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Cognitive Radios - A Solution for Dilemma Between Competition, Pricing and Practicality with Queuing Theory Approach

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Abstract

Pricing plays an important role in Network dynamics. In Cognitive Radio there are two classes- licensed and unlicensed users. So in this paper a mathematical model is derived trying to show the effect of competition can lead to channel allocation problem at the cost of revenue. Though the model reaches Nash Equilibrium but MM1/Q model really gives an idea how channel allocation problem is giving rise to Cognitive theory concept.

Keywords

Dynamic Spectrum Allocation, Cognitive Radio, Queuing theory, Profit margin.

1. Introduction

To design efficient and effective dynamic spectrum access technique for cognitive radio network the economic aspects (pricing, spectrum auction) needs to be considered. Basically there are two approaches competition and cooperation. While determining the pricing model, a highly available spectrum allocation service model in dynamic spectrum market needs to be considered. In [1] HA-SAS model is prepared to meet the reliability requirement of more secondary users with minimum price and they have proposed a greedy algorithm for MP problem (minimum price) and a dynamic programming for MR (maximum reliability).In [2] Sengupta et al analyzed spectrum allocation to WSP's and interaction of secondary users with the WSP's from an economic view point. In [3] a new DSM scheme is proposed based on game theory and the problem of competitive pricing in a dynamic spectrum access scenario is produced. Reputation mechanism is initiated to incentive selfish users to cooperate. It gives an optimal outcome of the spectrum allocation model and decreases pricing overhead due to frequent bid/ask updates and message exchanges. In [4] a Bayesian approach is followed for dynamic pricing of call rates. For this authors have adapted a non-cooperative game theoretic approach and have taken into consideration service provider's revenue, along with the cost of effort or resources to get the revenue. Freyan et al [5] depicted a question that which one is better a shared or exclusive radio wave. The paper is ultimately of the view that the combination will play an active role. In [6] the paper proposes a multi cell uplink power allocation scheme based on non-cooperative games. The scheme makes the performance of coverage and capacity balanced by the negotiation of the uplink power parameters among multi cells. So the performance of every cell can reach Nash Equilibrium, making it feasible to reduce the inter cell interference by setting an appropriate uplink power parameter. In [7] the concept of primary and secondary users has not been covered but rather generalizes the pricing based bandwidth allocation algorithm by the stackelberg game model which optimizes the profit of cooperative relay nodes while guaranteeing the bandwidth requirement of the client node. The profit maximization problem becomes a convex problem and the solution is made with the aid of convex optimization method. In [8] there is a distributed mechanism design which handles interference issues and provides scalable and incentive compatible allocation and pricing mechanism. In [9] also the direct link with the cognitive radio is not there but the service provider, which offers services based on elastic reservation with a GoS (Grade of Service) should be interested in knowing how to price these services, or in other words it is linked with how SP(Service Provider) provides the pricing scheme for its services.

In [10] cognitive radio is focused and spectrum management is taken into consideration. Price utility function-based power allocation is analyzed and optimization is taken into consideration. In [11] flexible spectrum management is taken into consideration and the emerging markets of India and Finland are taken as case studies. The paper also focuses on different policies that affect the spectrum management. In [12] different regulatory schemes have been taken into consideration. In this paper it is concluded that DSM (Dynamic Spectrum Management) facilitates detection and trading of spectrum in a very easy manner. It is also seen that transaction should take place between market participants rather than a regulator. In [13] problem of session establishment takes place and a game is formulated between different parties namely the provider, current user and potential customers. The solution produces a pricing scheme and admission control policy that achieves network operator's optimum utility. In [14] customer behavior pattern and migration is shown with C-means clustering and fuzzy logic is used extensively. Migratory behavior of customer is portrayed in this paper. In [15] a mixed strategy is chosen in the game theory model and it shows that the traditional maximum rate packet scheduling algorithm can cause non-cooperative devices to converge to highly inefficient Nash Equilibrium. However in this paper authors have proposed a repeated game to enforce cooperation and a new game theoretic model which attains the Nash Equilibrium. In [16] Paul et al focuses on dynamic spectrum allocation based on game theoretic approach and max-min fairness. Authors have come out with the concept of LSC (Local Spectrum Controller) which is dedicated for managing the common pool of spectrum allocated to each SP (Service Provider). The game has been designed as n player game between LSCs and ANs (Access Networks). They have solved the problem with the aid of a shapely value and t value (t value is a solution approach for solving cooperative games). In [17] a hybrid game model is constructed based on global information of relevant spectrum allocation of both primary and secondary users. Competition among primary user is modeled as a non-cooperative game and an iterative algorithm is employed to achieve the Nash Equilibrium. It tests the hybrid game model based on different parameters. In [18] it is seen that traffic load is unevenly distributed among access points (AP). It calculates AP's price when the vehicles are non-stationary and the whole process is acting as a repeated game model. The final equilibrium solution set is AP's pricing strategy and the paper claims that the equilibrium solution set can affect vehicle's selection and ensures AP's load balancing. In [19] an adaptive bandwidth allocation and admission control mechanism based on game theory is proposed. A non-cooperative 2 person non -zero sum game is formulated where the BS (Base Station) and new connection are the players of the game. A queuing model for the physical layer is constructed and the queuing model is used by the proposed Bandwidth allocation and admission control mechanism. The paper also ensures that the utilities for both BS and new connection are maximized. The paper also claims that the strategy outperforms the traditional schemes like static and adaptive schemes. In [20] an excellent survey on secondary usage of spectrum has been done. The challenges on real time secondary usage of spectrum have been addressed here. In [21] Yuedong et al proposes an oligopoly pricing framework for dynamic spectrum allocation in which the primary users sell excessive spectrum to the secondary users. Both the methods propose a low complexity searching method to obtain Nash Equilibrium. Here it also focuses on the chaotic behavior of dynamic price with respect to learning rate. In [22] Wang et al proposes that game theory is the tool in studying, modeling and analyzing the cognitive interaction process. Game theory model is used for spectrum sharing protocols.

2. Problem Statement Regarding Competition

In terms of Indian market scenario which we have taken into consideration in this paper number of mobile subscribers is almost touching the population rate. Early 21st century saw the voice communication as the only source in cellular market scenario but now we have smart phones coming in it has become an oligopoly market [23]. The exact situation will be made clear through the following diagram see Fig. 1.

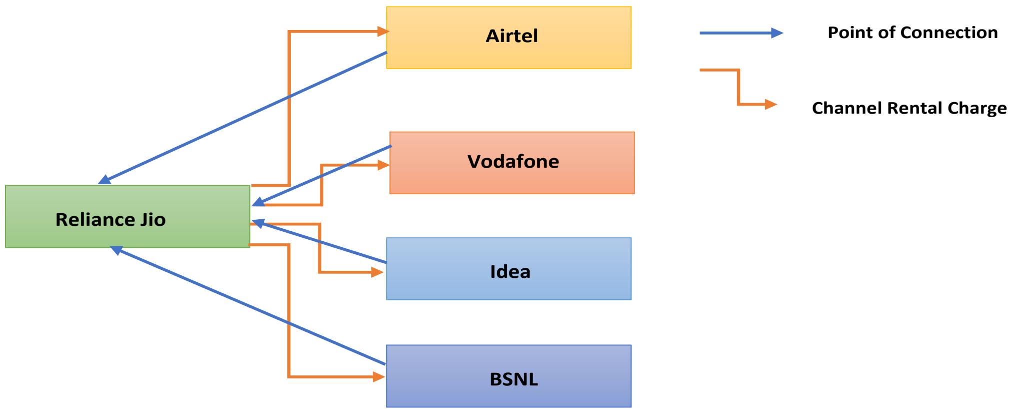

Fig. 1. Some Companies prevailing in Indian market

Now what we see from the above figure are the market players prevailing in the Indian market. But what about spectrum allocation of course the big majors who have got huge customer base have paid more and have got greater spectrum. But now due to the completion Suppose Reliance Jio now charges less and we have assumed a 20% probability that customers will shift to Reliance but the situation is cumbersome. Due to spectrum underlay Reliance have to depend on other companies so that the spectrum hole (cognitive Radio) can be utilized. The utilization may be based on game theory [1, 2….22] which is not the focus of the paper. In [14] migratory behavior of customer model have been prepared and we want to show the actual problem i.e the dilemma between revenue and service.

3. Proposed Mathematics Depicting the Dilemma

As we know from the basic architecture that each and every Service provider have got a certain capacity based on the spectrum allocation. So no. of channels is fixed. So let us go through the following example.

Table 1. Total Revenue of Companies at time t_0

Companies	No. of Customer	Total Capacity	Cost/Unit of Customer	Total Revenue
Reliance Jio	1	2	Rs. 1.0/-	Rs. 1.0/-
Airtel	2	3	Rs. 2.0/-	Rs. 4.0/-
Vodafone	2	3	Rs. 2.0/-	Rs. 4.0/-
Idea	1	2	Rs. 2.0/-	Rs. 2.0/-
BSNL	1	4	Rs. 1.5/-	Rs. 1.5/-

From the initial state we see that Airtel and Vodafone were having maximum capacity in the auction based on the market survey which they did. But now reliance taking the market say reduction taking place by 20% we go for 2nd iteration result.

At time t_1 what will happen -20% customers moving from other companies to Jio.

Table 2. Total Revenue of Companies at time t_1

Companies	No. of Customer	Total Capacity	Cost/Unit of Customer	Total Revenue
Reliance Jio	2.2	2	Rs. 0.5/-	Rs. 1.1/-
Airtel	1.6	3	Rs. 2.0/-	Rs. 3.2/-
Vodafone	1.6	3	Rs. 2.0/-	Rs. 3.2/-
Idea	0.8	2	Rs. 2.0/-	Rs. 1.6/-
BSNL	0.8	4	Rs. 1.5/-	Rs. 1.2/-

Table 3. Game Theoretic model depicting utility value based on Reliability & Price

COMPANY	R	A	V	BS	I
R	(0,0)	(1,1.5)	(1,1,5)	(2,1)	(2,1)
A	(1.5,1)	(0,0)	(0,0)	(0,0)	(0,0)
V	(1.5,1)	(0,0)	(0,0)	(0,0)	(0,0)
BS	(1,2)	(0,0)	(0,0)	(0,0)	(0,0)

If we consider the worst condition, we see that after 2nd iteration Reliance is filled up and here once again we refer to Figure 1. where we see that now it asks for holes/channels in the licensed or unlicensed bands from the cellular service provider majors. Though now Vodafone, Airtel, Idea and BSNL all can lend him and its here where auction and bidding will come into action. According to (1) now {V, A, I, B} all become the secondary users and the primary user is {R} and a game theoretic model can be constructed based on the price & reliability issue:

U (R, I) = (2,1) U (R, A) = (1,1.5) U (R, V) = (1,1.5) U (R, BSNL) = (2,1.5)

Reliability/price function = φ(x1 + x2)

X1= no. of channel left

X2= purchased spectrum cost

4. Game Theory and Nash Equilibrium

Does the above game which has been constructed reach Nash Equilibrium? The answer is yes with respect to Reliance of course. From the above game theoretic diagram, it is seen that (R, I) and (R, B) are the best approach for Reliance. Of course with constraint

Channel capacity of I= 1.2 at t1

Channel capacity of B = 3.2 at t1

So (R, B) is the best choice.

5. Proof with Queuing Theory why cognitive radio is required?

The above problem can be modeled with multiple channel queuing system, where two or more channels work simultaneously. By introducing the number of servicing units the length of the queue and the waiting time are reduced. The multiple channel system presented here assumes FCFS (First come First serve basis). It also assumes that arrivals follow a Poisson probability distribution and service time is exponentially distributed. [24]

λ = average arrival rate

μ = average service rate at each channel

5.1 Case Study-1

Suppose Reliance has 4 channels. Arrival average is 80 persons in 8 hour / busy hours. Average service time is 20s.

Assume λ=10/min, μ=3/min, k=4 channel

$$P(0) = \left(\sum_{n=0}^{k-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n + \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^\kappa \frac{k\mu}{\kappa\mu-1}\right)^{-1} \quad (1)$$

Applying the above formulae we get P (0) = 0.0213 no customer in the system. (All 4 channels are idle).

Average no. of customer in the system =

$$L(s) = (\tfrac{\lambda}{\mu})^k \, \lambda\mu \, 1/(k-1)! \, (k\mu - \lambda)^2 \, * P(0) + (\lambda/\mu) \quad (2)$$

= 6.61 customers

Average queue length =

$L(s) - (\lambda/\mu)$ (3)

=3.28customers

Average time a customer spends in a channel

$W(s) = (\frac{\lambda}{\mu})^k \mu/ (k\text{-}1)!(k\mu\text{-}\lambda)\ 2 * P(0) + 1/\mu$ (4)

= 0.66 min or 40 s.

Average time a customer waits for service

$W(q) = W(s) - (1/\mu)$ (5)

= 0.66-0.33 = 0.33 minute

The probability that a customer has to wait before getting a service

$P(n \geq k) = (\frac{\lambda}{\mu})^k \mu/ (k\text{-}1)!\,(k\mu\text{-}\lambda) * P(0)$ (6)

= 0.65

The expected number of channel at any specified time is given by

$P_n = 1/n!\,(\lambda/\mu)^n P(0)$ (7)

With the aid of the above formulae we get the expected number of idle channels at any specified time is 4P (0) +3P (1) +2P (2) +1P (3) = 0.666

Hence less than 0.666 channels are idle on an average at any time.

6. Result and Discussion

The above result mathematically proves the requirement of cognitive radios which will have to be extensively used in competitive market scenario. Whether cooperative game theory will be applied or not depends upon the market condition. Here are some of the results after only 2 iterations the net revenue of CSP.

Table 4. Initial revenue when no migration of customers.

Company Name	Revenue
Reliance	1
IDEA	2
Airtel	4
Vodafone	4
BSNL	1.5

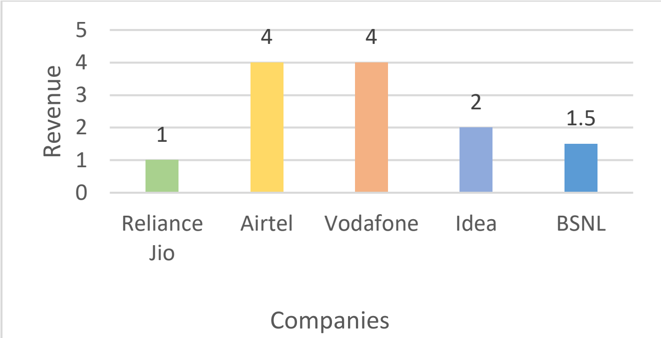

Fig.2. Revenue of Service Providers Before migration of customers

Table 5. After 1st iteration revenue with migration

Company Name	Revenue
Reliance	1.1
IDEA	1.6
Airtel	3.2
Vodafone	3.2
BSNL	1.2

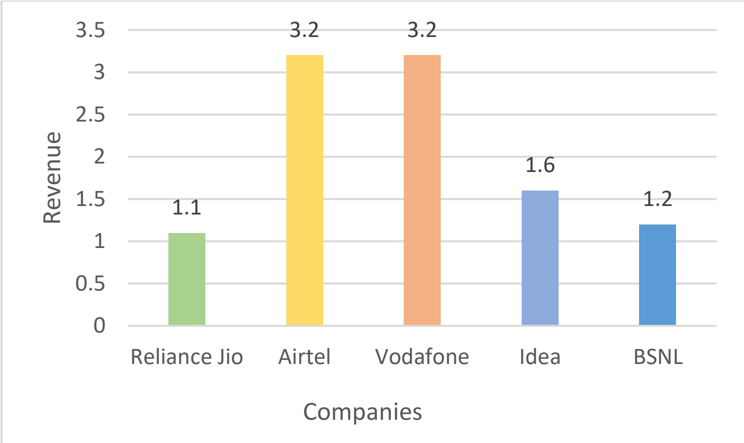

Fig. 3. Revenue of Service providers after migration.

Conclusions

Thus we see an interesting result. Just with 4 channels the primary service provider faces problem in customer satisfaction. So service providers must cooperate as spectrum is still a scarce resource. In the above paper we have not considered the revenue to be paid by the primary user to secondary user. Another interesting case of bidding needs to be considered. So, further enhancement to the job is required.

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