

Policies for Scheduling Primary and Secondary users in Cognitive Radio Network using Game Theory

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Abstract— Cognitive Radio Network consists of Secondary Users (SUs) and Primary Users (PU). Primary Users are the licensed owners of the band, which will lease a part of band to the Secondary Users. Thus the Secondary Users can transmit opportunistically whenever the queue of PU is empty. The Secondary Users can cooperate with the Primary Users when the queue is busy, so that the success probability of Primary Users will be increased. Thus Secondary Users need to take intelligent decision on whether to cooperate or not. Imperfect sensing finds out any false sensing in the channel. However it fails to find an optimal solution in spectral sensing, when channel sensing errors are considered. In order to overcome this problem, a robust game theoretic framework is used for Dynamic Spectrum Access (DSA) management over multiple channels for spectrum sharing between PU and SUs. It improves expected utility maximization and it is less complex. However it may have delay in retransmission of SUs as they send aggressively. To solve the retransmission delays, a power trading mechanism is introduced. Thus it improves the efficiency of the CRN by limiting the time and power usage.

Index Terms— Imperfect sensing, Primary User, Secondary User

I. INTRODUCTION

Recently Cognitive Radio Networks (CRNs) have higher importance since it can change or adjust its parameters dynamically according to the divers condition arises. CRNs have been commonly used for power control, energy detection, spectrum sensing, spectrum management etc. Its applications include rural broad band telecommunication companies, public safety, utilities/smart grids, mobile content providers, cable markets, military applications etc.

CRNs usually include Primary Users (PUs) and Secondary Users (SUs). Primary Users are the licensed owners of the band whereas the Secondary Users are unlicensed users. The PU leases a portion of its spectrum to the SUs to transmit SU's data, when they are idle. That is, the Secondary Users cannot utilize the band to transmit its own data when PU is busy. In such cases, the SUs will cooperate with PU, so that the probability of success transmission of PUs will improve. So the SUs need to identify the abundant spectrum holes (also known as white spaces) of licensed bands so that it can transmit its data. Here the interference of SUs with PU will be minimum.

This whole paradigm is called "Dynamic Spectrum Access" (DSA) [1]-[3], which can find solution for the current spectrum inefficiency problem.

With the use of CRNs, it is possible to provide benefits for both Primary User and Secondary Users by exploiting the transmit power resources of Secondary Users for the purpose to increase the successful transmission rate of Primary User. So the probability of PU queue being empty will be increased and hence the channel of PU will be more often free.

Making efficient use of PU channel as much as possible by increasing transmission rates of PU's while maintaining limited interference to SU's is the main objective. SU's only have a limited resources, hence they need to take intelligent decisions on whether to cooperate with PU or not[1]. So, for these intelligent decisions a dynamite decision policy for SU activities must be considered [1], [4]. The policy is having a constraint that the packet arrival of PU must not exceed a std threshold. so that PU queue will be stable even though no SU cooperates [1]. However this may not be true for all cases. so there is a need to consider the case where packet arrivals rate of PU exceeds the std threshold while still SU's can use the channel for performing their own transmission [1], [4]. Since the decisions and success probabilities of SU's changes with PU busy PU idle conditions, there is a need for solutions of a non-trivial constrained markov decision problem where is size of PU queue [1].

However when channel sensing errors have occurred, it is not possible to find a solution that is optima. To avoid this problem, a game theory model is proposed for regret minimization of power control and channel selection. To avoid the failure in SU transmission, when they transmit massively which may result in large retransmissions delays, a power trading mechanism is also proposed. Thus it will result in improved power saving.

At every time PU channel may be either busy or idle. When PU channel may be either busy, no SU can transmit its own data. They can only operate with PU, when PU channel is idle, SU can transmit their own data in appropriate power levels by renting the spectrum from the PU. Compared to other policies this provides a higher PU throughput. All the decision variables can be computed offline.

Here also investigate the impact of imperfect sensing of spectrum on the performances on transmission and distributed implementation implementations are also proposed to avoid any single point of failure.

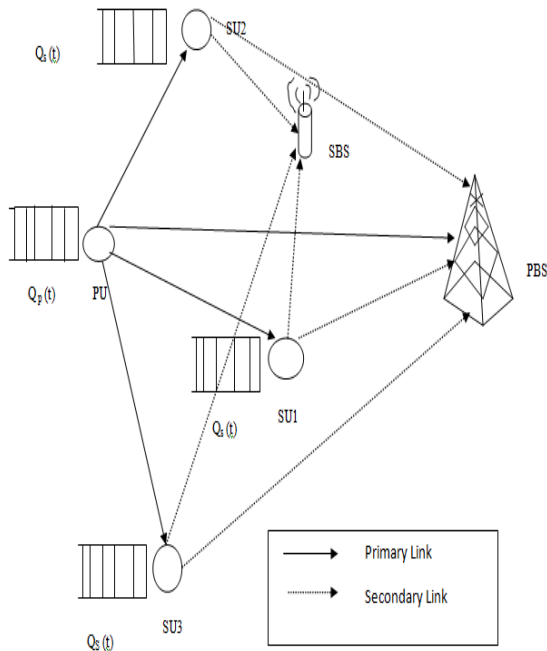


Fig 1. System Architecture

II. SYSTEM DESIGN

The system architecture consists of one PU and multiple SUs along with the Primary Base Station (PBS) and the Secondary Base Station (SBS) as shown in Fig.1. $Q_s(t)$ and $Q_p(t)$ are the queues for SUs and PU respectively. PU is the licensed owner of the channel and it will lease transmission opportunities to SUs when it is idle. SUs will cooperate with PU whenever the channel is busy. This is done by allocating a part of transmit resources of Secondary Users for the sake of Primary User. The cooperation of SUs with PU has been studied in many works that span over communication layers. This architecture covers the generality of all those methods.

One SU can cooperate with PU when the channel is busy. When the channel is sensed busy all the SUs together decide that which one of them will cooperate with PU at which power level. When the channel is idle SUs will decide that which SU can transmit its own data at which power level. The following represents the system model parameters and available controls.

A. Parameters

Considering a time-slotted model with the slot represented as 't' (where $t=0,1,\dots$). The time interval is represented as $[t,t+1)$; which are the beginning and end of the time slot 't'. The $A_p(t)$ is the arrival process with mean rate of y_b packets/slot (where $y_b = E[A_p(t)]$). Every SU $s \in S$, where S is the subset of SUs. All of the SUs can transmit their own data or cooperate with the PU only by using one

of the power levels $P_s(i)$, where $i=1,\dots,I_s$. Here assuming that SUs have an infinite number of packets to send. Only one transmission will take place at a time slot and during PU transmits its own data only one SU can cooperate with that transmission. For every s , the power level used at the slot t by the s must hold,

$$\limsup_{t \rightarrow \infty} 1/t \sum_{T=0}^t E [P_s(i(T))] \leq P_s^*, i(T) \in I_s^0(1)$$

$E[.]$ represents expectation $I_s^0 = I_s \cup \{0\}$

Here every transmission by both PU and SU are either completely received or completely erased.

B. Controls

$Q_p(t)$ is the queue of Primary User. Depending upon its busy or idle status various controls are available

When $Q_p(t) > 0$: PU channel is busy

- PU sends its own packet, where SUs cannot send any packets at this time. This is known as PU priority constraint [1].
- One of the SUs $s \in S$ is selected for cooperating with the PU's transmission at a suitable power level i . When $i(t) = 0$, no cooperation happens.

When $Q_p(t) < 0$: PU channel is idle

- One of the SUs $s \in S$ is selected for transmitting its own packet at the power level i . When $i(t) = 0$, no transmission happens.

C. Admissible, extended class of policies and rate regio

For a policy to be called admissible it should satisfy the priority constraint, PU queue must be stable in the sense of mean-rate and average power constraint of (1) must be satisfied. The long term average transmission rate under this policy is,

$$\tilde{r}_s = \lim_{t \rightarrow \infty} \inf \sum_{T=0}^{t-1} E [r_s(P_s(i(T)))] \frac{1}{t} \quad (2)$$

Where s transmits in the slot t with the power level $P_s(i(T))$

The objective function is of the form:

$$\text{Maximize: } f(\tilde{r}) \quad (3)$$

Where \tilde{r} belongs to the rate region and its linear function is $f(.)$.

Let C_1 be the class of admissible policies in Markov Decision Process. It is of the form:

- When PU channel is busy and $Q_p(t) = m$, a SU is selected to cooperate with PU at a power level i with a probability that depends on m .
- When PU channel is idle and $Q_p(t) = 0$, one of the SUs are selected to transmit its own packet with a certain probability

Let C_0 be a subset of policies of C_1 , then policy in C_0 is as follows:

- When PU channel is sensed busy or $Q_p(t) > 0$, a SU is selected to cooperate with PU at a power level i with a probability $q(s,i/b)$.

- When PU channel is sensed idle or $Q_p(t) = 0$, one of the SUs are selected to transmit its own packet with a probability $q(s,i/e)$.

Now consider C_2 , set of extended policies, which does not satisfies the PU priority constraint. So, it may transmit an SU packet instead of a PU packet when the queue is non-empty at the beginning slot. So the control is of the form (u,s,i) where $u = 0$ or 1 .

- Control $(1,s,i)$ means that PU packets are transmitted with the secondary user s cooperates on the power level i
- Control $(0,s,i)$ means that packets of selected SU s are transmitted at the power level i

From all these it is understood that $C_0 \subseteq C_1 \subseteq C_2$ and $R_0 \subseteq R_1 \subseteq R_2$; where R_0, R_1 and R_2 are the rate regions under C_0, C_1 and C_2 respectively.

III. ACHIEVABLE RATE REGIONS

A. Achievable Rate Region in C_0

The average packet service rate of PU queue for any policies in C_0 is as follows:

$$\tilde{r}_p = \sum_{s \in S} \sum_{i \in L_s}^0 r_p(s,i) q(s,i/b) \quad (4)$$

Let q_b be the steady state probability of PU queue being busy and let q_e be the steady state probability of PU queue being empty and $q_e = 1 - q_b$. On applying Little's formula, we get:

$$q_b = P_r \{ \text{PU queue is busy} \} = y_b / \tilde{r}_p \quad (5)$$

The average packet transmission rate of SU s traffic is as follows:

$$\tilde{r}_s = (\sum_{i \in L_s} r_s(i) q(s,i,e)) q_e \quad (6)$$

The average power consumption of every SU is:

$$P_s' = q_e \sum_{i \in L_s} P_s(i) q(s,i/e) + q_b \sum_{i \in L_s} P_s(i) q(s,i/b) \quad (7)$$

Eqn. (6) can be re-written as:

$$\tilde{r}_s = \sum_{i \in L_s} r_s(i) q(e,s,i) \quad (8)$$

Flow control action: Each of the $A_s(t)$ packets that arrive to SU s at time t , is admitted with probability p_s . The packet admission events are independent of each other and independent of other processes in the system. When $Q_p(t) > 0$, select a SU s to cooperate at i th power level with a probability $q(s,i/b)$. When $Q_p(t)=0$, select a SU s to transmit its own data at power level i . In case if the selected SU has no data to transmit, it will lose its transmission opportunity.

B. Achievable Rate Region in C_2

The available controls in C_2 do not obey the PU priority constraint. Hence these policies fall in the category of policies in [6]. The probability of successful transmission of SU s packet is given by;

$$\tilde{r}_s = \sum_{i \in L_s} r_s(i) p(0,s,i) \quad (9)$$

While the probability of successful transmission of PU packets is given by;

$$\tilde{r}_p = \sum_{s \in S} \sum_{i \in L_s}^0 r_p(s,i) p(1,s,i) \quad (10)$$

Where the stability of PU queue needs that the average packet rate should be greater than or equal to PU arrival rate.

$q(b,s,i)$ is the probability that PU queue is nonempty and SU s is selected for cooperation at i th power level, the $p(1,s,i)$ is known as the probability that an SU s is selected for cooperation at power level i . $q(e,s,i)$ is the probability that PU queue is empty and secondary user packets are transmitted in a slot at i th power level, while $p(0,s,i)$ is the probability of selecting a SU to transmit its own packet at the i th power level, while PU does not transmit.

C. Imperfect Sensing

It is a necessary to sense the channel to know if the channel is busy or idle. Sometimes this sensing may go wrong because of many reasons. Here we assume that the channel sensing events are independent across slots and transmission choices. Let P_D denotes the probability of detection and P_F denotes false alarm in sensing where $P_D = P_r \{ \text{sense busy} | \text{channel is busy} \}$ and $P_F = P_r \{ \text{sense busy} | \text{channel is idle} \}$.

When the channel is busy but sensed idle with a probability $q_b(1 - P_D)$, one of the SUs will transmit its own data along with the PU. Here collision occurs since both PU and SU transmit packets at the same slot. Thus both transmissions fail. But if no SU transmits packets then the PU can send its packet successfully. Its effect on the successful transmission of a PU packet is as follows:

$$\tilde{r}_p = (1 - P_D) \sum_{s \in S} q(s,0/e) r_p(0) + P_D \sum_{s \in S} \sum_{i \in L_s}^0 r_p(s,i) q(s,i/b) \quad (11)$$

When the channel is idle but sensed busy with a probability $q_e P_F$, then an SU is selected to cooperate with the PU thus losing its opportunity to transmit its own data. Its effect on the successful transmission of a PU packet is as follows:

$$\tilde{r}_s = q_e(1 - P_F) \sum_{i \in L_s} r_s(i) q(s,i/e) \quad (12)$$

The probability of the channel being busy and sensed busy is $q_b P_D$ and the probability of the channel being idle and sensed idle is $q_e(1 - P_F)$.

D. Game theory

Game theory is the study of mathematical models of clash and cooperation between intelligent rational decision-makers. Game theory is mainly used in economics, and psychology, as well as logic, computer science and biology. Originally, it dealt with zero-sum games, where one person's gains result in losses for the other participants.

Game engine based on regret minimization provides less complexity and quick solutions than traditional game solutions based on utility maximization. But this approach may cause failure in SU transmissions as they transmit

aggressively and cause large delay on retransmission [7]. In order to limit the time and power consumption of the network, a power trading mechanism is introduced, where the PUs rent their unused frequencies to SUs that use suitable power levels to transmit. It also ensures that the use of spectrum by SUs does not interfere with others in the network. Applying regret minimization techniques to choose a policy based on its regret, which is the additional cost due to not using the optimal policy. A decision making module will be there for each type of user, each with its own policy space and utility. The strategies of users include selecting channels and performing power control.

IV. SIMULATION RESULTS

First let us assume that SUs have infinite number of packets to transmit and spectrum sensing is perfect. The performance of a setup with 5 available transmit power levels is shown in Figs. 2, in terms of $f(\tilde{r})$ and average backlog of PU queue. Here we are considering a system with one PU and several SUs. Mainly, we assume for this setup that $I^0_s = \{0,1,2,3,4\}$, $P_s = \{0,0.25,0.5,0.75,1\}$, $r_p(0) = 0.4$, $r_p(s,1) = 0.5$, $r_p(s,2) = 0.6$, $r_p(s,3) = 0.7$, $r_p(s,4) = 0.8$, $r_s(1) = 0.3$, $r_s(2) = 0.5$, $r_s(3) = 0.8$, $r_s(4) = 1$, and the average power constraint is $P_s' = 0.15$, for all $s \in S$.

Fig. 2 shows the rate region R_0 for a system setup with only two Secondary Users with all the above assumed conditions.

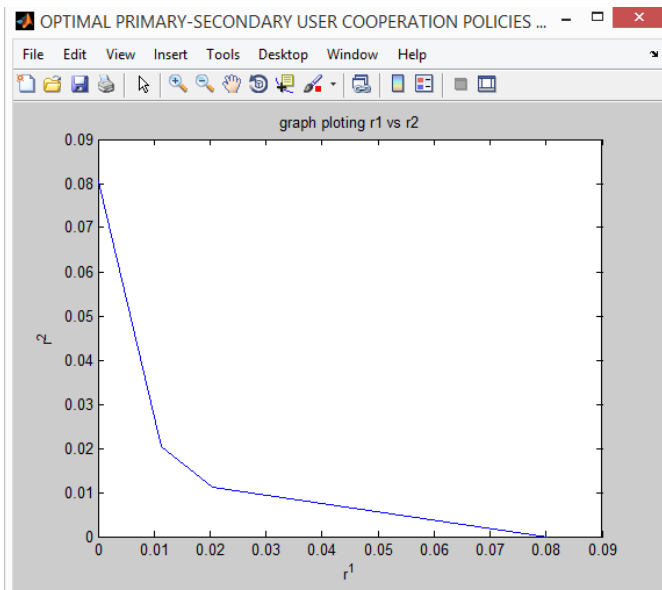


Fig. 2. The rate region R_0 for a system

From Fig. 3, it is understood that the sum rate achieved with five SUs from restricted policies C_0 is almost identical to the sum rate achieved with the policies in C_2 but the average backlog of PU is very low in C_0 . Y_b is the arrival rate.

Fig. 4 shows the effects of imperfect sensing of spectrum, by fixing q_b and calculating maximum value of $g(q_b)$ where $q_b \in [0,1]$ for different values of P_D and P_F . Those are $P_D = 0.26, 0.07, 0.39, 0.27, 0.42$ and $P_F = 0.81, 0.75, 0.92, 0.99, 0.99$. The simulation results shows

that $g(q_b)$ is concave with respect to q_b for any values of P_D and P_F . Here we set 5 set of P_D and P_F . Due to this property which is general, the computational complexity and overhead of distributed implementation can be reduced.

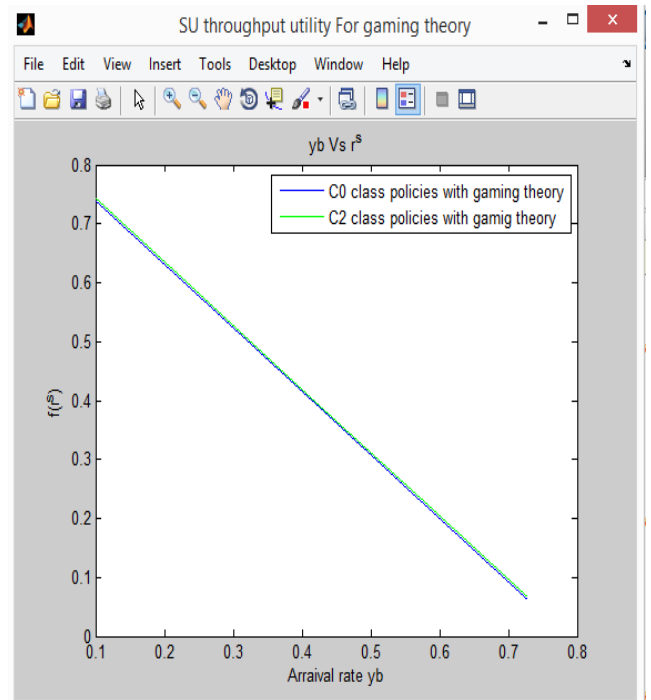


Fig. 3. SU throughput utility function

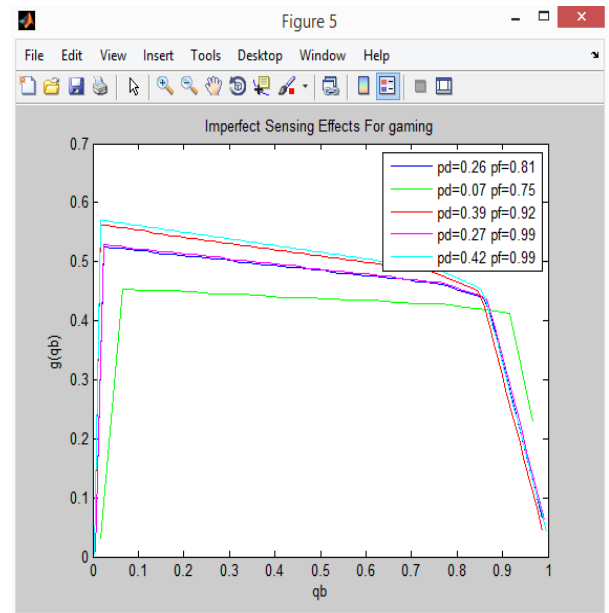


Fig. 4. Imperfect sensing effects

Fig. 5 shows the comparison of one existing system and our proposed system with gaming theory. The existing system represents the algorithm presented in [1]. From this it is possible to find that the SU throughput utility for both classes C_0 and C_2 in our proposed method is better than that of the method in [1].

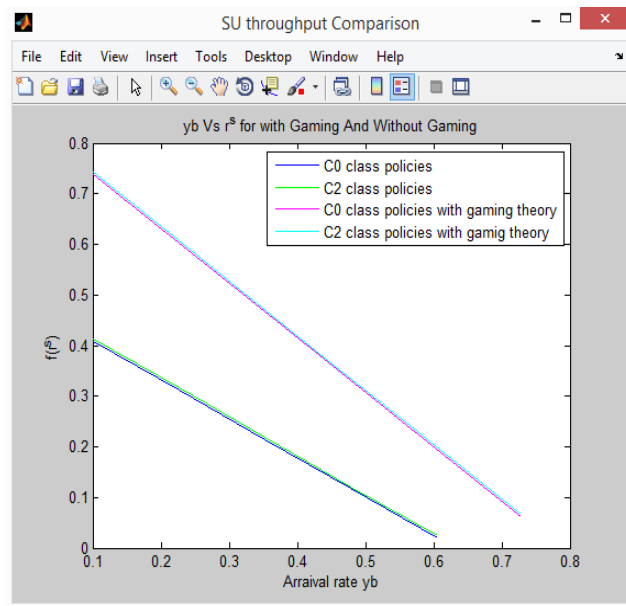


Fig. 5. SU throughput comparison

V. CONCLUSION

CRNs mainly have both Primary and Secondary Users. The existing work learned about optimal cooperative PU-SUs transmission control algorithms PU channel are used as efficiently as possible, namely maximize the transmission rates of the SUs, while guaranteeing uninterrupted packet transmission for the PU, and stability of its queue. The secondary users (SUs) may assist the primary user (PU) thus the PU transmission rates are improved, while SUs obtain more transmission opportunities.

However this work fails to find an optimal solution in spectral sensing, when channel sensing errors are considered. In order to overcome this problem, a robust game theoretic framework is used for dynamic spectrum access management over different channels for spectrum sharing between PU and SUs. It improves expected utility maximization and it is less complex. However may have delay in retransmission of SUs as they send aggressively. To solve the retransmission delays, a power trading mechanism is introduced. Thus it improves the efficiency of the CRN by limiting the time and power usage.

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