# Towards Self-Configuration Techniques for Cognitive Radio Networks

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**Summary**
Cognitive Radio Networks (CRN) are networks that can sense their operating environment and adapt their implementation to achieve the best performance. Therefore, a cognitive radio must dynamically configure and reconfigure itself under changing environments. Self-configuration is the ability to adjust operation parameters and transmissions on the fly without modification on the hardware components. This paper reports on the mechanisms that can help radio networks to be self-configured. These mechanisms are channels aware schedulers, location aware schedulers, autonomous mechanisms and self-adjusting frequency reuse mechanisms. Furthermore, we introduce coverage optimization, capacity optimization, routing strategies, Mac Protocol design, energy efficiency design and synchronization schemes to enable the radio to adjust easily, use and provide information in a dynamically changing environment.

***Key words:***
*Self-Configuration, Cognitive Radio, Software Defined Radios, Schedulers, Nodes.*

## 1. Introduction

Today's wireless networks policies are regulated by government agencies. These agencies are responsible for granting the right of owning the license to operate on a particular frequency spectrum band for long service term in large geographical regions. However, increasing demand by spectrum users, and the increase in new wireless communication applications have resulted in overcrowding of the allocated spectrum bands, thus creating an ever increasing demand for more radio spectrum [1].
On the other hand, while some certain portions of the licensed spectrum have concentrated usage, a significant amount of licensed spectrum bands are underutilized, resulting in scarcity of spectrum, spectrum wastage and poor service delivery [2].
Cognitive radios (CR) are radios that can dynamically sense and react to its operating environment. Cognitive Radio Technology (CRT) provides a solution to the spectrum inefficiency problem by making it possible for unlicensed users to make use of idle licensed frequency. This new communication paradigm known as dynamic spectrum access (DSA), was invented because of the limited available spectrum and the inefficient way the spectrum is being used. CRs can opportunistically make use of temporarily free licensed bands when the licensed users are not using them [1,3].
CR transceivers have the capability of completely changing their transmitter parameter based on changes in the environment in which it operates. Their transmitters are capable of sensing a wide spectrum range dynamically, identifying current unused spectrum blocks and intelligently access the unoccupied spectrum [3]. Dynamic spectrum access is the technology that allows the radios to operate on the best available channels.

CRNs are created by a network of spectrum-agile devices with cognitive capabilities, as viable architectural solutions to address the inefficiency in spectrum usage and the limited spectrum availability [4]. Cognitive radio networks (CRNs) have two types of users sharing the same spectrum portion with different rules: (i) primary user or licensed user have priority in utilizing the spectrum and (ii) secondary user accesses the spectrum in an opportunistic and non-intrusive manner.
In order to use the spectrum efficiently, cognitive radios should be able to utilize the free frequency without interfering with the primary or licensed user. Therefore, cognitive radios should be able to (1) determine which portions of the spectrum is available and detect the presence of a licensed user (spectrum sensing), (2) select the best available spectrum channel (spectrum management), (3) coordinate access to this channel (spectrum sharing) and (4) vacate the channel when a licensed user is detected (spectrum mobility).
To achieve the above mentioned functionalities, cognitive radios should be able to configure and reconfigure themselves dynamically, as cognitive radio data and communication networks become more complex and distributed in nature.

A key technology enabler for cognitive wireless networks is the Software Defined Radios (SDR) along with software defined antennas. A software defined radio is a radio

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communication system where components that have been typically implemented in hardware are instead implemented by means of software. It is a radio whose channel modulation waveforms are defined in software and software defined wireless communication protocols. A software-defined radio is capable of being re-programmed or reconfigured to operate with different waveforms and protocols through dynamic loading of new waveforms and protocols. It is flexible enough to avoid the limited spectrum assumptions of other devices and uses cognitive radio techniques in which each radio is able to: (a) measure the spectrum use, (b) communicate information to other radios, (c) avoid frequency currently in use or unusable, (d) shift transmission to empty frequencies and (e) have dynamic transmitter power adjustment [2]. A cognitive radio network may therefore consist of a set of software defined radio devices that collaboratively, incorporate multiple sources of information to dynamically adapt their transmission waveforms, channel access methods and transmission protocols as needed for good systems and application performance. Therefore, in order to achieve the above mentioned functionalities, this paper suggested and pointed out mechanisms which cognitive radios and cognitive radio networks need so as to be self-configured.

## 2. Dynamic Self-Configuration Mechanisms

Self-configuration makes radios to adapt to dynamically changing environments. A cognitive radio must dynamically configure and reconfigure itself automatically under changing conditions. This chapter introduces ways and methods that will help radios to achieve self - configuration properties. Such methods are: Installing channel aware schedulers, location aware schedulers, autonomous and self-adjusting frequency re-use mechanisms, coverage and capacity optimization, routing and situation awareness, MAC protocol design, energy efficient design and time synchronization.

### 2.1 Channel Aware Schedulers

In a CRN, the set of available channels could change overtime and from one region to another. It is therefore necessary to use dynamic channel assignment schemes for communication among the cognitive radio nodes. Radios are equipped with channel aware schedulers, and this is achieved by equipping radio nodes with GPS to enable physical location awareness and time synchronization among nodes. Communication among the radios is done using a common channel because the network topology in a cognitive radio network changes dynamically. Wireless communication among nodes in a cognitive radio network can be facilitated by: (i) a channel common to all the nodes to exchange control information, (ii) a set of channels at each node that it can use to exchange data with its neighbors, (iii) the ability to determine and use an alternate common control channel if the original channel is jammed, and (iv) a mechanism to determine efficient routes based on the channels available on each link in the network. Each node in the network is assumed to be aware of the common control channel (CCC) and the set of channels available to itself for data communication (D). The set of channels that the node then uses for exchanging data with its neighbours can either be a set common to all nodes in the network or a set that is common to its k-hop neighbours (Hk). If the common control channel becomes unavailable, one of the channels from D can be selected as the new control channel. This method ensures good utilization of available channels because using locally common channels enables parallel communication among nodes with close proximity if they employ different frequencies to avoid interference. In addition, by exchanging GPS positional data among nodes, each node can be made aware of the physical location of the other nodes in the network. This information is particularly useful in hostile and chaotic environments, where correct identification is of paramount importance.

Let N be the total number of possible nodes and M be the total number of possible channels (in addition to a control channel) that the nodes can operate on. A MAC layer configuration protocol enables the nodes to dynamically discover the global network topology in a distributed manner, is introduced, provided all nodes are aware of N and M. Let us assume that N is fixed and known to all nodes in the network. The identities of nodes are unique and are preassigned from the range [1,…,N]. The nodes are GPS equipped and also equipped with one configurable IEEE 802.11a wireless card in addition to a transceiver capable of operating over the frequencies available for a cognitive radio network. The IEEE 802.11a cards provide the nodes with a common control channel that the nodes are aware of as soon as they are turned on. The cards are configured in the sense that they will use a contention-free slotted scheme for communication instead of the usual contention-based scheme employed by such cards. The nodes repeat the MAC-layer configuration protocol every T time units and the time instant at which each execution of the protocol is invoked is assumed to be known to all the nodes in the network. Such an assumption is feasible because of GPS capability in the nodes. The nodes use IEEE 802.11a cards for exchange of control messages and it ensures that every node is tuned to the same control channel during MAC-layer configuration operation. The nodes invoke the MAC-layer configuration every T time units to maintain accuracy despite (a) changes in the network topology, (b) changes in the channel availability set maintained by individual nodes and (c) node movements.

### 2.2 Location Aware Schedulers

Each node should know its location and couple its location information in the data that it sends. Two basic mechanisms for location discovery are described below:
(i) Indoor Localization: Indoor localization techniques use a fixed infrastructure to estimate the location of sensor nodes. Fixed beacon nodes are placed strategically in the field of observation. The randomly distributed sensors receive beacon signals from the beacon nodes and measure the signal strength, angle of arrival and time difference between the arrivals of different beacon signals. Using the measurements from multiple beacons, the nodes estimate the location.
(ii) Sensor Network Localization: In situation where there is no fixed infrastructure available and prior measurements are not possible, some of the sensor nodes themselves acts as beacons. They have their location information, using GPS, and these send periodic beacons to other nodes. The time difference between beacon arrivals from different nodes is used to estimate location, which offers greater accuracy in estimation.

### 2.3 Autonomous and Self Adjusting Frequency Re-Use Mechanisms

Cognitive radio networks need to be installed with autonomous mechanisms so that they can be able to manage themselves, cope with complexities and in turn ensure maintainability, usability, functionality, portability, efficiency and reliability. An autonomic system or network has four objectives- to be self-configuring, self-healing, self-optimizing and self-protecting. These represent broad system requirements and to achieve these requirements, the system must be aware of its internal state (self-awareness) and current external operating conditions (self-situation)detect changing circumstances (self-monitoring) and accordingly adapt (self-adjustment). These four attributes constitute implementation mechanisms and the system must therefore have knowledge of its available resources as well as its components, their desired performance characteristics, their current status, and the status of interconnections with other systems, along with rules and policies of how these may be adjusted.

The radios also need to be equipped with frequency re-use mechanisms. Frequency re-use is the usage of the same frequency by different users separated by distance without interfering with each other. Frequency re-use depends on the fact that the signal strength of a frequency gets attenuated with distance. The radio nodes which use the spectrum are grouped into clusters with the cluster size N being the number of nodes in each cluster. No two nodes within a cluster use channels of the same frequency. Clustering ensures that the nodes which use the same frequency are separated by a minimum distance, called the re-use distance D. applying the frequency re-use concept increases the number of radios that can be supported in a given network area.

### 2.4 Coverage Optimization

A radio node should be able to monitor and report events or phenomena taking place in a particular area. Coverage is one of the parameters which define how well a node in a network observes a given area and is a measure of how well the network can observe or cover an event. It depends upon the range and sensitivity of the sensing nodes, the location and density of the sensing nodes in the given region. Coverage optimization mechanisms need to be introduced in radio networks to aid in solving the worst case coverage problem, which defines areas of breach, that is, where coverage is the poorest. This can be used to determine if additional sensors need to be deployed to improve the network.

### 2.5 Capacity Optimization

Methods have been devised to enhance the capacity of cognitive radio networks. Reduction of cognitive radio network capacity can be caused by off-center placement of antennas in the nodes, limited frequency re-use imposed by a strict clustering scheme and inhomogeneous propagation conditions. Also, the nearest control channel is not always the best for a mobile radio, due to shadowing, reflections and other propagation-based features. Therefore, the model of cognitive radio networks has to be modified to account for these variations. A method that can be used to improve the capacity of cognitive radio networks is:
**Sectorization**: This concept can use Space Division Multiple Access (SDMA) to let more channels be re-used within a shorter distance. Antennas are modified from omnidirectional to sectorized, so that their signals are beamed only in a particular sector, instead of being transmitted symmetrically all around. This greatly reduces the downlink interference, and the antennas can be down tilted to reduce co-channel interference even more.

### 2.6 Routing Strategies

Based on the topology information collected, each node can compute the best routes to all the nodes in the network. In addition to using the number of hops as metric for route selection, nodes can use other metrics such as number of channel switches along a route and frequency of channel switches over a link. A routing strategy that can be used is:

**Routing based on frequency of channel switches over links**: to account for the possibility of a link becoming unusable, every node maintains a weighted average of the duration for which each channel is available along each outgoing link. Based on the weighted averages maintained, a node can compute the probability of a channel being available on a link. Every time a node has a packet to transmit, it selects the channel with the highest probability.

## 2.7 Situation Awareness

This is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. Situation Awareness is important for effective decision making and performance in cognitive radio networks. Besides exchanging network topology information during the MAC-layer configuration protocol, nodes also propagate GPS positional data. Thus every node in the network is aware of the physical location of other nodes in the network and can be said to possess a limited amount of Situation Awareness which is useful in chaotic environments.

## 2.8 MAC Protocol Design (Network and Radio Models)

Under heavy network traffic, severe MAC contention and network congestion can occur, which decreases the end-to-end throughput and increases the end-to-end delay. These issues can be addressed using transport layer protocols such as Transmission Control Protocol (TCP) using end-to-end flow control. Considering a cognitive radio network consisting of N cognitive radio nodes and K is the total number of frequency channels available for cognitive radio operations, then the cognitive radio nodes have the following features that are relevant to the MAC design:

**(a) Multiple-receive, Multiple-transmit**: Each cognitive radio is equipped with multiple radios and is capable of multiple transmission and receptions at the same time with one of the receive chain always tuned to the control channel.

**(b) Interference Sensing**: When not transmitting, a cognitive radio can measure the interference level of all K channels using an energy detector. This form of sensing has negligible switching and sensing overhead. It is also relatively cheap to implement several detectors at a node, allowing it to measure the interference level for several channels simultaneously. In practice, the maximum number of channels that are available for cognitive radio operation is in the tens; with such a number and using an array of energy-based sensors, it is possible to scan all K channels in no more than 0.1ms. Relative to transmission time of a packet, this sensing time is negligible.

**(c) Rate/Signal-to-Noise Ratio (SNR) Relationship**: The radios use forward error correction (FEC) together with spreading to reduce the impact of interference. The combined effect of FEC, spreading, and modulation is reflected in the relationship between the transmission rate and SNR.

## 2.9 Energy-Efficient Design

Energy optimization in radio networks must prolong the life of a single node as well as of the entire network. The choice of a processor for a node should be application specific, such that performance requirements are met with the least power consumption. Computation can be carried out in a power-aware manner using Dynamic Power Management (DPM), which shuts down several components of the sensor node when no events take place. The processor has a time-varying computational load, hence the voltage supplied to it can be scaled to meet only the instantaneous processing requirement. This is called Dynamic Voltage Scaling (DVS). The software used for the networks, such as the operating system, application software and the network software can also be made energy-aware. The real time task scheduler should actively support DVS by predicting the computation and communication loads. Sensors will perform the most significant applications first, so that premature termination of computation due to energy constraints does not affect the result by a large margin.

## 2.10 Synchronization

Synchronization is useful for determining the temporal ordering of messages sent from radio nodes and the proximity of the nodes. It is also the way by which nodes can determine their relative positions and evolve a common timescale using their synchronized clocks. Node sensors must be able to recognize duplicate reports of the same event by different nodes and discard them, which means that nodes must be able to precisely determine the instant of time at which the event occurred.

A low-power synchronization scheme or protocol can be used by the radio nodes in the networks. In this scheme, the clocks of the nodes are normally unsynchronized. When an event is observed, a synchronization pulse is broadcast by a beacon node, to which all nodes normalize their time-stamps for the observation of the event. This scheme offers short-lived synchronization, creating only an “instant” of synchronization among nodes which are within transmission range of the beacon node.

A global synchronization protocol based on exchange of control signals between neighboring nodes can also be used. A node becomes the leader when elected by majority nodes in the network. A distributed election protocol is used which ensures the presence of a unique leader for the network. The leader then periodically sends synchronization messages to its neighbors. These messages are broadcast in turn to all the nodes in the network. The time-difference bound is theoretically analyzed and fault-tolerant techniques added to account for errors in the synchronization messages.

## 3. Conclusion

The power of cognitive radio is drawn from its ability to reconfigure itself in response to a change in the radio frequency environment or a change in the requirements of the application running on the cognitive radio network. Self-configuring networks are radio networks that can reconfigure their operation based on application requirements, policy updates and environmental conditions. This paper introduced and pointed out methods and ways to achieve self-configuration in cognitive radio networks. These methods range from installing channel-aware and location-aware schedulers whereby dynamic channel assignment schemes are used by the radios for communication, and how a node should couple its location information in the data that it sends. Autonomous and self-adjusting mechanism was also recommended so that radios and networks can manage themselves to ensure to ensure that they achieve the quality factors associated with the characteristics of autonomous systems. Routing is done using other route metrics such as frequency of channel switches over a link in the network. MAC protocol design, energy-efficient design and time synchronization mechanisms were analyzed and recommended, to help in self-configuration in cognitive radio networks and ensure proper utilization of the spectrum.

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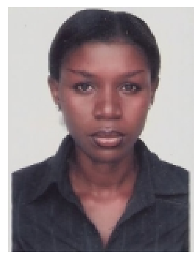

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