but the limitation of this method was accuracy, the cyclo-stationary based method was then introduced and was more accurate but complexity is also increased, the same issue reoccurred with matched filter method, overall, this method is efficient method for spectrum sensing but again complexity level increased and energy consumption was high. A multidimensional correlation based sensing scheduling algorithm (CORN) was developed to minimize energy consumption [8]. In this method sensing quality is based on correctness of spectral availability information.

In addition to the above mentioned spectrum sensing techniques, blind detection and feature detection are the two classifications by which spectrum sensing can also be studied. Blind detection is most popular method because previous information like signal characteristics, available noise power and channel used, do not required by this method hence the performance of such algorithm is relatively not up to the mark [9], on the other hand, feature detection sense particular uniqueness of a known signal and it gives relatively improved performance than blind detection [10]. The hardware complexity is quite an issue in feature detection mechanism. Energy detector algorithm is one of the simplest sensing algorithms but its performance is not ideal in the presence of undecided noise power. A novel blind detection method called feed forward neural network based spectrum sensing overcame this problem and enhanced the throughput of the network without being affected by environmental noise power. It is implemented to avoid the major issue of spectrum scarcity. As an advantage the unauthorized user can utilize the spectrum when it is sure that it will not create any kind of interference to the licensed users. As this paper approaching for the detection of possible vacant frequency band the actual mechanism of frequency utilization band can be understood with the help of figure shown below [8] :

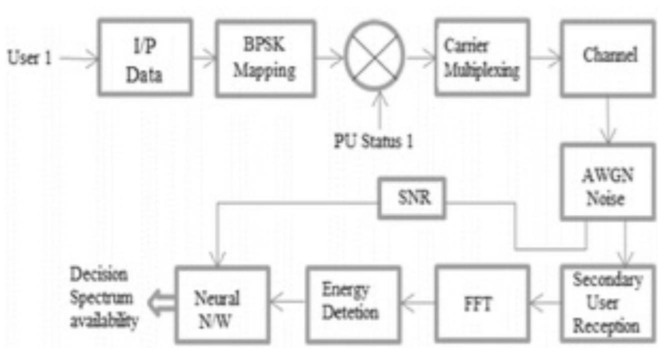


Figure(1): Signal strength distribution over the wireless spectrum.

2. Related work

Multi-path routing and shadowing effects have a direct impact on the spectrum sensing in the form of degradation of system performance, in general, communication systems give different results over different fading channels like AWGN, Rayleigh, Nakagami channels [11]. By using SVM, ANN, k means techniques, system performance can be improved but there are different challenges, advantages and limitations in different techniques [12]. To cope with these challenges some modern Machine Learning algorithms are developed in CR. There are different types and variants of Artificial Intelligence (AI) and machine learning algorithms that can be used in CR such as fuzzy logic system (FLS) for decision making , neural network model for prediction of spectrum holes . The state of-the-art of machine-learning techniques in cognitive radios is presented in [13]. The most common Cooperative Spectrum Sensing (CSS) algorithms for CRN based on ML techniques which are used for pattern classification are explained in [14].

The performance of neural networks based algorithms in cognitive radio was the primary concern of a number of studies and researches, in [15], the authors emphasis is to maximize the decision accuracy under different noisy condition and its implementation through the Neural Network system (NNS) that tremendously enhance the desirable throughput, the proposed system assumed that 20 users are concurrently communicating each other simultaneously , i.e., some users are active while others are not in the same time, the users are supposed to use Binary Phase Shift Keying (BPSK) modulation , then this data merge with well-known primary user's status and after carrier multiplexing it is transmitted into wireless channel where Additive white Gaussian noise (AWGN) noise added with that data and then it is received at the receiver end by secondary reception.



Figure(2): Flow mechanism of Neural Network based Spectrum sensing

Fast Fourier transform applied and received energy is detected. Received energy is compared with primary user's status and cross verifies. This process done with all N number of user and determine the energy of all users. Now obtained energy, SNR value and probability of false alarm is provided to the feed forward neural network. After training process neural network give the decision of spectrum availability. Above whole process described the working of the system[15], The authors have also analyzed the performance of neural network based spectrum sensing algorithm in cognitive radio network with better performance, their observations have concluded that in the presence of different noise level, the decision accura-

cy is improved as well as it could achieve higher efficiency.
A comparative analysis of energy detection and artificial neural network for spectrum sensing in cognitive radio was conducted in [16] where an implementation of spectrum sensing (SS) in Cognitive Radio Network (CRN) was presented, the authors have used supervised Machine Learning (ML) and conventional spectrum sensing method were used to check the availability of spectrum along with an Artificial Neural Network (ANN) classifier for the purpose of signal and noise classification, Energy Detection ED and ANN were used to implement the system considering AM, FM and BPSK signal and both were compared to Spectrum Sensing SS , the analysis has shown that ANN gives better performance as compared to ED method in terms of SNR, but The ED method is less complex as compared to ANN because it does not require training data, priory knowledge of signal and multilayer network.

3. Disaster response Networks DRNs

Disaster can be simply defined as the occurrence of an unfortunate event whose time is unpredicted or expected and whose consequences are seriously destructive, calamitous and disruptive for the functioning for the society or a community and hence causes a wide range of losses in humans, material, economic and environment that are beyond the ability of the community or society to cope with its consequences using their own available resources, hence; this event can be characterized by three main characteristics which are suddenness, unexpectedness, significant destruction and adverse consequences.
A quick and synchronized response must be given to the rescue and relief entities, the first responders and victims present in the post disaster scenario. Another important action is to save the lives as much as possible, meet the needs of the victims and minimize the losses due to the disaster. The collection and analysis of situational data of the disaster affected area are one of the most important necessities to minimize injury, loss of life and property damage, the obtained information is helpful to the main coordination center of the rescue and relief operation to coordinate and manage the resources [17].

4. Artificial intelligence for Spectrum Sensing in CR-DRNs

Artificial Intelligence (AI) refers to intellectual capability exhibited by computing systems through leaning, adapting and updating knowledge base. More essentially, a device that senses its environment and contextually performs actions based on the perceived information basically forms an artificial intelligence system. The main goals of AI include sensing, learning, training and performing tasks. In fact, an AI System is extended with enhancements in such a manner that allows it to perform tasks with human-like intelligence. Recently, the role of AI in Cognitive Radio Networks (CRNs) has become impeccable & inevitable in executing basic processes, involving sensing, learning, training, and performing overall functions dynamically and intelligently, similar to operations of a human brain.

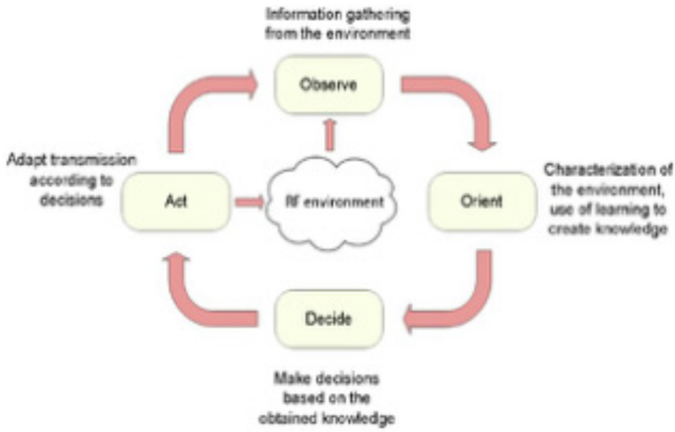
Cognitive Radio (CR) is a technology capable of learning and adapting the surrounding environment with help of sensed environmental parameters. The term cognition means gaining of knowledge by experiencing the externalities of the environment. CR exhibits a self-programming ability that allows learning intelligently and autonomously over the wireless domain. Main objective of CR device is to optimize the use of radio frequency spectrum by sensing free spectrum availability and minimize interference between the primary and secondary users, i.e. managing permanent reliable communication dynamically. CR has an ability to access spectrum and allot available spectrum to secondary user animatedly. In order to equip spectrum management with power of dynamism, CR must rely on artificial intelligence. The learning problems in CRN mostly include decision making and feature classification problems. Feature classification problem occur at the time of spectrum sensing while decision making problem is to determine the spectrum sensing rules along with policies. To overcome these challenges, different types of learning paradigms are available, such as supervised learning and unsupervised learning for classification problem and reinforcement learning for decision making problem. In addition, AI technique extends learning paradigms over Artificial Neural Network (ANN), K-means, Support Vector Machine (SVM), Hidden Markov, and Game Theory. The main factors that need to be focused when designing algorithms involve learning in partially perceivable environments, multi-agent learning and autonomous learning in unknown radio frequency environments. The cognitive technology aims to perform its task optimally with increased robustness in CR-based applications. Normally, in case when no prior information of the radio parameters (i.e. signal to noise ratio, bandwidth and bit error rate, vulnerable rate), AI-based techniques tend to behave more optimally over Very High Frequency (VHF) and Ultra High Frequency (UHF) FM and TV bands.

The artificial intelligence applications implement the capabilities of this technology in different forms, based on the type and architecture of this application , in the domain of cognitive radio network, these networks benefited from this technology via implementation of different AI based models and algorithms, in the coming section we highlight few of them for the purpose of outlining how beneficial this technology is in the field of communication systems specially cognitive radio based communication systems, their features included a wide range of operations , our concern in this paper is to outline those implementations that are related to spectrum sensing and management in these networks.

4.1 Artificial Neural Networks for Spectrum Sensing in Cognitive radio

In general human brain is composed of 100 billion nerve cells called neurons. Each of them attached to another thousand cells by Axons [10] . These sensory inputs produce electric urges and they can move quickly through neural network. Each neuron is responsible to produce a single output value by accumulating inputs from different neurons through a activation function. The number of input nodes depends upon parameters we considered for training and the output depends upon the classes we want to classify. The hidden nodes are random which are still in research. Each link connection is specified with particular weight. The weights are updated during training by Back propagation algorithm. Neural networks provide signal detection, modulation identification and classification in cognitive radio networks. The classifications of signal processing perform simple multi operations on the data module. A cognitive radio is a reconfiguration network where it accepts any type of modulation in the signal received and reconfigures itself accordingly. There are different types of network topology used in ANN called feed forward and feed backward [18].

The potentials for cognitive Radio operations in CR-based networks in harsh environments like DRNs are majorly spectrum sensing, Spectrum mobility and spectrum management. In Figure (3) CR operations are composed of five steps cognitive cycle , Observe, Orient, Plan, Decide and Act (OOPDA). In Observe phase it collects information about available spectrum bands from the surrounding environment by data collectors usually sensors, the orient phase establish priority for actions, then in decide it selects the best to act. This procedure is repeated as long as the network is operating and attempts of network nodes are being made to participate in the network .

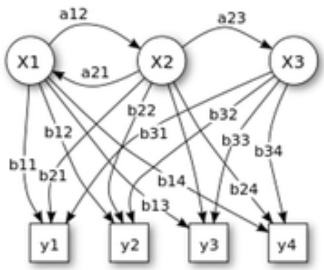


Figure(3): the cognition cycle

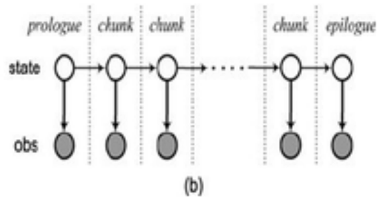
In order to learn and act Artificial Intelligence (AI) algorithms are used in literature. The type of learning and decision depends either as supervised learning or unsupervised learning. For classification with less false rate simple learning algorithms are used. Channel selection, power and topology control, adaptive modulation and coding are taking place in the "act" phase of the cognition cycle. In this paper, we focus on the 'orient' and 'plan' aspects of cognition. Mainly used for spectrum sensing, which depends on game theory, artificial intelligence, multi-objective reasoning, and deep learning systems without any supervision. Dynamic spectrum sensing can be implemented by many methods. Neural Networks (NNs) are imposed multiple combination of node points which is organic neurons in human brain. Each neurons are joined by multiple link connections and easily interact with each other [19].

4.2 Hidden Markov Model (HMM) for Spectrum Sensing in Cognitive radio

The concept of HMM arises from the well-known Markov chain, the states emit physically observable symbols. In Figure (4) only the input and output states are observable directly where the intermediate states are hidden, that is why the name is HMM. Hidden Markov models are significantly having more applications in intelligent communication systems and CR-based systems compared to observable Markov models. Already there are papers presented the HMM for speech recognition algorithms [20].



Figure(4): Basic Hidden Markov Model.



Figure(5): Hidden Markov Model for concatenated variables

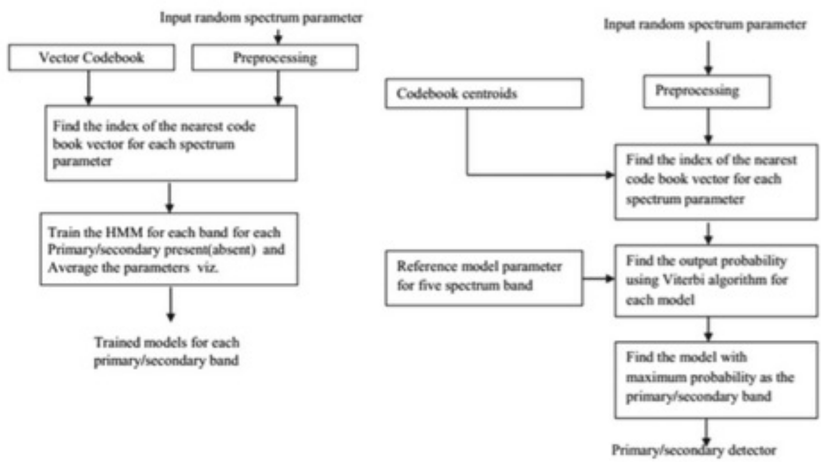
Figure(4): Basic Hidden Markov Model. Figure(5): Hidden Markov Model for concatenated variables

In cognitive radio networks, information is processed and the channel condition statistics are studied to yield whether channel is occupied by primary or secondary user. It can capable to improve classification modules according to the classification models to measure particular distance between different states in Figure (5) [21].

4.2.1 HMM-Based Cognitive Radio Spectrum Sensing

HMM is used to classify the state of the primary user by using the spectrum sensing techniques. However, most of these techniques make instantaneous decisions based on current measurements, and they do not consider the past status of the primary user. The prediction of primary user activity allows from all available data and choose a CR to better utilization of spectrum. The observation probability is considered for Power, BER, Bandwidth, and Modulation. The particular parameters for a channel statistics is mapped to a codebook index. Baum Welch algorithm is used for Training the opportunistic parameters for primary and secondary. Hence all the channel statistics are averaged finally to yield only two models for primary and secondary. The trained codebook indices are used testing phase. Viterbi algorithm is used to find the optimum path in the model to select the current channel condition from the past sequences of previous channel states as shown in Figure (6).

Each spectrum band corresponding, the A (Transition), B (Observation) and π (initial) model parameters are computed for primary and secondary users. The A, B and π matrices of all bands is averaged to get a generalized reference model λ , the input random spectrum parameters constituting the feature vector. Next, the nearest codebook index vector is found for feature vector. HMM models worked on the codebook indices to produce and the output probabilities. The output probabilities of each model are calculated by viterbi algorithm.



Figure(6):Block diagram of HMM training and recognition

Finally, Out of two output probabilities, the model which gives the maximum probability will be said as “primary” or “secondary”.

4.3 Fuzzy Logic (FL)

The term fuzzy refers to things which are not clear or are vague. In the real world many times we encounter a situation when we can’t determine whether the state is true or false, their fuzzy logic provides a very valuable flexibility for reasoning. In this way, we can consider the inaccuracies and uncertainties of any situation.

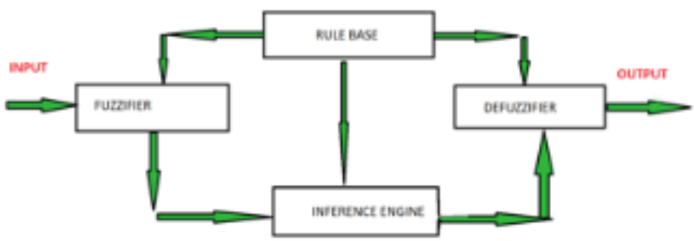
In Boolean system truth value, 1.0 represents absolute truth value and 0.0 represents absolute false value. But in the fuzzy system, there is no logic for absolute truth and absolute false value. But in fuzzy logic, there is intermediate value too present which is partially true and partially false, the architecture of a Fuzzy logic based system contains four parts [22]:

A. Rule Base: It contains the set of rules and the IF-THEN conditions provided by the experts to govern the decision making system, on the basis of linguistic information. Recent developments in fuzzy theory offer several effective methods for the design and tuning of fuzzy controllers. Most of these developments reduce the number of fuzzy rules.

B. Fuzzification: It is used to convert inputs i.e. crisp numbers into fuzzy sets. Crisp inputs are basically the exact inputs measured by sensors and passed into the control system for processing, such as temperature, pressure, rpm's, etc.

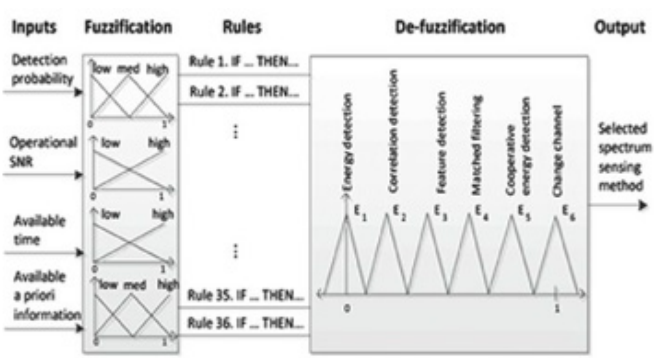
C. Inference Engine: It determines the matching degree of the current fuzzy input with respect to each rule and decides which rules are to be fired according to the input field. Next, the fired rules are combined to form the control actions.

D. Defuzzification: It is used to convert the fuzzy sets obtained by inference engine into a crisp value. There are several defuzzification methods available and the best suited one is used with a specific expert system to reduce the error.



Figure(7):Fuzzy Logic Architecture.

When used for CR-DRNs , fuzzy logic is used for spectrum sensing techniques, where compromise decision-making is required. Fuzzy operators NOT, AND, and OR enables to combine different conditions to make a decision. it takes input from different types of information to make a model which is simple and human understandable way.



Figure(8):spectrum decision of rule based selection system

The spectrum decision of rule based selection system given in figure(8) incorporate spectrum sensing selection methods, adaptive transformation, finding the performance and depends up on it the FL will be updated with new rules and inputs [18].

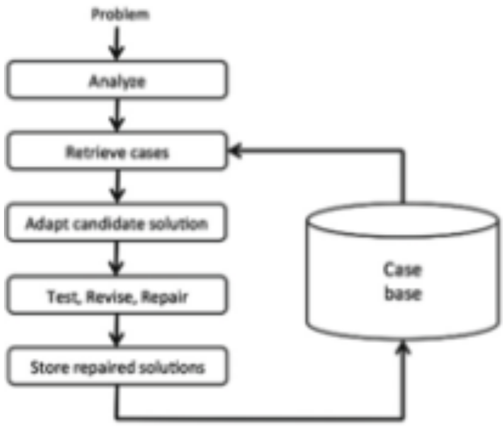
4.4 Evolutionary Algorithm (EA)

The genetic algorithm is a search algorithm based on the mechanics of natural selection and genetics. It combines a strategy of "survival of the fittest" with a random exchange of information, but structured [23], Cognitive Radio interacts with the environment at all times to detect free frequencies. To achieve this interaction, the cognitive user must detect changes in the environment and dynamically adapt to prevent interruption of the communication, or to improve the quality of the transmission. Consequently, the CR must perform several functions grouped in three steps.

The first is the spectrum sensing. CR control the spectral bands, detects the holes and the presence of licensed users that operate on bands. The second step is the spectrum management. After the detection of various spectrum frequencies, secondary users must be able to estimate the quality of the frequency band obtained, this quality is determined and classified with respect to several criteria [24]. After ranking all spectrum bands, we apply a set of intelligent rules that will allow deciding the appropriate band to the current transmission in terms of the secondary user requirements. The last step is the spectrum mobility, the secondary user must avoid the interference to the licensed users, therefore, it must be able to change his operating frequency and switch to another idle frequency.

4.5 Case-Based Reasoning (CBR)

The case-based reasoning is one of the commonly used AI technique based on past knowledge decision selection. The case-based reasoning chosen by the past cases and it is best applicable to the current problem [25]. The optimization adopts to practice the each and every problem with less time consumption. The basic case-based reasoning is shown in Figure (9). Since Cognitive radio works in the principle context reasoning. i.e., the environment awareness applications mostly depend on the past situations of climatical conditions sensed. If the condition is new it will be stored as a database for the future cases.



Figure(9): Basic case-based reasoning.

The case-based reasoning has a high potential to be used for the purpose of exploiting available frequency channels for a CR-DRN while aiming to protect incumbent communication devices which are mainly primary user (PU), from undesired harmful interference. For DRNs, there is an urgent need to identify available frequencies for opportunistic and dynamic access to channels on which the PU is active. The case-based reasoning introduces reliable and efficient platforms for determining the available channels on the basis of a case-based reasoning technique deployable as a core functionality on a cognitive radio engine to enable dynamic spectrum access (DSA) with high fidelity via characterization pf the channel usage pattern who's main function is to extract the best channel candidate for the DRN's cognitive radio node (DCRN) [18].

4.6 Deep Learning and Cognitive Computing

Deep Learning has set new records at different benchmarks and led to various commercial applications in different domains of industry and technology [26], Deep learning is the art of research in the recent days in the field of machine learning and pattern recognition. Deep learning is a reinforcement learning of ANN with more hidden layers and nodes, useful in the field of computer vision (CV) and Natural Language Processing (NLP). It is not a new technique in the field of AI, but it requires high-speed computing and large memory to store the meta-data. It is an unsupervised learning with large data sets. Classification accuracy is high for many classes. In cognition, learning is necessary for the classification and prediction. Classification performance mainly depends on learning algorithm's used. Deep Belief Network (DBN) model are applied to improve accuracy. Cognitive computing involves the collection of all AI techniques [27], It depends on cognitive thinking not on perception, In cognitive computing, selection of input factors is more important because a wrong input factor leads to more bias decisions in CR networks.

5. Conclusion

Artificial neural networks techniques and applications are highly growing and widely spreading in different fields of information and communication systems due to their capabilities of handling a number of issues and challenges in the era of cognitive radio like spectrum sensing and spectrum management, Selection of the proper AI and ANN based approach provides the best realization of cognitive engine design with spectrum sensing, monitoring, and management. In this paper we have summarized several AI including ANN based methods, In the cognitive radio environment, AI shows best attainment to solve the complexity problem regarding the spectrum sensing and management, the future works and challenges in this field include Improving the choice of AI techniques, learning and preserving the past capabilities and implementations for CR-Based environments specially for constrained networks like emergency networks in general and specifically disaster response networks.

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