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Energy Efficient Power Allocation In Cognitive Radio Network

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Abstract— Energy efficient wireless cellular networks have been the subject of intense research in recent years. Green radio networks are the demand of new era of communication system. In order to improve the energy of cognitive radio network, the technique for power allocation in transmission link is proposed in this paper. Recently, many technological and network issues like interference and resource allocation or power optimization in cognitive radio network have been studied but only in terms of spectrum sensing. Different from the other work, the optimization of power in order to maximize the energy with consideration of imperfect spectrum sensing is proposed. Simulation result shows that for every value of power levels energy will be improved.

Keywords- *Cognitive Radio Network; Energy Efficiency(EE); Imperfect Spectrum Sensing; Power Allocation; Transmit Power Constraint.*

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I. INTRODUCTION

Due to usage of smart mobile application demand of mobile data traffic is increasing. Spectrum resources are becoming increasingly limited with the emergence of various wireless devices and applications [3]. With the development of wireless devices and technology, new frequency bands are being used in the radio spectrum. Due to increase in the wireless device count, the radio spectrum is becoming gradually congested. Also, the extension in the new wireless devices with the development in technology has promised more and more frequency band to be utilized. This may result in the high level of intrusion among the frequency bands which are being operated adjacent to each other.

The statistics show that a broad range of the spectrum is not being used all the time, depending on the geographical region, whereas the other ranges are used heavily. Thus, the radio spectrum is being underutilized depending on the place and time of the day. This results in the inefficient use of the spectrum. Generally, the frequency bands which are licensed operate at fixed time and remaining time they are free. These free or unused bands of the spectrum cannot be used by conventional wireless systems because these are licensed and can be used only by the respected owners of that band. So, to use those bands which are unused by the licensed user during certain time, we need a device which can automatically change the operating parameters whenever it senses the unused band.

The fifth generation(5G) technology provides the promising solution in cognitive radio which shares the spectrum to the secondary users(SU) when primary users(PU) are inactive or absent. The main functions of cognitive radio are Spectrum Sensing (SS), Spectrum Sharing, Spectrum Decision and Spectrum Mobility. Cognitive radio (CR) improves spectrum efficiency and interference mitigation by sensing the spectrum. The Spectrum sensing and power allocations are two key Functionalities of a CR system, which involves discerning the spectrum usage and salvaging the primary band under given interference constraints. The earliest spectrum access approach is the opportunistic spectrum access where secondary user (SU) can only access the primary band when it is detected to be idle. The second approach is the underlay where SU is allowed to transmit beneath the primary user (PU) signal, while sensing is not needed as long as the quality of service (QoS) of PU is protected. The recent approach, sensing-based spectrum sharing, performs spectrum sensing to control the status of PU and then accesses the primary band with a high transmit power if PU is claimed to be absent, or with a low power otherwise. There are two important metrics in spectrum sensing: 1) detection probability P_d and 2) false alarm probability P_f [2]. The higher the P_d, the better the PUs are protected; the lower the P_f, the more efficiently the channel can be reutilized by SUs.

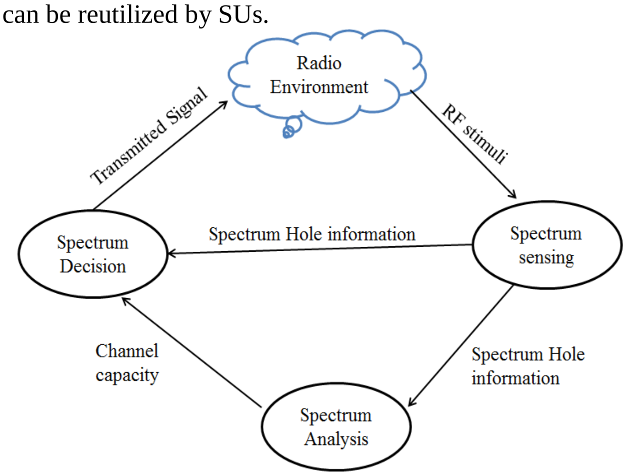

Figure 1 Cognitive Radio Cycle [6]

Cognitive radio based on battery-powered wireless devices can improve spectrum efficiency, meanwhile it will incur lower energy efficiency due to extra sensing time overhead and energy consumption [4]. Therefore, research on energy efficiency of CRNs has been considered more and more important in future wireless systems. Maximization the energy efficiency in wireless communications has been proposed for a long time.

However, in recently years, the evaluation metric of energy efficiency had been paid much attention to. Energy efficient transmission in wireless communication system. The utility function represented the total number of bits that were delivered with per joule of energy consumed. That made the evaluation metric of energy efficiency suitable for application where EEC was more important than achieving high network throughput. A maximization problem for energy efficiency under a minimum data rate constraint and an interference power constraint on SUs [4], [5].

In cognitive radio channel broadcast can be studied for transmission power constraint and interference power constraint. The sensing-access strategies and channel sensing order were jointly designed to optimize the energy efficiency of CRNs based on sequential channel sensing. The optimal transmission duration and power allocation were designed to improve energy efficiency.

In order to do power allocation analysis, we need first detect spectrum holes or lightly used band with fast changing environments; second we need to predict a vacant spectrum in the future for the faster dynamic spectrum access.

There are few main challenges of power allocation analysis in cognitive radio network.

- The main challenge is to find the optimal transmission power levels. The more transmission power, the higher is the transmission data rate. Increasing the transmission power also increase the interference to other users.
- Total transmission power constraint which can protect the primary users by keeping the total interference due to all CR users at PUs below a threshold.

The paper is organized in further section II System Model which shows the complete experiment setup and III Optimal Power Allocation that shows the formulation of energy maximization. At last IV Numerical Result shows for every power level energy is maximized.

II. SYSTEM MODEL

We consider sensing based cognitive radio in which the secondary transceiver pair can utilized the licensed band of primary users. It is assumed that secondary users first perform channel sensing possibly with errors and then initiate data transmission with different power levels based on sensing decisions. The cognitive radio first detects the 'spectrum holes' i.e. frequency band which is allocated to licensed user(PU) by some government agencies but not used at specific time by this user.

In order to detect the spectrum holes, secondary users initially perform channel sensing over a duration of τ. It is assumed that secondary users employ frames of duration T. Hence, data transmission is performed in the remaining duration of $T-\tau$.

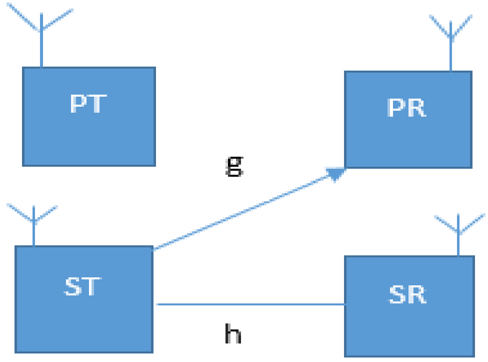

Figure 2 System model Cognitive Radio Setup

Here, we consider the hypothesis setting of primary users when it is active or inactive. Here the system model setup considers the primary transmitter(PT), Primary receiver(PR), secondary transmitter(ST) and secondary receiver(SR). The hypothesis shows the primary users are active and inactive in the channel respectively with representation of H_0 and H_1. The channel or spectrum sensing decision is corresponding with primary users, the channel can be represent as idle and busy with $\hat{H}_0$ and $\hat{H}_1$ respectively.

All the sensing method is having advantages and disadvantages also they are subject to errors of false alarm and miss-detection due to low SNR of PUs, noise and fading in wireless channel [1]. The imperfect sensing consider all the possible errors and performance depends on probability of false alarm and miss-detection. So we are considering the power allocation with imperfect spectrum sensing in cognitive radio network with possible errors like false alarm and miss-detection and with its probabilities. As a result, any sensing method can be employed in the rest of the analysis. Let $\hat{H}_0$ and $\hat{H}_1$ denote the sensing decisions that the channel is occupied and not occupied by the primary users, respectively. Hence, by conditioning on the true hypotheses, the detection and false-alarm probabilities are defined, respectively, as follows:

$$P_d = P_r\{\hat{H}_1|H_1\} \quad (1)$$
$$P_f = P_r\{\hat{H}_1|H_0\} \quad (2)$$

And the correspond conditional probabilities are:

$$P_r\{\hat{H}_0|H_1\} = 1 - P_d \quad (3)$$
$$P_r\{\hat{H}_0|H_0\} = 1 - P_f \quad (4)$$

The channel is considered to be block flat-fading channel in which the fading coefficients stay the same in one frame duration and vary independently from one frame to another; where g and h denotes the channel co-efficient of interference link and transmission link respectively. Secondary users are assumed to transmit under both idle and busy sensing decisions. The rate of secondary user can be defined as:

$$R_a = E_{g,\hat{h},h}\{R(P_0(\hat{g},\hat{h}), P_1(\hat{g},\hat{h})\} \quad (5)$$

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Where, $P_0(g, h)$ is the probability of channel is detected to be idle while it is $P_1(g, h)$ is the probability of channel is detected to be busy.

III. OPTIMAL POWER ALLOCATION

A. Average Transmit and Interference Power Constarint

We obtain the optimal power allocation strategies to maximize the EE of secondary users under average transmit power and average interference power constraints in the presence of different levels of power regarding the transmission and interference links.

Maximization of energy with average power constraint and interference constraint can be formulated as:

$$Max\ \eta_{EE} = \frac{E_{g,h}\{R(P_0(g,h), P_1(g,h)\}}{E_{g,h}\{P_r\{\hat{H}_0\}P_0(g,h) + P_1\{\hat{H}_1\}P_1(g,h)\} + P_c} \quad (6)$$

$$Subject\ to,\quad E_{g,h}\{P_r\{\hat{H}_0\}P_0(g,h) + P_1\{\hat{H}_1\}P_1(g,h)\} \leq P_{avg} \quad (7)$$

$$E_{g,h}\{[(1-P_d)P_0(g,h) + P_dP_1(g,h)]|g|^2\} \leq Q_{avg} \quad (8)$$

$$P_0(g,h),\ P_1(g,h) \geq 0 \quad (9)$$

Here, P_{avg} is total maximum average transmit power and Q_{avg} is maximum allowed average interference power. The average transmits power constraint in (7) is chosen to satisfy the long-term power budget of the secondary users and average interference power constraint in (8) is imposed to limit the interference, and hence to protect the primary user transmission [1].

We use Lagrange Multiplier to solve non-convex optimization problem. It is iterative method; also the Lagrange Multipliers is solved by Sub-Gradient Method iteratively. Here, there are two constraints for optimization problem so we have two Lagrange Multipliers. The $P_0(g, h)$ and $P_1(g, h)$ is given by:

$$P_0(g,h) = \left[\frac{\frac{T-t}{T}P_r\{\hat{H}_0\}\log_2 e}{(\lambda_1+\alpha)P_r\{\hat{H}_0\}+v_1|g|^2(1-P_d)} - \frac{N_0+P_r(H_1|\hat{H}_0)\sigma^2{}_s}{|h|^2}\right] \quad (10)$$

$$P_1(g,h) = \left[\frac{\frac{T-t}{T}P_r\{\hat{H}_1\}\log_2 e}{(\lambda_1+\alpha)P_r\{\hat{H}_1\}+v_1|g|^2(P_d)} - \frac{N_0+P_r(H_1|\hat{H}_1)\sigma^2{}_s}{|h|^2}\right] \quad (11)$$

Here, λ and ν are Lagrange Multipliers. The Lagrange multipliers λ_1 and v_1 can be jointly obtained by inserting the optimal power allocation schemes (10) and (11) into the constraints (7) and (8). However, solving these constraints does not give closed-form expressions for λ_1 and v_1. Therefore, we employ the sub gradient method, i.e., λ_1 and v_1 are updated iteratively until convergence according to the sub gradient direction.

The iterative algorithm is:

Step 1: Initialize the parameters like λ,ν and δ and P_{avg}. make n=0.
Step 2: Repeat: make k=0
Step 3: Calculate the $P_0(g, h)$ and $P_1(g, h)$ according to (10) and (11).
Step 4: Update the λ and ν using Sub-Gradient Method. The equations are given by:

$$\lambda_1^{(k+1)} = \left[\lambda_1^k - t\left(P_{avg} - E_{g,h}\left\{P_r[\hat{H}_0]P_0^{(k)}(g,h) + P_r[\hat{H}_1]P_1^{(k)}(g,h)\right\}\right)\right] \quad (12)$$

$$v_1^{(k+1)} = \left[v_1^k - t\left(Q_{avg} - E_{g,h}\left\{(1-P_d)P_0^{(k)}(g,h) + P_d P_1^{(k)}(g,h)|g|^2\right\}\right)\right] \quad (13)$$

Step 5: Repeat:
Until

$$\left|v_1^k(Q_{avg} - \mathrm{E}_{g,h}\{[(1-P_d)P_0^k(g,h) + P_dP_1^k(g,h)]|g|^2\})\right| \leq \delta \quad (14)$$

$$\left|\lambda_1^k(P_{avg} - \mathrm{E}\{P_r\{\hat{H}_0\}P_0^k(g,h) + P_r\{\hat{H}_1\}P_1^k(g,h)\})\right| \leq \delta \quad (15)$$

Step 6: make k←1 and n←1.
Step 7: Calculate the energy efficiency by:

$$\alpha^{(n+1)} = \frac{E_{g,h}\{R(P_0(g,h), P_1(g,h)\}}{E_{g,h}\{P_r\{\hat{H}_0\}P_0(g,h) + P_1\{\hat{H}_1\}P_1(g,h)\} + P_c} \quad (16)$$

In the inner loop, Lagrange multipliers are updated using the sub gradient method, which involves the computation of sub gradient and simple projection operations. The sub gradient method is widely used to find Lagrange multipliers. Due to its simplicity, easy implementation, the speed for computing a direction, and the global convergence property [1].

IV. NUMERICAL RESULT

In this section We initialized the parameters according to spectrum sensing requirements of the cognitive radio-based IEEE 802.22 wireless regional area network, the probability of detection should be at least 90% and false alarm probability should be at most 10%. Therefore, in the simulations, we analyze the impact of detection probability and false alarm probability on the energy efficiency performance of secondary users and consider imperfect sensing decisions with $P_d = 0.9$ and $P_f = 0.1$.

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TABLE I. INITIALIZATION PARAMETERS

Parameter	Value
$P_r\{H_0\}$	0.6
$P_r\{H_1\}$	0.4
N_0	10^{-8} W/Hz
P_{avg}	-15:0 dBW
Q_{avg}	-25 dBW
$P_r\{\hat{H}_0\}$	0.58
$P_r\{\hat{H}_1\}$	0.42
P_d	0.9
P_f	0.1

Here, $P_r\{\hat{H}_0\}$ and $P_r\{\hat{H}_1\}$ are probabilities of channel sensing decision that wheter channel is occupied or not by PUs.

The simmulation result shows the values of Lagrange Multipliers are decreasing so that the maximization problem of energy can be improved. As shown in TABLE II the energy is increasing i.e maximized as value of average power level is increasing.

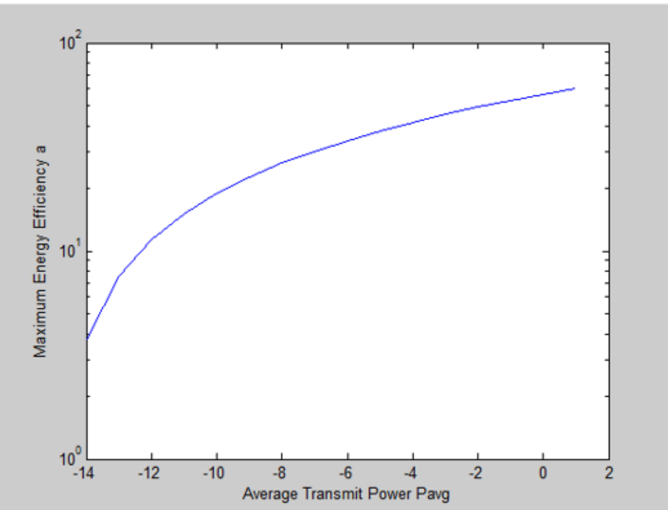

Figure 3 Maximum EE vs. average power constraint perfect sensing

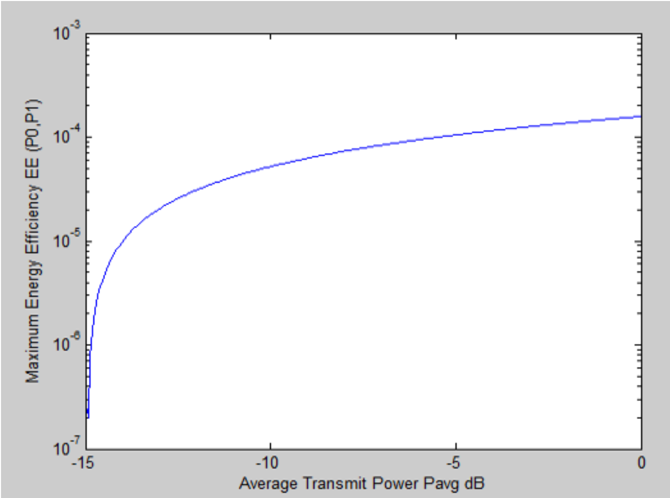

Figure 4 Maximum EE vs. average power constraint with imperfect sensing

TABLE II. DETERMINED VARIABLES

PARAMETER	Values (for every value of average power)			
α	2.096	3.489	4.2797	4.5238
λ	0.1	0.042	-2.0866	-5.2954
ν	0.1	0.037	-7.245	-14.96
P_0	5.227	6.269	7.404	9.8913
P_1	7.49	11.283	20.679	36.963

Table 2 indicates that the energy α is increasing i.e maximized as value of average transmiting power level and average interference power level (P_0 and P_1) is increasing.

Here Figure 3 and Figure 4 shows the power allocation scheme assuming perfect channel sensing can exploit favorable channel conditions and higher transmission power is allocated to better channel, and hence a secondary user's power budget is more efficiently utilized compared to the power allocation scheme assuming imperfect sensing in which the power levels do not change according to channel conditions. It is also seen that imperfect sensing decisions significantly affect the performance of secondary users, resulting in lower EE under both optimal power allocation strategies.

V. CONCLUSION

Due to growing demand for high data rates and increased number of users, energy consumption of wireless systems has gradually increased. Cognitive Radio (CR) is promising solution for it which is effective. For optimal and efficient use of energy resources with the goal of reducing costs and minimizing the energy consumption of wireless systems is of paramount importance, and energy-efficient design has become a consideration in wireless communications from the perspective of green operation. For that allocation of power to cognitive radio is even more important which can be done smartly as no other user can harm of it and transmission can be

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done easily in low energy level and cost. The approach is done by using the iterative method in which Lagrange multipliers are used to reduce the computational complexity. It gives the result as some point the power get minimum but the energy efficiency is maximum and the it become constant.

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