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Spectrum Allocation in Cognitive Radio Networks Using Genetic Algorithm

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Abstract: ***In this model, we present a method in which the Dynamic Spectrum gets optimized for its usage in Cognitive Radio Networks. Firstly, based on the Interference Temperature model, we determine the interference constraints and there is a check on the transmission power of the secondary users. We then formulate the SINR by considering the noise spectral density of the Environment and the Transmission Power's of the surrounding neighbors. Using the Shannon formula, we calculate the co-channel interference between potential links on each channel. Next, using Genetic Algorithm, we formulate the spectrum assignment problem. Genetic Algorithms are adaptive heuristic search algorithm based on previous and historic results obtained earlier. Although random, Genetic Algorithms exploit historical information to direct the search into a set of better solutions. It is observed that, the total network capacity is improved by a significant margin Bio inspired Algorithms have always been promising in giving Optimum solutions.***

Keywords: Cognitive Radio Networks, Secondary User, Primary User, Spectrum Allocation, Interference Temperature

1. Introduction

A considerable amount of algorithms have been introduced in the domain of spectrum access in Cognitive Radio networks. These methods have risen by the arrival of CR Technology and change from the usual fixed spectrum assignment to the newer spectrum access techniques. These models aim at improving the spectrum efficiency by regarding opportunistic and dynamic spectrum access for the Secondary Users. Considering Cognition and Re-Configurability as two of the main features and capabilities of the CR node, it comprises mostly two types of phases. The first Phase revolves around by having the spectral environment sensed.

The CR user captures the information of the spectrum bands and based on quality level, classify the channels available. The second phase comprises an algorithm of spectrum allocation which apart form satisfying the interference constraints, allows available channels to SU's in such a way that the spectrum efficiency is maximized. Most works, disregard the QoS parameters of such as SINR and capacity and simply try to maximize the number of active links between SU's using the method of Binary Integer Linear Programming (BILP). They rely on unrealistic thought that all channels have homogeneous nature with regard to their QoS parameters. It was noted that using a smaller number of simultaneous communication links around the SU's but applying a higher rate on each would lead to a higher total capacity. The heterogeneity of links have been considered in a 3 step manner by computing the maximum allowable power received from receiving nodes and the actual transmission power at transmitting nodes, spectrum between SU's is classified to high and low power transmissions. Basically, the channels have been classified into two categories according to their transmission power and haven't captured the exact link capacity. Models based on Interference range have also been used but are not accurate enough though. These models usually define an interference range in the surroundings of the receiver where no transmission is allowed. The conservative nature of these models might degrade the spectrum utilization methods. New Link capacity aware algorithms are used to maximize the capacity to such an extent that it includes different QOS parameters like their SINR and bandwidth to consideration along with temperature interference models.

Using the interference graph, the modeling of all co channel interference among the links on various channels takes place. Following that the allocation is formulated in the form of BILP to get a usable set of active links among other links in the graph in such a way that maximum capacity is attained. To tackle the high complexity of these fields, we use Radix Tree structure in which we have scattered parts of the solution space removed. Following that the problem is formulated onto a radix tree search the non-interfering links in the graph.

Over the past two decades, there has been a rapid increase in the use of wireless applications, which in return leads to the need of more Bandwidth. Unfortunately, that situation has lead to a scarcity in the Spectrum, which arises due to the inefficient use of EM spectrum. EM Spectrum is the electromagnetic radio emitted from different sources, which accompany its own frequency and wavelengths. The FCC (Federal Communications Commission) controls the EM Spectrum and only licensed users can use the EM Spectrum. The use of these spectrums varies from locality to locality. The misuse often leads to the efficiency decreasing throughout the spectrum amongst the wireless networks. Hence cognitive radio has been introduced to take care of these spectrum allocation problems. It is a kind of smart radio, which can adapt and change its behavior according to the environment. There can also be a borrowing of unused spectrum from the primary user to a secondary user. Although, this kind of an arrangement must make sure that the primary user's communication is not interrupted. Quite a few issues can arise while the spectrum is handed over from one user to another. The device must be intelligent to sense any holes in the Radio environment. It must be able to understand the requirements of application. Studies have proven that the QOS constraints aid in giving efficient wireless communication. The proper sharing under the basis of

agreement of the unlicensed spectrum with the licensing authorities should be met with, to use spectrum without harming the licensed users. It should also be self aware of it's own operational capabilities.

1.1 Objective

In this model, we present a method in which the Dynamic Spectrum gets optimized for its usage in Cognitive Radio Networks. Firstly, based on the Interference Temperature model, we determine the interference constraints and there is a check on the transmission power of the secondary users. We then formulate the SINR by considering the noise spectral density of the Environment and the Transmission Power's of the surrounding neighbors. Using the Shannon formula, we calculate the co-channel interference between potential links on each channel. Next, using Genetic Algorithm, we formulate the spectrum assignment problem. Genetic Algorithms are adaptive heuristic search algorithm based on previous and historic results obtained earlier. Although random, Genetic Algorithms exploit historical information to direct the search into a set of better solutions. It is observed that, the total network capacity is improved by a significant margin Bio inspired Algorithms have always been promising in giving Optimum solutions.

1.2 Motivation

Primitive spectrum access was confined only to primary users where only the licensed users were authorized to use the spectrum. In this spectrum access technique, the spectrum wasn't utilized completely, hence resulted in white spaces and spectrum holes. In order to utilize the spectrum to the fullest, we explored into the domain of dynamic spectrum access techniques. The concept of secondary user comes in in the former technique, where the secondary users to communicate with each other use the white spaces. All these circumstances motivated research scholars and scientists to obtain a solution in order to maximize the spectrum access. Thus, unlicensed users can access the spectrum completely, when the primary users are not using it. This should be done in a way not to counter the functioning of the primary users by imposing interference on them. The dynamic spectrum access is implemented by incorporating cognitive radio in the network setup. A cognitive radio has functions and characteristics as discussed earlier enables it to adapt itself to the drastic changes in the spectrum environment. The spectral efficiency of Wireless networks is improved by dynamic spectrum access. The unlicensed spectrum needs to utilize appropriately in order to meet the Quality of Service requirements of different applications. A cognitive radio is an independent and self-sustaining system, which eases the work of spectrum allocation process.

1.3 Background

1.3.1 Architecture:

A Cognitive Radio Networks comprises of primary and secondary users. Each primary user is associated with at least one primary base station, which together forms a primary network. Primary users are the authorized personnel to utilize the spectrum, hence are called licensed users. Base station is the only source by which, primary users exchange information amongst each other. On another note, Each secondary user need not be associated with a base station, but all of these secondary users as a whole form the secondary network. Each secondary user can access the spectrum through its secondary base station but is limited to the range of their respective base station. Since the secondary users shouldn't intervene with the functioning of the primary users, they are incorporated with Cognition abilities. In other words, Secondary users should inhibit the usage of the Spectrum as soon as it senses a primary user within its proximity.

1.3.2 Characteristics:

1. **Radio Environment Sensing:** Cognitive Radio Networks adapts itself to the rapidly changing spectral environments. It informs the other members of the network about its changed mode of operation. Hence, it is best suitable for environments that drastically change with time.

In order to share information in a CRN to another node in the environment, it needs a coded language. Radio Spectrum is a scarce resource, hence should be distributed evenly in a uniform order. Therefore, many algorithms have been developed to optimize the spectrum and allocate it appropriately.

2. **Functions**:

Spectrum holes are highly required to be sensed in order to prevent interference. The technique incorporated by the Primary user is the most efficient in terms of spectrum sensing. These techniques are divided into interference based detection, transmitter detection and co-operative detection.

To ensure the user's communication requirements, it is highly necessary to capture the best available spectrum. A collective decision must be met with to determine the best band spectrum that would meet or fulfill the QoS in the range of all bands. This intricate procedure is known as Spectrum detection and Spectrum analysis and fall under the domain of Spectrum Sensing.

To avail the best frequency bands for operations and transferring of information, it is required to exchange the operating frequency. The shift or transfer onto another frequency must be smooth. This shows good prospects of Spectrum Mobility.

A major Area of concern in today's spectrum world is the inability to share the spectrum properly. These issues directly correspond to MAC problems. Hence the idea of Spectrum sharing needs to be taken as a serious issue, as its proper application can ensure better usage of the Spectrum.

2. Project Description

2.1 Basic Concepts in Cognitive Radio:

The QoS is defined as the required set of qualitative and quantitative characteristics of the communication system required getting the proper or desired functionality of application. A QOS parameter can be based on human perception of different media and its attributes. Such as time dependence and symmetry.

Long back the software defined Radio was introduced and is defined as a terminal that is competent to operate with a lot of bandwidths. They are able to support different standards such as GSM, OFDMA, CDMA, and WiMAX. They promise the best solution for best connectivity problem, but the requirements of QOS by an application is still under consideration. Thus cognitive radio is introduced.

CR is a radio that can read and understand context in which it can tailor the communication process along with understanding.
If a SDR needs to be a CR then:

1. Management and optimization of spectrum
2. Optimization and management due to interface consisting variety of wireless networks.
3. Aiding humans using EM Resources.

There has been a rapid increase in the use of wireless applications, which in return leads to the need of more Bandwidth. Unfortunately that situation has lead to a scarcity in the Spectrum, which arises due to the inefficient use of EM spectrum. EM Spectrum is the electromagnetic radio emitted from different sources, which accompany its own frequency and wavelengths. The FCC (Federal Communications Commission) controls the EM Spectrum and only licensed users can use the EM Spectrum.

2.2 Behavior and Cognition Capabilities:

For efficient communication, the systems available in today's world follow a different nature in their behavior. For e.g.the power imbalance can be nullified between different users by the proper use of the output power. A phone can adapt with the added noise in the incoming signal regardless Wi-max network can maintain good throughput. It also has a decent link stability factor and the characteristics of its signals have the ability to adapt.

2.2.1 Behavior:

It is adaptive in nature and in a high manner. It is very much increased and can adapt to many types of parameters such as the beam pattern of an antenna, the power, the modulation technique, coding technique and the operating frequency. It also takes into consideration the battery and processor usage. The adaptation can occur in planned and unplanned manners. The cognitive radio device recognizes the radio environment to bring out further more potential in communication.

2.2.2 Cognition capabilities:

The different abilities as seen before allow to define the must have radio capabilities. These are regarded as the cognition capabilities. The various capabilities include reasoning, learning, sensing and awareness. Due to these parameters the Cognitive radio device can be defined as a radio that is capable to comprehend the different environments that it gets involved in, its requirements, its potential and its regulatory policies.

In Lehman words we can say that it has the complete ability to be self-aware and completely know about its environment and its variant nature over a period of time. It executes the received information and makes its own decision on how it needs to make necessary arrangements to put together a successful communication process.

2.3 The Cognition Cycle:

Cognitive Radio is the radio that has in itself the ability to reason with regulatory policies, different user requirements, be self aware of its potentials and requirements. It these capabilities are taken as observations for a CR, there is still a need to make a proper decision on which way an action must be made. By remembering this factor we can conclude that the cognitive radio has the ability to observe, decide and act.

When we talk about observation, it involves the process of learning and sensing the radio environment of the outer world. The Observations recorded are given as the input into the Cognitive Radio where it is left to make a decision on the basis of the mechanism, which is inculcated in it through several algorithms.

The observations and decisions decide the complexity of a process in Cognitive Radio. And those parameters can decide if or not the process shall occur as complex or non-complex procedure using the involvement of past knowledge or future knowledge and few probabilities. Hence it is very important to properly design so that intelligent and appropriate decisions can be tallied.

According to the cycle, it starts at the observation end and then goes further traditionally. The cycle,although, actually starts at the "act" end and that is due to logical reasoning. It is so to know what actions are of importance and has the possibility to occur. And this needs to occur before we get to understand what decisions need to be taken and what decision needs to be made.

Hence the important three steps include as;

1. Taking an Action
2. Making an Observation
3. Making a Decision

2.3.1 Taking an action

These are the actions that can bring out a certain set of performance out of a cognitive radio or the different alterations and actions of all forms. The action process depends on the observation part and the necessary

indications for alterations are provided by it. The CR can be made efficient to achieve a desirable goal by altering various parameters such as the pattern of antenna beam, the power, the modulation techniques used, the bandwidth, frequency etc. The parameters must be decided first before proceeding and the CR must be aware of all the actions possible before it goes onto perform a certain task.

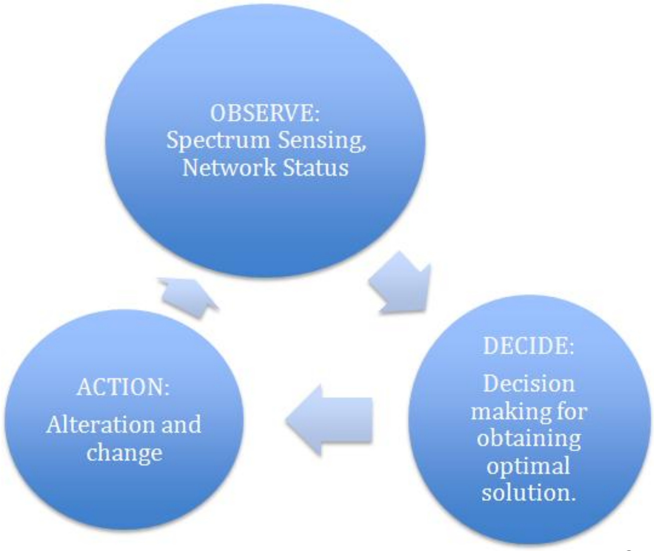

Figure 2.1: Cognitive Cycle

2.3.2 Making and Observation

To get a certain level of performance, the parameters of radio are altered in many ways. Clues and a few hints are attached along with these parameters to enable the necessary alterations. The observations that are tallied throughout the process help in aiding the radio with the necessary clues. This area is used as the input and helps in determining which state the radio is working on. After deciding the state the decision is made and the action is taken accordingly.

The observation part involves understanding the requirements of the users and the policies involved. Also it needs to be aware of its own capabilities. A cognitive radio is capable of discovering its own observations or it can receive tallied observations from external sources.

The four general approaches used for observations include:

1. A CR can acquire the observed data in a natural manner
2. With the likes of GPS Devices used, the hardware devices can be used to make certain observations. These are few of the unnatural forms of attaining certain observations of the environment
3. By using the technique of special signal analyzing the observed data can be acquired
4. By considering the environment it is operating in and learning its parameters.

The last seen method is the most analytical of all methods when it comes to making remarks.

As a part of making observation, necessary spectrum sensing needs to be done to come up with certain conclusions regarding the environment the radio is operation in. Generally the spectrum sensing part is synonymous with the cognitive cycle.

2.3.2.1 Spectrum Sensing

This technique mainly involves in ruling or detecting the signal transmitted and of interest of the CR Receiver. With this method, the CR is enabled to spot or find the existence of other radios or find whitespaces in its concerned radio. Further into Spectrum sensing, it is divided into further aspects such as Accurate Sensing, sensing the Appropriate Range and In time Sensing.

2.3.2.2 Accurate Sensing

In order to detect the spectrum accurately, the CR must be made smart enough. It can have a missed detection and a false alarm. For E.g. It would detect a primary user in the environment when there is no primary user in reality. The other scenario is pretty much the opposite, as the CR would not detect a user when it in reality is really present. Both of these scenarios lead to inefficient communication and lead to problems such as interference.

2.3.2.3Sensing in the appropriate range

It helps in increasing or improving the sensing. Every transmitter in itself has a defined range of spectrum. Having this defined range in it, it is able to receive and decode signal. The range depends on the receiver's sensitivity and the transmitter's power. Both primary and secondary users are able to sense within a certain range as they have receivers having such level of sensitivity. If sensing is done with the proper range in hand it can avoid making mistake such as the false alarm scenario or the missed detection.

2.3.2.4 In time sensing

It majorly senses the primary user in the spectrum. It can be classified into two terms, the first being white spaces and the second being return of the primary user. White spaces, The first term, stresses on the free time of the primary users which ends up in creating spaces or holes in the spectrum. Therefore it is required to find the opportunity to communicate and finding these holes help in enabling that. The opportunity to communicate is lost if a lot of time is taken to sense these holes. The second term applied, the return of the primary users mainly addresses the return of the licensed user to the spectrum. It is highly required to avoid the unwanted interference between the secondary and primary users. There is a high chance of interference to occur is it takes too long to observe a primary user and that wouldn't be suitable for efficient and enhanced communication process.

2.4 Selecting a Proper Interference Model:

The primary step in building a CRN is to choose an appropriate interference model. The foremost thing in constructing an interference model is to build a channel propagation model relative to the radio environment. We

shall consider deterministic path loss, large scale and small scale fading which are the propagation effects in channel models. Under the assumption that there aren't any obstacles in the radio environment; we ignore the fading effects and consider only deterministic path loss effect in our channel model. The next stage is to establish an appropriate transmission channel model, which exhibits the effect of interference on the received signal at the receiver end. Primitive channel model were derived from collision channel model where if two or more transmitters try to send a signal to a receiver at the same time. All of the signals would be summed to zero due to the collision effect.

In the recent new era of models, capture channel model is proposed where if one of the received signals is strong enough compared to the other signals that signal would win over the other and reach the receiver. Vulnerability circle capture model and power capture model belong to the above category. In the vulnerability circle capture model for an i^{th} transmitter signal to be successfully received, its receiver power must be more than the power of any other received signal by a factor β

$$Pr,i / Pr,j > \beta$$

$$for \rightarrow j = 1,2....n; j \neq i$$

Let us consider a model where there is uniform transmit power level for all the transmitters. Mathematically, according to the definition of vulnerability circle model, the radius of the circle is $r=\beta^{1/n}$

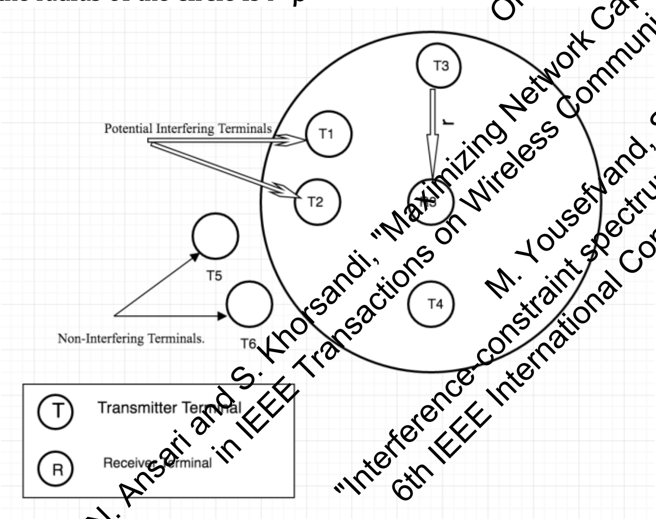

Figure 2.2: Vulnerability Circle

In the above diagram, the vulnerability circle diagram is demonstrated. The transmitted signal from T_1 is intended to be received by R_1 but it is interfered by the signals transmitted by other transmitters within the vulnerability circle.

This is a primitive model, which imposes huge restrictions on the transmitted terminals located around the receiver and results in degradation of spectrum efficiency.

For example, if we take a transmitter node T_3, it's signal is intended to the receiver R_3, without causing any interference on any other receiver. In present times, according to practical power capture models, a signal is set to be received successfully at the receiver end if the received power supersedes the power of the accumulated signals from all other receivers by a factor β_P.
Mathematically we can deduce signal to interference ratio as :

$$SIR = \left(P_{r,m} / \sum_{n \neq m} P_{r,m}\right) > \beta_P$$

In the above equation, the received power at the receiver end of the transmitted signal i is $P_{r,i}$. In a more realistic scenario, we need to consider additive noise power which is denoted as σ^2, mathematically the signal to noise interference ratio

$$SINR = \left(\left(P_{t,m}/|x_m - x_{R(m)}|^2\right) / \left(\sigma^2 + \sum_{n \neq m, n \in N} \left(P_{t,n}/|x_n - x_{R(m)}|^2\right)\right)\right) > \beta_P$$

In the above equation, $|x_m - x_{R(m)}|$ implies the distance between transmitter m and its receiver. The bandwidth in the above model is at a constant rate W_m, for a given link (T_m, R_m). For reliable transmission to take place at radio environment, the SINR for any given link should exceed a threshold. Otherwise it is nullified. From the definition of Shannon's formula for link capacity, the data rate for the given link (T_m, R_m)

$$W = B\log_2\left(1 + \left(P_{t,m}/|x_m - x_{R(m)}|^2\right) / \left(N_0 B + \sum_{n \neq m, n \in N} \left(P_{t,n}/|x_n - x_{R(m)}|^2\right)\right)\right)$$

B represents channel bandwidth and N_0 denotes the noise spectral density.

3. Technical Specification

3.1 Genetic Algorithm:

Evolutionary algorithm was found to be promising in solving the optimization problem. Hence we have opted for genetic algorithm to maximize the network capacity, thus optimizing the spectrum as a whole.

3.1.1 Approach:

The algorithm is carried out by random choice of chromosomes that have a particular trait which are computed through generations. The fitness of a given chromosome at a particular generation is evaluated on the basis of a random probabilistic calculation. Calculation of fitness of chromosomes is based on individuality, the process continues for several generations iteratively till we reach an optimum solution.

3.2 Stages of Genetic Algorithm

3.2.1 Initialization:

N chromosomes re generated randomly which form the initial population. Probable solutions for the given problem are part of the population stated above.

3.2.2 Fitness Measure:
This stage includes computing the fitness of chromosomes, which constitute the initial population.

3.2.3 Construction of New population:
Selection: A set of chromosomes is selected based on the criteria of fitness from the available population

3.2.4Crossover:
New progeny are part of the upcoming generation by the method of crossover. Progeny are formed or reproduced based on the probability of crossover

3.2.5 Mutation:
The chromosome structure of the offspring is converted from string to binary format and the binary values are toggled at a particular point to retain the diversity of the upcoming generations.

3.2.6 Stopping Criteria:
This iterative method is run through multiple times till we reach an optimum solution. It is also found that, the stopping criteria are relative to the complexity of the chromosome structure.

3.2.6.1 Roulette wheel selection:
In this selection process probability of selection of a given chromosome is directly dependent to its fitness. Consider M(I) as the fitness measure of a chromosome, then the selection probability of this chromosome is given as P(I), which can be mathematically formulated as fitness measure M(I) of the given chromosome divided by summation of all the fitness measures of 'N' number of chromosomes present in the solution domain. In roulette wheel selection process, each chromosome is estimated with the sum of fitness of all the chromosomes and the chromosome with greater probability has more chance of being selected. Using any of the above-mentioned procedures reproduces the child chromosomes.

Table 3.1: Roulette Wheel Selection

Chromosome No.	Total Fitness	Selection Probability
1	80	25.5%
2	45	14.3%
3	95	30.35%
4	72	23%
5	21	6.7%
Total	313	100%

To comprehend the selection process, we have taken a possible set of solutions of 5 chromosomes with their fitness measures and evaluated probabilities of selection as given in the above table. It is evident from the table above that the 3rd chromosome has maximum fitness measure among the whole set and the 5th chromosome has the least fitness measure and hence the corresponding selection probabilities.

This selection process has been named Roulette Wheel because, the wheel is whirled N times for N number of chromosomes in the solution domain.

Since the first chromosome has the maximum selection probability, it shall occupy maximum portion on the wheel whereas the fourth chromosome with least selection probability occupies the least portion on the wheel. While the wheel is spun, the probability of selecting the first chromosome, which has a larger area, is always more than the rest of its counterparts. Thus this whole process eliminates the selection of the poorest chromosome almost unlikely.

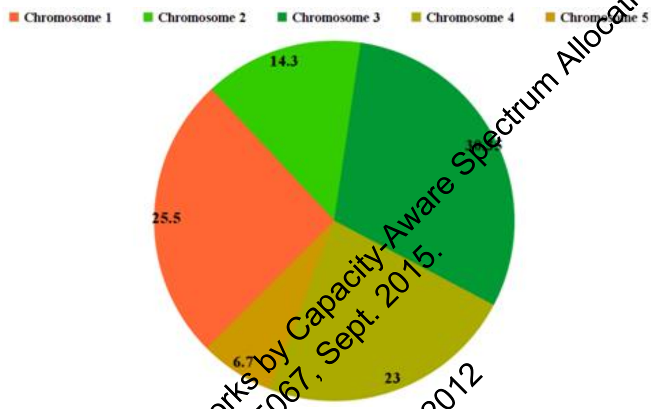

Figure 3.2: Roulette Wheel

3.2.7 Chromosome structure:
The process in genetic algorithm can be carried out only upon selecting an appropriate chromosome structure. Each chromosome comprises of different genes. Each gene in a chromosome depicts some characteristics of the RF environment. The common genes in a chromosome of a RF environment are signal power, data rate, and operating frequency. Chromosomes are the basic elements of Genetic Algorithm, which must be showcased in a way that the information of the probable solution is accompanied with it.

The most generalized form of representation is in the form of binary string. The genes of a chromosome are built using basic radio parameters. The most essential condition is the variety of chromosome's necessary process. Power is the greatest necessary radio parameter for communication. The quantity of power is completely relative to specific applications. Extreme powers which maybe too high or too low maybe undesirable for effective communication. Thus it is mandatory for power to be in optimum range, which can boost the chances of reliable communication. Signal power is generally kept low to remove flaws in the communication.

3.2.8 Binary Encoding of Chromosome:
In them mutation state of genetic algorithm, chromosomes are binary encoded. Each gene in a chromosome is transformed from decimal to binary for the mutation to carry out. Soon after them mutation process the genes are changed back to their original decimal forms.

3.2.8.1 Fitness measure:
An objective function is defined to determine the standard of each chromosome that comprises a part of the Genetic process. The fitness measure is directly dependent on the nature of the problem. A new generation in the iterative cycle is formed by the application of the fitness measure.

In fact, it replicates a filter which restricts individuals that are not meeting a particular level of fitness So that the chromosomes that are deviating from the optimized solution will be truncated. This stage is followed by selection crossover and mutation.

3.2.8.2 Crossover:

After the selection stage in genetic algorithm, fit chromosomes are chosen and the next stage is to takeout crossover. Crossover is a technique by which dealings of any two chromosomes can be interchanged with each other to form two new offspring. There are multiple crossover techniques, namely single point, multi point, two point and uniform crossover. Research shows that, two-point crossover technique yields better solutions relative to other techniques. Generally, crossover rate is between 85-95%.

Random cluster of crossover points are chosen in the chromosomes, which will segregate them into parts having different parameters. Crossover process is followed by mutation. The random value that is generated is compared with the mutation probability if it is found to be lesser, than a reversal of one of the bits in the process. It is ideal to keep the process rate low so that it doesn't interfere with the fitness level and nature of offspring.

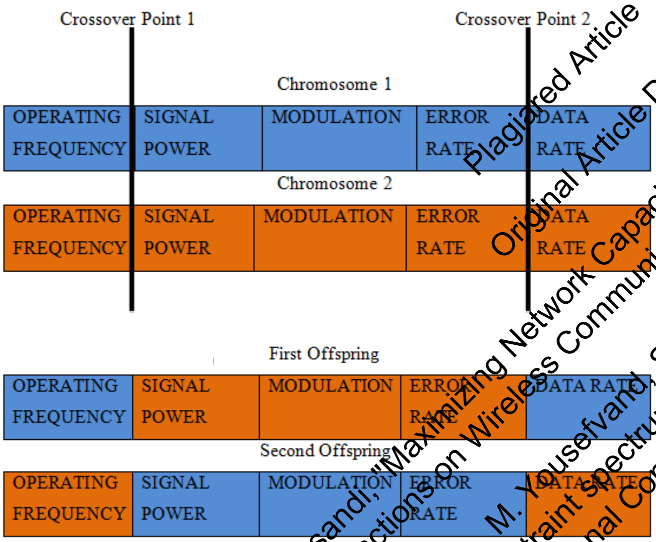

Figure 3.4: Reproduction of new Off Springs using Two-Point Crossover

3.2.8.3 Mutation:

In order for the genetic diversity to sustain from parents to child chromosomes, mutation is another essential stage in GA. Mutation is carried out on the genes of the offspring which are just produced after the crossover, by toggling binary bit of 0-1 or vice versa. Unlike crossover, mutation cannot be formed with decimal representation. Hence, chromosomes have to be converted into binary form. There may be adverse effects on the chromosome structure of the offspring hence the mutation rate is kept low which is around 2-4 %

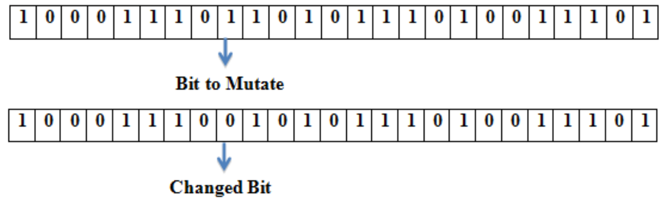

Figure 3.3: Mutation Process

3.2.9 Stopping criteria

This criterion is completely related to the optimization problem. When a solution with desired values is reached then the stopping criteria comes to play. It is a common observation optimum results are produced in between 60-90 generations and the genetic process paces down with increase in the number of generations. Fitness measure is imposed on the final generated cluster. The most desirable one is chosen as optimum. Genetic algorithm is associated with random values, so there is a fair chance of choosing wrong results. GA is known to produce a set of optimum solutions rather than a single solution.

3.2.10 Conclusion:

The most challenging aspect in cognitive radio network is spectrum allocation and quality of service requirements of the applications. It is not feasible to allocate the perfect band due to radio environmental constraints but the ability to assign the best band among the existing bands is a topic to be researched. Cognizant about all these constraints, we have proposed a spectrum allocation solution for cognitive radio networks that provides best possible solution from the available set of solutions. Without compromising the QOS requirements, Genetic algorithm doesn't give 100 % efficient solution due to its random behavior but choosing a seeded population can rectify this.

In a seeded population, the first portion of population is randomly generated. And the second part is generated using the information of first. This reduces the randomness of population. The seeding of population can cause another issue that is premature convergence. Premature convergence can be countered in the following ways. By increasing the rate of crossover and mutation, we can decrease the probability of pre convergence. But this will increase the iteration time and also randomize the solution.

By increasing the initial population, we can decrease the probability of premature convergence. However, execution time will increase corresponding. Although the above solutions are proposed, there is uncertainty in radio communication. It is concluded that the proposed solution is favorable for removing white spaces and best possible usage of the spectrum in cognitive radio networks.

3.3. Spectrum Allocation:

The heart of our project work revolves around Spectrum optimization in CRN. Cognitive radio receiver senses a radio frequency environment and a spectrum hole is allocated to a requesting user without compromising with the quality of the service requirements

Spectrum allocation test: is performed for the given spectrum and if the resulting parameters meet the users QOS requirements, the process is stopped; if not, multiple

tests are carried out until we reach an optimum solution. Spectrum allocation regulations are to be followed which the regulatory authorities authorize. These norms serve to decrease the interference in the spectrum bands and also to meet the QoS Requirements.

Spectrum allocation test: is performed for the given spectrum and if the resulting parameters meet the users QOS requirements, the process is stopped; if not, multiple tests are carried out until we reach an optimum solution.

3.3.1Making a decision:
The decision making process is the most pivotal aspect in determining the performance of a cognitive radio. The distribution and the usage of radio resources are the elements that require the most precise decision-making. It also helps in enabling fair communication amongst other users.

3.3.2Optimization:
The best choice of the existing options, which is most feasible choice, that enhances usage and also enables to reach the desired goal with high efficiency.

Optimization hovers around three different types of scenarios, which include;

1. Optimization Goal
2. Available options
3. Determining the best option

3.3.2.1 Optimization Goal:
Selection of efficient systems in such a way that as a whole the effective communication is maximized.

3.3.2.2 Available options:
They comprise of a set of feasible solutions or options out of which the best option is chosen in order to reach a particular goal.

3.3.2.3 Determining the Best Option
A fitness test is set to determine the best option. The best available solution is selected from the fitness test. White spaces are assigned to secondary users that are found in spectrum sensing. Another aspect of this optimization is putting a check on the power consumption. A feedback mechanism is required for every user in a given cognitive radio to control the power by itself. QoS requirements of a given communication system is met by the above power control mechanism.

3.3.2.4 Merits of Genetic Algorithm
The key utility of Genetic Algorithm is its computation ability, which can reduce the simulation time. It can optimize for many number of variables. It doesn't give a single solution but a list of optimum solutions. Fast co-incidence is another utility of Genetic Algorithm that can meet the solution in minimum time.

3.3.2.5 Demerits of Genetic Algorithm
A complexity is involved during the encoding and fitness measure stages of GA. Given, the number of variables is high; It would lead to cumbersome process in applying the algorithm. Thus the simulation time gets longer. In situations like these other techniques prevail over Genetic Algorithm. In short, the algorithm faces major constraints with respect to number of variables. Although, this particular drawback can be resolved, Given, Sophisticated hardware architecture has been applied.

4. Design Approach and Details

4.1 Methodologies and Design of Spectrum Allocation:
Our proposed model consists of five stages. All these stages form the cognition cycle. It is named as cognition cycle because of the ability of cognitive radio nodes to sense the spectral environment and dynamically adapt itself to the new state of the environment. In the spectrum-sensing phase, existing frequency channels are being monitored by the SU's to get information such as the noise and interference level of the physical layer

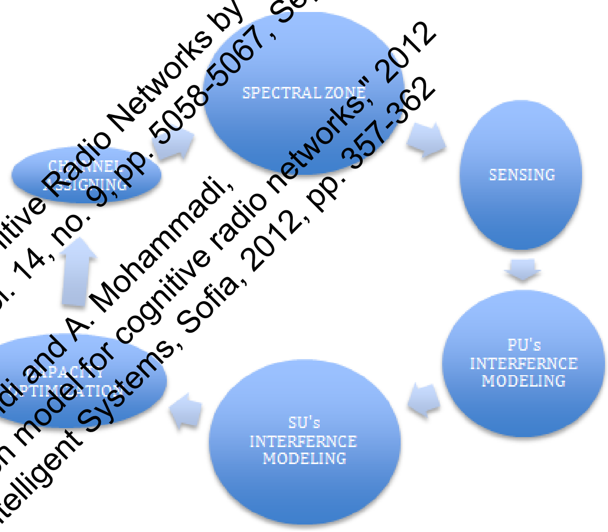

Figure 4.1: Cognition Cycle for spectral Users

Secondary users are authorized to increase their transmission power in such a way so as to not interfere of the primary users by being aware of their position and interference temperature thresholds, so that the constraints of the primary users should be met.

In the second stage, On each channel, the transmission power of the secondary users are increased; given that interference constraints on all the affected primary users are met. By determining the transmission power and positions of users at their respective channels, we can calculate their capacities by making use of Shannon's formula. Since there exists Co- Channel interference between adjacent channels, hence we need to capture this first before applying the optimization. It is not possible for all the potential links to be active simultaneously in a given channel; we determine a feasible bunch of Active links operating at the same time in order to maximize the network capacity. In the final stage of channel assignment, after identifying a bunch of non-interfering links, the remaining channels will be allocated to the secondary users correspondingly. There are two sub stages in interference control of cognition cycle.

In the first sub stage, being cognizant about the primary users events we finalize maximum permitted transmission power for secondary users to assure that the primary users that their interference constraints. In the second sub stage, we make sure that interfering links on each channel does not get activated simultaneously, by modeling the co channel interferences. Secondary users can raise their transmission power between the lower and the upper bounds; the upper bound is the maximum allowable transmission power. But SINR should meet its threshold level for reliable transmission.

4.2System design and Analysis:

Let us assume that there are K primary users in the spectral environment transmitting to each other through C channels and L secondary users. Competing against each other to access the spectrum opportunistically.

Let us define a matrix to determine the availability of link between two users. Mathematically

$$B_c = \left\{ b_{m,n,c} \mid b_{m,n,c} \in \{0,1\} \right\}$$

In the above equation $b_{m,n,c}=1$ if both secondary users m and n sense the channel c as a free channel. If not, $b_{m,n,c}=0$. In order to infer if the channel c is free or not each secondary user relates its observed interference on that channel with the interference temperature threshold. In fact, mathematically, secondary user m senses the channel free if the following condition is satisfied.

$$\sum_{k=1, k\neq i}^{M} P_{r_{m,n,c}} + N_c \leq T_c$$

In the above equation, $P_{r,m,n,c}$ is the power received by secondary user m from a signal sent by k[th] primary user via channel c. The noise on the channel c is given by N_c. Soon after discovering a set of potential links for each of the users, each link is associated by a weight. Since our motto is to increase the network capacity, we allot each link as link capacity. Each secondary user m, raises its transmission power for a given channel c by simultaneously being in accordance with the interference constraints of the primary users. In fact, mathematically, we can strike a relation for the transmission power of the secondary user by determining the maximum allowable transmission power. If the transmission power from the secondary user exceeds the limit by a factor λ, then the condition on interference threshold is violated. Hence we can mathematically deduce the following equation.

$$P_{m,c} \leq p_{max_{m,c}} \quad \forall r : T_{r,c} \leq T_c \quad 1 \leq r \leq M$$

$$P_{m,c} = \left(p_{max_{m,c}} + \lambda \right) \exists r : T_{r,c} > T_c \quad \lambda > 0$$

Apart from the maximum limit imposed on the power transmitted by the secondary user, there is also a minimum transmission power level required for each secondary user's transmission so that the condition of minimum SINR is met. Each secondary user has to choose its transmission power from its minimum and maximum bounds. Mathematically, we can deduce the relation as $P \in [P_{\min m,c}, P_{\max,m,c}]$. Having deduced the transmission power of each secondary user m on their channels, we shall determine link capacity of each potential links on these channels. We shall construct the weight matrix W_c as $w_{m,n,c}$. Each element in this matrix represents weight of the link in between transmitter m and receiver n on channel c. mathematically we can determine it as:

$$w_{m,n,c} = B \times \log_2(1 + SINR_{m,n,c})$$
$$1 \leq m,n \leq N$$
$$1 \leq c \leq C$$

In the above equation, B implies bandwidth on channel c and $SINR_{m,n,c}$ implies the SINR of the link amidst transmitter m and receiver n on channel c. we can calculate SINR of the potential links as:

$$SINR_{m,n,c} = \frac{P_{r_{n,m,c}}}{N + \sum_{l=1, l\neq m}^{K} P_{r_{n,l,c}}}$$

In The above equation, the power received by receiver n is $P_{r,n,m,c}$ which is from transmitter m on channel c. The background noise and the channel are denoted by n. The total number of active transmitters on channel c is k. in order to control the co channel interference on each of the potential links; we construct a matrix to remove all possible conflicts.

$$G_c = G_{c_{m,n,p,q}} \in \{0,1\}$$

In the above equation, $G_{c(m,n,p,q)}$ will be taken as unity under the condition that a potential link between transmitter m and receiver n intervenes with the link between transmitter p and receiver q on channel c. if not, , $G_{c(m,n,p,q}$ will be nullified. One link intervenes with the other, under the condition that coinciding transmissions on

these two links result in the SINR of one of them to dip below a certain threshold SINR required having successful transmission. To avoid non- active links to be part of our solution set, we construct a channel assignment matrix, which remove non active links. This matrix consists of binary values [0,1].

$$D_c = \{d_{m,n,c}\} \in \{0,1\}$$

Thus it can be said that, when $d_{m,n,c}$ =1, then the link between transmitter m and receiver n will be part of a bunch of potential links for the channel c. if not, $d_{m,n,c}$

Will be nullified. In order to put a check on link conflicts, we impose the following condition on the spectral environment.

$$a_{m,n,c} + a_{p,q,c} \le 1$$

$$if G_{c_{m,n,p,q}} = 1$$

$$1 \le m,n,p,q \le N$$

We can determine the total network capacity of the spectral environment by taking the sum of products of channel assignment matrix and link capacity matrix. Mathematically,

$$T = Agg(\sum_{c=1}^{C} D_c \times W_c)$$

In the above equation, Agg is the operator that calculates the addition of all entries of the matrix. T indicates the overall network capacity of the spectral environment. It is observed that D_c and W_c have uniform dimension. The above equation can be made as an optimized equation which can be used as an objective function in an evolutionary algorithm such as genetic algorithm.

4.3 Genetic Algorithm Construction:

In order to optimize the spectrum, we need a low complex interactive algorithm hence we sort it for genetic algorithm. Each chromosome in genetic algorithm depicts an optimum solution from the total set of solutions.

Orderly arranging the rows of the assignment matrix Dc of multiple channels side by side to form a string having binary format builds chromosomes. For example, let us take three matrices namely P4, P5, P6 indicating the links on the channels 4,5,6:

$$P_4 = \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

$$P_5 = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \end{pmatrix}$$

$$P_6 = \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}$$

In the above equation $P_{c,m,n}$ represents the link amidst secondary users m and n if it is unity. Hence, we systematically connect all the matrices into a string of binary format of length 27 bits. Since our motive is to improve the network capacity the fitness measure of each of the chromosome implies the capacity of feasible network setup. For every iteration of genetic algorithm, each of the chromosomes is sorted in accordance with their fitness measures. The chromosomes with improved fitness are obtained in the subsequent generations. The below figure shows crossover points on the edges between the links which indicate that they are from different channels. The main utility of these crossover points are the truncated co-channel conflicts shall not be carried to the subsequent generation.

Table 4.1: Crossover Points

CROSSOVER POINTS
xx

0	1	0	0	0	1	0	1	0	0	0	1	1	0	0	1	1	0	0	1	1	1	0	1	0	1	0

CHANNEL 4 LINKS | CHANNEL 5 LINKS | CHANNEL 6 LINKS

4.4 Codes and Standards

Government authorities like Federal communication commission control the EM spectrum. Under the federal radio act of FCC, only the licensed users who are the authorized personnel can use the EM spectrum. The misuse of the EM Spectrum results in the production of Spectral efficiency of the wireless networks. To solve the spectrum under utilization problem, cognitive radio has been introduced. A cognitive radio should be cognizant of regulatory policies enforced by the licensing authorities. Cognitive radio is a self-functioning system hence it doesn't need any monitoring and can manage the wireless networks on its own. For reliable communication to happen, it is mandatory for QoS necessities to be met. Hence we sort it out for cognitive radio. In other words,

QoS is described as calculable and filled with high quality features that are needed to accomplish the working of a function. Before the advent of cognitive radio, Software defined radio was being used for a wide range of operating frequencies. SDR is a radio terminal, which is capable of functioning in different bandwidths. To counter the drawback of an SDR i.e. QoS necessities are not met in a SDR hence it directed to the improvement of CR. The subsequent three meanings were additional to the SDR to make it a CR:

- Spectrum Management
- In line with a wide range of wireless networks and humans too thus delivering reserves to help humans in their activities.

5. Schedule Tasks and Milestones

Our Project journey was embarked by first being aware of the current work in Cognitive Radio and how it is being used to optimize the Spectral Environment. We first tried to understand the problem statement of our project. So that we can ponder over and arrive at an optimum solution.

Spectrum Optimization through dynamic spectrum access is our problem statement. Network Capacity has to be improved and the betterment of QoS parameters was necessary to ensure reliable communication. We sorted out for evolutionary algorithms to optimize the objective function (Total Network Capacity). We found that bio encouraged algorithms were promising in determining optimum solution for the given objective function.

Essential tasks of our project are to eliminate white spaces from the spectral environment by opportunistically accessing the spectrum, this is done by secondary users who approach the band when it is unexploited by the primary users. The primary users and the secondary users should be topographically located so that their power levels are within the bounds as discussed earlier. SINR of secondary users should have a minimum value of 1. Each channel is associated with an interference temperature threshold, which should not be violated. Therefore the secondary users should raise the transmission power in accordance with the constraints.

We have faced couple of milestones in our journey. Some of them are:

- As the number of primary and secondary users are increased, the elapsed time in converging to an optimum solution will increase exponentially
- By increasing the number of active links, disrespecting their capacities heads to ruining of the overall network capacity.
- Genetic algorithm has an intrinsic trait of being random in nature. Hence due to the operations like mutation and crossover, by increasing the number of iterations does not necessarily assure us of an optimum solution.
- We also cannot ignore the time complexity in the functioning of the genetic algorithm.

6. Project Demonstration

We have built an environmental setup comprising of 4 primary users and 16 secondary users, which are spread across an area of 1024, square meters, as shown in Fig 6(a). As discussed earlier, we shall operate the cognition cycle stages to this spectral environment. With a supposition that secondary users operate through six operational channels. We have restricted interference on each of the channels by imposing an interference temperature limit of 10db on each of the channels. Also we have a requirement of at least unity as the SINR.

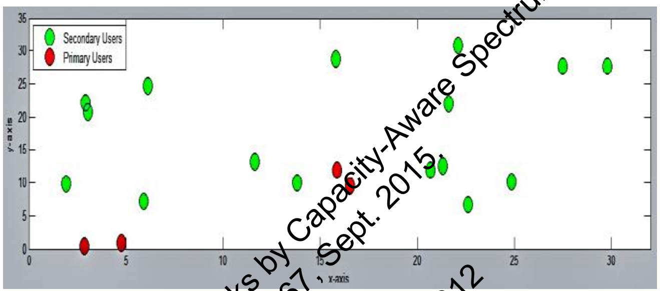

Figure 6(a): Spatial Distribution of PUs and SUs

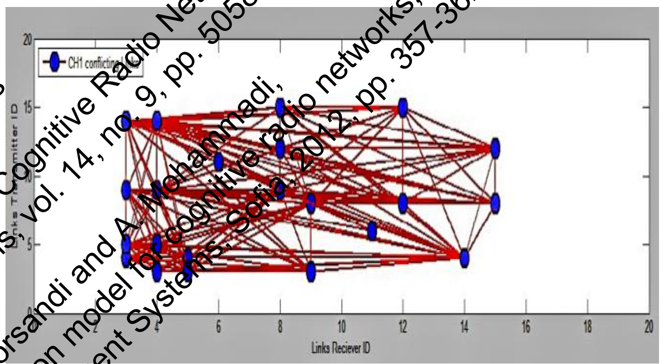

Figure 6(b): Interference Graph for channel 1

For trustworthy transmission, we initially spot the potential links and determine their network capacities and SINRs. We neglect the links with SINR less than 1. We build an interference graph for each channel as shown in Fig 6(b), which represents the interference graph of channel 1. It is observed that genetic algorithm converges to an optimum solution as the number of iterations increases as shown in Fig 6(c).

We take another case where we have 25 secondary users and 5 primary users, spatially distributed across 2500 square meters. It has been observed that in this scenario that by increasing the number of active links among the secondary users, it need not certainly improve the network capacity by a significant factor as shown in fig6(d). The network capacity may increase only if we consider all the links as uniform, which is not practical. Intrinsic trait of genetic algorithm is highly arbitrary due to processes like crossover and mutation.

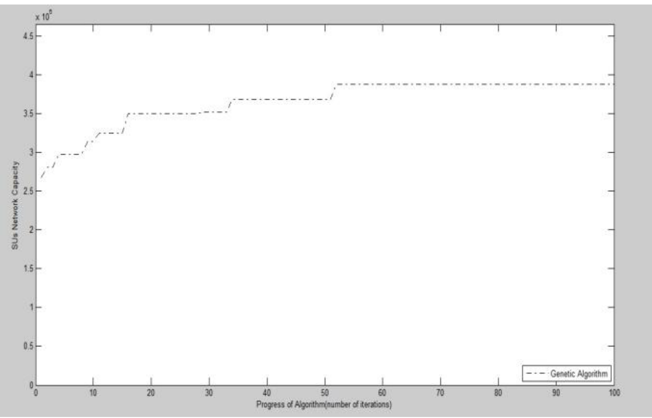

Figure 6(c): Total Network Capacity of the Secondary Users.(scenario-I)

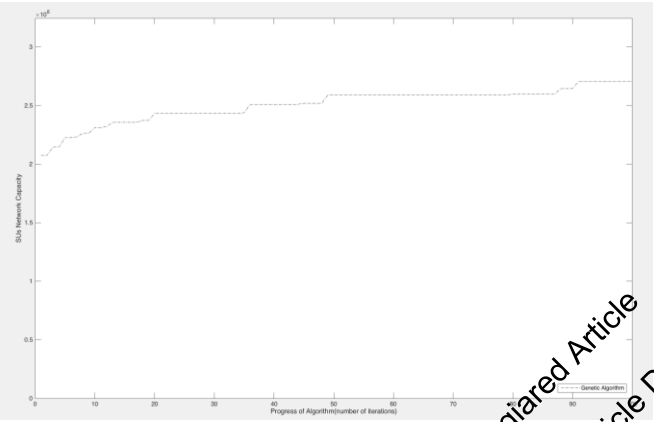

Figure 6(d): Total Network Capacity of secondary Users (scenario-II)

The progression of iterations in GA does not mandate an optimum solution, which is evident from the periodic movement in the coming generations. In our proposed model, we have distributed the nodes in random fashion due to which secondary users can control the transmission power. Decreasing the distance between the secondary users in populated areas, which in turn increases the link SINR. Also, does this; there is more number of links that satisfy the SINR criteria. Therefore improving the overall network capacity significantly.

7. Summary

By providing opportunistic access to usable and available channels for the secondary users, the technology of Cognitive Radio proves itself to be highly promising. And in that matter highly helps in making the usage of spectrum better. By optimization of variable number of parameters, the enhancing of spectrum is met with and conducted. In our project we have come up with little interference limited capacity known spectrum allowed design, to facilitate maximum capacity in Cognitive Radio. The results shown in the simulation prove that it is able to achieve higher network capacity by inculcating the suggested model than the normal methods used for allocating the spectrum wisely. It has also come to our observation that, by maximizing the number of links that are active amongst the secondary users, it need not directly lead to the increase or maximization of the capacity of the network. It could be taken like that if we make an assumption that all the links are equal. But that form of an assumption would not be pragmatic to the approach of our scenario. We have also noticed that the scenarios in which the secondary users are equipped with the capability to control power, it is able to achieve higher capacity; given that the secondary users are distributed in a random manner as compared to the case in which they are laid out in a definite manner.

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