# Spectrum Pricing in Cognitive Radio Networks: An Analysis

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***Abstract*—The wireless technology is applied in developing various applications in different trust areas. Due to this there is a huge demand for the spectrum band. The available spectrum can be shared among the primary users and the secondary users. The spectrum is utilized by the secondary user on rental basis. In this competitive world, the primary users provide a good quality for services to the end users for retaining the spectrum band. The pricing is one of the vital components in Cognitive Radio Networks (CRN) for owning/renting the spectrum. The spectrum is utilized by the secondary users when the spectrum is in idle state. This research work focuses on the spectrum pricing for the secondary users based on the price paid by the primary user. The primary users generate revenue, the same price is utilized for maintenance or annual fees which is to be paid to the governance of telecommunication department. The pricing and trading issues is one of the research areas for allocating the spectrum to the primary users. This research work focuses on providing spectrum to the secondary users with the minimal price for utilization during the specified time. The work highlights the open fact that there is a huge scarcity of the spectrum and the price are high, and not affordable to the individuals. Hence primary users lease/rent out the idle bandwidth for the secondary user. To utilize the spectrum for a dedicated period of time the secondary user has to pay the usage charges to the primary user. In this research work, various methods are presented for determining the price for the secondary users. The pricing components are analyzed by adapting the one-way Anova which compares the values among the groups. The results indicates that all the group means are not same and they are independent variables.**

***Keywords*—Price; game theory; analysis of price; trading; usage**

## I. Introduction

The spectrum is one of the important resources for wireless communication. Due to the huge demand, there is a scarcity of spectrum band. These issues are resolved by cognitive radio networks. These radio networks are self-configurable hence these networks are called as intelligent radios. The spectrum hole is detected by using match-filtering method, cyclo-stationery and energy detection method. There are four different challenges in spectrum management:

- Spectrum Sensing: Detect the unused portion of the spectrum.
- Spectrum Decision: Based on internal/external policy allocating the available spectrum.
- Spectrum Sharing: sharing the available spectrum between Primary user (PU) and Secondary user (SU) without overlapping.
- Spectrum Mobility: Hand-off of the signal between the networks.

The spectrum allocation problem is solved by different perspectives such as criteria, approaches, techniques and challenges [1]. The spectrum pricing is one of the major criteria in spectrum utilization. Since individuals cannot purchase the spectrum band, the primary users are responsible of owing the spectrum. The underutilized spectrum or unused spectrum can be reused for various communication purpose by allocating the bandwidth to the secondary users. The primary user (PU) sends the signal status which indicates idle or busy state. If the channel state is idle. The allocation is based on the rental/leased method. The system works based on the sharing of the frequency band between the primary user and the secondary user. To improve the QoS for wireless communication, the economics plays a vital role for setting the charges based on the demand for the purpose of developing wireless technology. The available bandwidth is shared between the Pus and SUs on mutual agreement. The primary user decides to lease/rent some portion of the unused spectrum to the secondary user. This technique is called trading. In trading both users are involved. The spectrum allocation and pricing depend on the bandwidth that are available for bidding. Fig. 1 depicts the trading of spectrum between the PUs and SUs. The spectrum is shared among the primary user and secondary user.

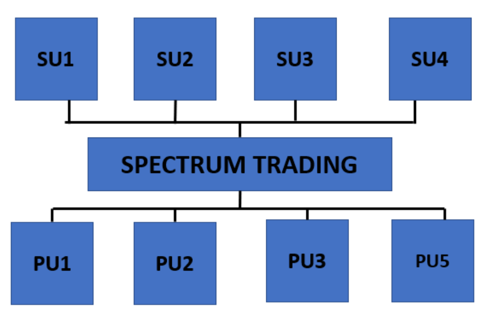


Fig. 1. Spectrum Trading.

The spectrum trading is a mutual agreement between the buyer and the seller. The licensed user needs to renew for the allocated spectrum bandwidth annually. The spectrum regulators or the managers fix the price depending on the services, usages and geographical locations.

## II. Literature Review

There are certain parameters which are needed to be considered while utilizing the spectrum as a secondary user. One such parameter is price of the spectrum, owner of the spectrum etc. The researchers have proposed different spectrum allocation and pricing mechanisms. The process of allocation may be dynamic based on Vickery Auction method wherein the revenue is optimized [2]. Two models such as NLMF and NLMB are suggested which results in better pricing and maximum sharing of the spectrum. In NLMF mode the price is decided by the primary user and the values are set as 0 and 1. In NMBF the part of price is transferred to the SU and the primary user will never predominates. In this research, the work results in optimization of pricing when Nash equilibrium is combined with swarm particle [3]. The SU are imposed with the admission fee, the behavior is analyzed in two ways such as optimal and social behavior. The following assumptions are considered:

- The SU doesn't have any information.
- The SU packets are transmitted successfully.
- The cost for SU packet staying in the system is C per unit time.
- Net-benefit is and additional.
- The services are provided based on FCFS [4].

The secondary user can purchase the spectrum from primary user (PU) or through the broker by auction process where it does not include any interaction between PUs and SUs [5]. The two auction mechanisms are proposed first method is based on the received power, i.e., the users are charged based for the received SINR second method the receivers are co-located where the users can use total available bandwidth [6]. The spectrum trading is processed between multiple PU selling to the multiple SUs [7]. The pricing of spectrum was modeled as an evolutionary game and non-cooperative game. The power of the spectrum is one of the essential parameters which is recommended for fixing the price. Later the decision making is carried out for studying the behavioral models by using the utility Theory where rationality assumptions are made between the users [7-8]. There are two models one with monopoly PU market and the other with the multiple PU market. Spectrum trading is one of the efficient ways of using idle spectrum. The spectrum sharing models, spectrum trading form and related problems were discussed [9]. The multiple PUs has an opportunity to sell the spectrum to multiple SUs. The problem was modeled based on the evolutionary game and the competition among the SUs [10]. The quality of channel and maximum power that SU can transmit on the channel depends on the $P_{min} \leq q \leq P_{max}$.

The primary spectrum owner can fix the cost of the channel by the equation [11].

$$c(q) = C0 + T(q) \quad (1)$$

The SU model prefers higher channel capacity, where the channel capacity for SU is given by Shannon-Hartley theorem [12]. Multiple bidders represent their bids for the available capacity of the bandwidth. There are issues in designing auctions i) attracting bidders ii) preventing bidders to control the auctions iii) maximizing the auctioneers revenue. The wireless service providers acquire the spectrum to provide service to the end users. The revenue generated by the end user indicates the true valuation price of the band. Later the true valuation price is used for the governance in forthcoming auctions. Spectrum allocation auctions can be synchronous and asynchronous. In asynchronous whenever the service is requested by the service providers the request can be serviced from coordinated access band (CAB) using pool of resources. In synchronous auction the spectrum bands are allocated/de-allocated in fixed time intervals. The service providers demand their request to the spectrum owner and what they are willing to pay for the allotted spectrum band [13].

## III. Spectrum Allocation Pricing Objectives and Principle

It is important to understand the pricing methodology to determine the spectrum price which certainly links with economical and market conditions along with the technological factors. The spectrum manager reviews the fee payment depending on type of use or type of user. This includes some of issues such as fiscal context, relevant principle and objective for certain types of spectrum fee, funding regulatory operations, demand and supply for spectrum and technology change.

### A. Principles of Spectrum Pricing

The Spectrum management is important task which includes different activities such as spectrum planning, allocation, licensing, coordinating, sharing regional and global standards. The spectrum management principles reflect economical and behavioral aspects. The list of spectrum allocation pricing principles are as follows:

*1)* Spectrum should be allocated with the highest value.

*2)* Greater access to spectrum will be facilitated with least cost and least restrictive approach.

*3)* Promote regularity and flexibility in spectrum usage.

*4)* Fairness of price to all the licensed holders in the given frequency band.

*5)* The fee calculation should be clear and published as a document for maintain the transparency.

*6)* Administrative cost will be lower if the fee schedule is simpler.

*7)* Spectrum fee are set to take different parameters such as bandwidth, frequency band and coverage area.

### B. Objectives

*1)* Spectrum price should promote efficient use of spectrum.

*2)* The cost of spectrum is associated with managing and regulating radio frequency should be covered from those who benefit from spectrum management.

*3)* Spectrum pricing should facilitate the achievement of government social and cultural activities [14].

## IV. Game Theory for Spectrum Utilization

Statement: The price P varies for the secondary users depending on the usage of the spectrum at any instant of time t.

Let su be the set of secondary users such that.

su = {s1, s2, s3…., n}

Let pu be the set of primary users such that.

pu = {p1, p2, p3, …, m}

The primary user can offer any opportunistic spectrum to any secondary user when the spectrum is idle. There exists a relationship between the primary user and secondary user which can be represented by using the graph theory. According to Bipartite graph, any secondary user can utilize any primary users available or idle spectrum. Fig. 2 shows the mapping between the PU and SU.

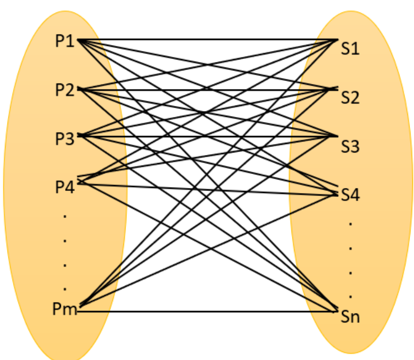


Fig. 2. Bipartite Graph showing the Relationship between PU and SU.

## V. Strategy for Price Competency (SPC)

The available spectrum is identified based on the location *Loc* further the channel is allocated to the SUs. The status of the channel is obtained by the SUs and later the channel is allotted based on the usage with the time the price is evaluated. The procedure for evaluating the spectrum is calculated as follows:

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Procedure for price competency

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Step1: Let *Loc* be the location
$P_K$ - Primary Spectrum
$S_k$- Secondary Spectrum
Step 2: $S_k \alpha$ Loc
Step 3: If (Loc ==0)
$P_K$ is Available
else
Channel is busy
Step 4: $S_k$ = Ch
Step5: Start t=0
Step 6: $P = P + \Delta$
Step 7: Ut=$\sum_{i=1}^{n} S \times L$
Step 8: $P = \frac{\lambda}{Ut}$

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The SU searches the available bandwidth with the PU. If loc is found the PU assigns the location with the initial time t. once the process starts the price is evaluated dynamically based on the time where $\Delta$ is price variation with the usage time. The utility function (Ut) is evaluated depending on the number of users requesting for spectrum usage and the location. The initial price is set based on the usage of the spectrum.

## VI. Two-Stage Games of Complete but Imperfect Information

The spectrum utilization by the secondary user can be assumed as a dynamic game. According to game theory. Consider p1 and p2 as players, A be the set of actions and S be the strategies.

The Gaming between the PU and SU involves the spectrum utilization effectively. The PU displays the channel information to the SU. Depending on the request price set by the PU. The analysis of the game is shown below:

- The player pl chooses an action A1 from the feasible set fs = {I, O}.
- The player S observe the action A1 and makes the decision A2 from fs1= {$I^C$, $o^c$}.
- The payoff matrix is prepared by using the actions of each user U1{A1, A2} and U2 {A1, A2}.

The decision tree is represented below for the player S and P Fig. 3:

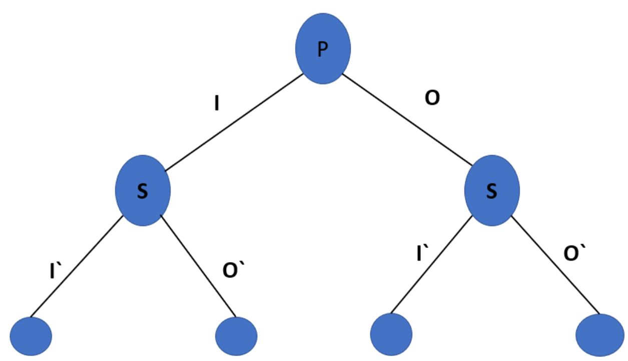


Fig. 3. Decision Tree for Channel Utilization.

The gaming strategy for the user is described below:

Strategy 1: If primary user P plays, I then Play $I^C$; If player P plays O then it is denoted by ($I^C$, $I^C$)

Strategy 2: If Primary user P play, I then play $o^c$ it is denoted by ($I^C$, $O^C$)

Strategy 3: If primary user P play, I then play $o^c$, if player P plays O, then denoted by ($I^C$, $O^C$)

Strategy 4: If player P plays, I then play $o^c$ if player P plays O, then Play $o^c$ denoted by ($o^c$, $o^c$)

The payoff matrix can be computed as below where the row represents the player 1 and column represents player 2. According to CR the player1 is PU and player2 is SU. The strategy is designed between these two players based on the information of the channel state i.e., the channel state is dynamic which takes two different state Idle or Busy represented I and O respectively. The numeric value for the channel states is 1 and 0. The below table represents the payoff matrix for the game:

TABLE I. PAYOFF MATRIX

| P2 / P1 | $I^C, I^C$ | $I^C, O^C$ | $O^C, I^C$ | $O^C, O^C$ |
|---|---|---|---|---|
| I | (I, I) | (I, O) | (O, I) | (O, O) |
| O | (O, O) | (O, I) | (I, O) | (I, I) |

Depending on the payoff matrix as shown in Table I, the secondary user makes a decision and then pays the rent to the primary user.

Assumptions:

- The spectral power is constant then the price is fixed which indicates QoS is good.
- The spectral power may vary due to uncertain, in that case the SU pays only for actual service provided.
- During the entire allotted time if the SU is unable to utilize the spectrum, then the price is considered as zero.

## VII. EVALUATION OF SPECTRUM BY THE STANDARD ORGANIZATION

The TRAI uses the marginal cost of fund-based lending rate (MCLR) to index value based on the previous auctions. The spectrum evaluation methodologies were proposed by the international telecommunication union (ITU) they are listed below:

- price from previous auctions duly indexed.
- assessing producer surplus.
- production function approach.
- revenue surplus approach.

The other components are telecom index price or the consumer price index (CPI).

Methods for valuation of spectrum.

*1)* Base Rate: The interest rate can be used by banks or for computation. The base rate is used to calculate the present index value.

*2)* Weighted Average cost of Capital (WACC): The value of the firm is created based on the rate of returns of WACC. The cost is been invested in different types of shares such as investors of equity, debt, preference share, etc.

*3)* Cost Inflation Index (CII): The price of inflation rate is matched with the CII. An increase in the prices. The present value of the spectrum is calculated from the past.

*4)* Produce surplus method: the surplus is calculated when additional spectrum is allocated to an existing TSP. It is calculated as shown (The present value of the expenditure on the network during the next 'y' year without additional spectrum of 'a' MHz) – (Present value of the expenditure on the network during the next 'y' years with additional spectrum of 'a' MHz).

*5)* Production function approach: It is used for the technological relationship between quantities of physical inputs and quantities of output of goods. The production function is determined by the following equation: $X=Ay^{\alpha}z^{\beta}$.

x- Dependent variable can be minutes of use/ no. of subscribers.

y- Allocated spectrum.

z- No. of Base transceiver stations deployed by the service providers.

$\alpha$ and $\beta$ – Percentage of change in minute of use for a percentage change in spectrum and BTS.

*6)* Revenue Surplus Approach: It is based on the concept of net present value. It estimates the TSP willingness to invest in spectrum based on their projection of potential revenue or surplus over the license period [15].

## VIII. ANALYSIS OF SPECTRUM PRICING USING ANOVA

Spectrum pricing is a huge task that are carried out based on the regulations by the government. The pricing is categorized into reserved price, market price and revenue price. The bidder's pays the reserved price for participating in the bidding auction. The participant will not receive the amount if he does not win the bid. Compared to the bidding price actually the reserve prices are higher. To identify the relationship between market price, reserved price and revenue price statistical method is applied. One-way Anova is applied to find out the relationship and independence among two or more groups. The Anova test is carried out using anaconda with python coding. The data is collected from the secondary source by the author [15]. The below Fig. 4 shows the actual values of the various prices.

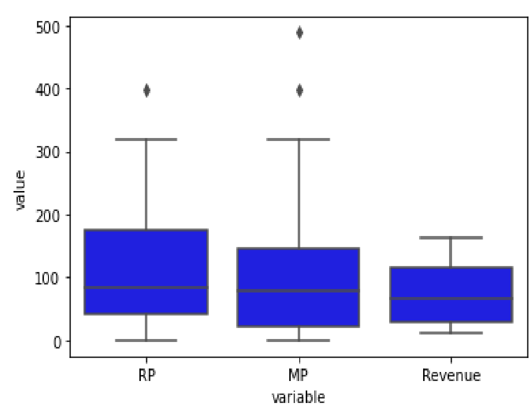


Fig. 4. Boxplot of Various Prices.

The F-value indicates the largest value associated with the independent variable which is real. The Pr(>F) indicates the value which is calculated from the test would have occurred if null hypothesis of no difference among the groups are true. The below Table II shows the F-value and P-value.

Let the null hypothesis H0: All means of prices are same and H1: All the means of prices are different.

TABLE II. F-VALUE AND P-VALUE

| **F-value** | **P-value** |
|---|---|
| 1.3467 | 0.2674 |

The Table III describes the sum of squares among the groups and the degrees of freedom with the F-value and the P-value.

TABLE III. ANOVA TABLE SUMMARY

| | **Sum_sq** | **df** | **F** | **Pr(>F)** |
|---|---|---|---|---|
| **C(variables)** | 29995.8987 | 2 | 1.3467 | 0.26748 |
| **Residuals** | 701618.722095 | 63.0 | NaN | NaN |

According to the value of Pr (>F) is 0.26748 evidence is small which indicates that all means are not same. The residuals represent the individual observation from the list it can take positive value if the individual observation is greater than the mean value. The residuals are negative if the individual observation is lesser than the mean value. The below Table IV describes the mean squares along with the sum of squares.

TABLE IV. MEAN SQUARE VALUES OF ANOVA TEST

| | **Mean_sq** | **Sum_sq** | **df** | **F** | **Pr(>F)** |
|---|---|---|---|---|---|
| C (variables) | 14997.949365 | 29995.8987 | 2 | 1.3467 | 0.26748 |
| Residuals | 11136.805113 | 701618.722095 | 63.0 | NaN | NaN |

Later post hoc test is conducted to verify the null hypothesis, this test is called Tukey's test which is tested for the group after the one-way Anova test. Anova specifies the significance of overall group but Tukey HSD performs on each group means where the means are different. Table V shows the Tukey HSD result.

The residuals are interpreted through the graphs which consists both the positive and negative values.

TABLE V. TUKEY HSD RESULT SUMMARY

| | **Group 1** | **Group 2** | **Diff** | **Upper** | **Lower** | **q-value** | **p-value** |
|---|---|---|---|---|---|---|---|
| 0 | RP | MP | 0.22 | -76.147 | 76.602 | 0.010 | 0.90 |
| 1 | RP | Revenue | 45.3 | -31.037 | 121.71 | 2.015 | 0.33 |
| 2 | MP | Revenue | 45.1 | -31.265 | 121.48 | 2.004 | 0.33 |

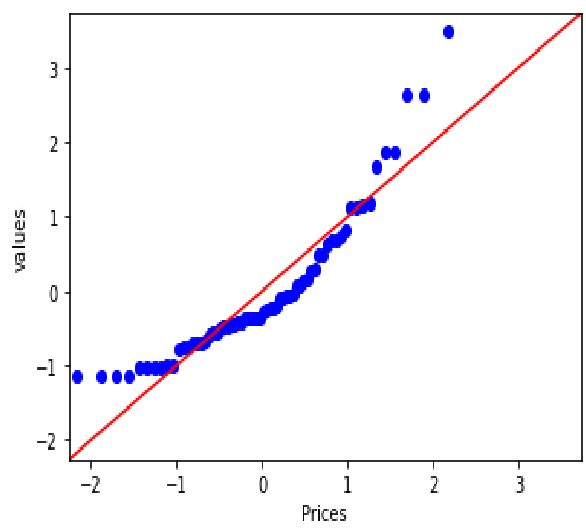


Fig. 5. Q-Q Plot of Residuals.

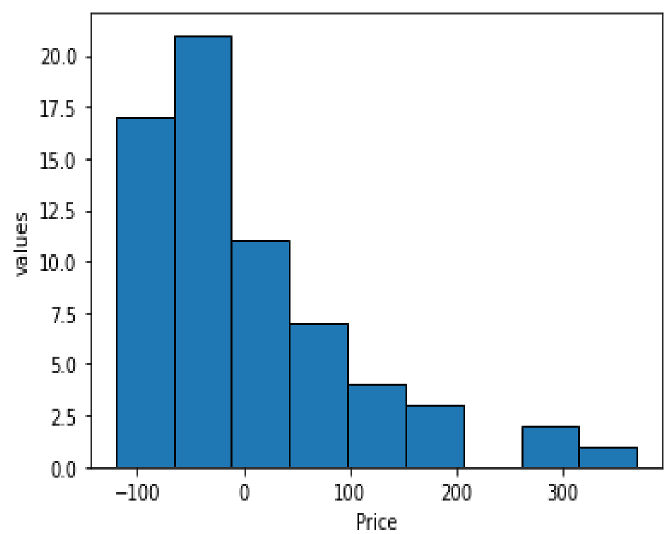


Fig. 6. Hist-Plot of Data.

## IX. INFERENCE FROM THE EXPERIMENTAL TEST

The experiment result for analyzing various price components is discussed in this section. Fig. 4 is an actual data value plot which shows the variation of prices in Market Price Reserve Price and Revenue generated. In this the p-value is 0.2678 the null hypothesis is accepted indicating that all three group price values are considered. In post Tukey HSD test, it determines the significance difference between the groups. The results of p-value of Tukey HSD are 0.9, 0.3350 and 0.3386 which indicates there is no significance difference among the groups. Fig. 5 depicts the Q-Q plot of residuals of Anova Test which indicates that the price is non -normally distributed. Fig. 6 depicts the Histogram suggests that the values are normally distributed with extreme values greater than 300.

## X. Conclusion

In this research work, the strategy for spectrum utilization among the users by applying game theory design mechanism is discussed which provides an incomplete information about spectrum status. The different price components were tested using Anova and later Post Hoc Tukey HSD was conducted to determine that there is no significance difference among the groups and in-between the groups. The residuals indicate that the price components are non-normally distributed and the histogram plot are normally distributed with errors. The future work will focus on minimizing the base rate for bidding the spectrum and maximizing the spectrum utilization with minimal price and time.

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