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# A Comprehensive Review of various Data mining Algorithms for Cognitive Radio Networks

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*Abstract*— **As cognitive radio systems are gaining popularity in the present communication systems, lots of research is being carried out to make them more and more intelligent. Till now most of the research is focused on areas of lower layer abstraction (physical layer and transport layer) such as spectrum sensing or spectrum allocation and sharing. A very less research has been done on the learning and reasoning techniques which is the backbone of the Cognitive radio networks. Imparting Cognition or Intelligence in Cognitive Radio Systems is one of the prime areas to thrust upon and data mining has an important role to play in the context of cognitive radio systems. In this paper we suggested some of the important data mining techniques that would serve as the model for learning and reasoning and helps to develop efficient and robust cognition engines and learning base for Cognitive Radio networks. We have also given a comparative analysis of these techniques and how they can be useful for extracting interesting patterns for cognitive networks**

**Keywords—Cognitive Radio, Cognition Engine, Data Warehouse, Artificial Intelligence, Data Mining, Cognition Cycle, Cloud Computing**

## I. INTRODUCTION

**Cognitive Radio** network is an intelligent and self configuring network which is aware of its environment. It posses the capability to adjust its parameters dynamically according to its environmental characteristics [1]. All the spectrum policies and Spectrum decisions are taken by network itself without the interference of some external entities such as human beings. Formally we can say that a cognitive radio is a radio whose control processes permit the radio to leverage situational knowledge and intelligent processing to autonomously adapt towards some goal. The power of cognition or intelligence of the network depends upon the algorithms or techniques used to build robust and sound cognition engines.

Cognition engine is the tool that is used to impart learning and reasoning to the network [5] [2] so as to make it powerful enough to take network decisions independently without the intervention of human beings. Building such cognitive engines needs lots of observations of outside world which acts the basis of learning and reasoning. The data acquired through observation is very huge and we must refine it so that it can be easily transformed into useful knowledge. This transformed knowledge would be helpful in making spectrum policies based on past experiences and serve as the building block of the decision making process. Figure 1 shows a typical Cognition cycle through which a network can be made intelligent.

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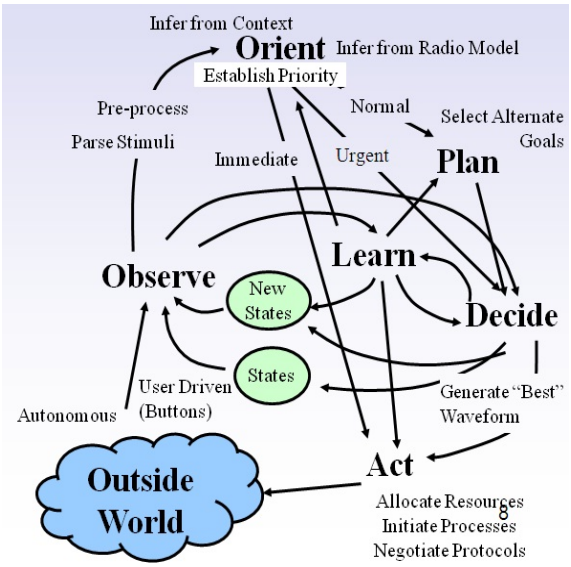


Figure1. A Typical Cognition Cycle

**Data mining** is the process of extracting the useful information from large amount data. Data is collected and stored in database or other information repositories for further analysis [22]. Data mining is not a single step process. It comprises data cleaning to remove noise, data integration to combine heterogeneous data, data selection in which only relevant data is retrieved for analysis then to apply intelligent methods in order to extract data patterns representing the knowledge and at the end present this useful knowledge to the user.

In the subsequent sections we present some of the important data mining and artificial intelligence algorithms that are quite useful in the process of making a radio network intelligent. In These sections we have also highlighted some of the key features of each algorithms and how and where it can be implemented in different situations.

## II. Data Mining Approaches to Cognitive Radio

### *A. Observation Sources*

The first step towards imparting cognition in radio networks is to observe the outside world to collect the raw data as shown in figure 1. Cognitive radio network operates in real time and dynamically changing environment. The data is coming in large volumes from different sources [12]. For example data is coming from operating environment in the form of GPS signals to determine the exact location or data may be coming from spectrum itself for sharing information with other cognitive networks on collaboration basis etc. This multiple heterogeneous data has to be stored in a sophisticated way so that it can be easily accessed in future. One solution to this problem is store the data in data warehouse; a single repository organized under unified schema at a single site. Although data warehouse supports multidimensional analysis and decision making [14], additional data analysis tool must be required for in depth analysis. In addition, huge volume of data cannot be accumulated in a single site. Another solution to this problem is to store the data in distributed data bases. A more advanced and powerful storage technique called *cloud storage* can also be employed, which enables the user to retrieve data on demand. This technology allows for much more efficient computing by centralizing data storage, processing and bandwidth.

### *B. Orientation Process*

Learning of Cognitive radio networks starts from orientation process. Before the orientation, pre processing of data is also required in order to remove noise and ambiguities. As real world data is not only huge in size but also highly susceptible to noise and inconsistencies due to their likely origin of multiple different heterogeneous sources. It becomes imperative to remove redundant data and correct inconsistencies. Orientation is done by parsing the observed data and infers constructive rules from pre-defined rules. These inferred rules are further used in the process of decision making. Several data mining algorithms are available for orientation process. The choice of algorithm is based on the area of application where cognitive radio is operating. Two types of users work in cognitive radio environment; primary users or licensed users and secondary users or unlicensed user [8]. They operate in the common network on sharing and cooperation basis. Sharing can be done through giving the priority to primary user. The prime issue in this regard is how cognitive radio allocates and share the band in different working environment [6] i.e. (i).when only primary users are accessing the network, (ii).When only secondary users are accessing the network (iii).When both primary and secondary users are accessing the network. Since primary users have the priority over secondary users to access the spectrum band, a robust algorithm must be there to classify them according to their characteristics on the network. Bayesian classifiers are the first choice to determine the class of each user in the network. These classifiers have minimum error rate as compared to other classifiers. But it fails to give the accurate results if the initial assumptions are not accurate and there is lack of available probability data. Artificial Neural Networks can be good choice to train the data for learning. During learning network learn by adjusting the weight so as to predict the correct class label of the user node. Advantage of neural networks is its high tolerance to noisy data and ability to classify patterns on which they have not been trained. As cognitive radios operate in real time environments so this slow convergence is acceptable. Case based reasoning algorithms are also suffered due to its incompatibility to the individual solutions. Case based reasoned may employ background knowledge and problem solving strategies in order to propose a feasible combined solution.

### C. Decision Process

The main purpose of the decision process in Cognitive radio systems is to map what radio believes about network state to an adaptation. Decision process primarily guided by the specific goal to be achieved but somehow restricted by the policy regulations [16]. For example if Spectrum band has been used by secondary users then each user has the equal right to access the unlicensed band. Here the decision is to remain in the band to execute operation. But when the network policy is to share the spectrum band with primary users then for every time quantum, secondary user must have to sense the presence of primary user and if it detects the primary user in the same band, it must have to vacate the current band and switch to some other empty band [9]. An intelligent radio network has to take these kinds of decision and sometime optimize his decision policies in order to use the underutilized network efficiently without compromising the quality of service.

### D. Learning Process

Logically learning process is just the extension of orientation process. It comes into play when given situation does not corresponds to any of the known situation. It informs and directs the network when the current situation has never seen before. In this situation radio network must have the capability to learn from the present rules and derive the new rules to tackle the situation. To do this it must have to increase the hypothesis space in order to refine the pre existing models. Bayesian belief network is one of the potential technique which has the capability to increase its hypothesis space from a predefine evidence described by measurements made on a set of attributes [21]. Bayesian Belief networks specify joint conditional probability distributions. They provide a graphical model of casual relationships, on which learning can be performed.

### E. Actions Plan

Action refers to the tasks performed by cognitive radio once it gets intelligence. A cognitive radio has number of actions to perform. Actions include allocation of resources [10] to its various users, initiate new user process, and negotiate with other networks. Actions performed by radio network determine its cognition capability of how it can cope with the dynamically changing environment [10], how it can regulate the mobility of various users entering in its environment. Some other miscellaneous actions are also performed by it like acting on the possible of security attack that might arise during the operation, restrict the number of user nodes entering in the network, prevents the deadlocks which are occurring when the resources are being allocated, restrict the spam packets arising at the various nodes etc. In the context of data mining these actions are the outcome of the various intelligence techniques used at every stage of cognition cycle and must be represented in the form of some data mining language such as Data Ontology Language so that it can be further used to make new decision rules, new actions, new channel models, new goals and new algorithms.

Optimization of cognition engine using simulation annealing is the best solution to the problem of optimizing decision processes. Simulation annealing is a metaheuristic optimization algorithm. It is used where the ultimate goal is to provide good acceptable solution rather than best possible solution. Genetic algorithms are also feasible for effective decision making. Genetic algorithms are very useful in solving single objective problems as in the case of cognitive radio networks but they are very difficult to optimize due to its slow convergence [6]. Genetic algorithms are based on the notion of survival of the fittest. Based on this notion a new decision rules are formed from the fittest or feasible current and past rules. The process of generating the new rules based on prior rules continues until each new rule satisfies the pre specified fitness threshold.

## III. Conclusion

From the above discussion we can conclude that the cognition power of a Cognitive radio network can be best described by the algorithms used for imparting intelligence. In general we can say that different algorithms will perform better in different situations. Many applications can be implementable using simple algorithms whereas some applications required more advanced techniques. All the learning and reasoning algorithms discussed in this paper has a significant role to play in the development of cognition engine for making radio network intelligent. A cognition engine can be viewed as software architecture. It provides structure for incorporating and interfacing different algorithms. There must exist some mechanisms for sharing information across various algorithms incorporated at each cognition stage. Further greater flexibility can also be achieved with a cognitive engine approach. Strong cognitive radios have potential to achieve both much better and much worse behavior in a network, but difficult to realize. In essence we can say that performance and reliability of cognitive radio networks can be achieved if we apply potential data mining and artificial intelligent techniques which in turn serve as the groundwork for the future of the intelligent networks.

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