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Energy Efficient Power Allocation in Cognitive Radio Network: A Case of Imperfect Spectrum Sensing- A Study

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Abstract:- A wireless cellular network with energy efficient is the important subject for research in recent years. Cognitive radio can play an important role in improving energy efficiency in wireless networks, because from the green perspective, spectrum is a scare natural resource which should not be wasted but be shared. In this paper we study energy efficiency aspect of imperfect spectrum sensing and power allocation in cognitive radio network. The optimization model is established in which the focus is on maximization of energy efficiency with different power level in transmission link and interference link in considered of error in sensing i.e. imperfect sensing. The problem has been studied out of average transmission power level of cognitive radio and optimum value of energy efficiency has been carried out. By search method of optimization plenty of numerical result is produced. Through numerical result the impact of sensing performance and transmit and interference power constraint on the energy efficiency is shown. Calculation shows that for every value of average transmitting power the energy efficiency will be optimum.

***Keywords*:-** *Cognitive Radio Network, Energy Efficiency (EE), Imperfect Spectrum Sensing.*

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. In CR networks, secondary (unlicensed) users (SUs) should sense the radio environment, and adaptively choose transmission parameters according to sensing outcomes to avoid the interference to primary (licensed) users (PUs). Spectrum Efficiency (SE) and Energy Efficiency (EE) are most important issues to be addressed. 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. Therefore, research on energy efficiency of CRNs has been considered more and more important in future wireless systems. So, to maintain the Quality of Service (Qos) and transmit the power to the secondary users without interfering primary users the Energy Efficiency (EE) is required. The ability of energy efficient Cognitive Radio Network (CRN) is to transmit maximum data without interfering primary spectrum. The Energy Efficiency is defined as number of bits transmitted per total power consumption. Both sensing and transmission consume energy. For a given level of transmit power, sensing more channels can help explore the diversity among different channels, and possibly find a channel with higher transmission rate.

This paper focuses on the power allocation strategies in CRN in consideration of energy maximization. The optimization problem is considering maximization of energy. However, all of the work on this area is focused on maximizing the transmission throughput. In this case, maximum transmit power is always preferred and no design of power allocation is needed. However, when energy efficiency is of concern, power allocation affects the design through both the throughput and energy consumption. Hence, maximum transmit power may not be optimal from the perspective of energy efficiency. There is a need to incorporate power allocation design in the study of energy efficiency. Here we focused on maximization of energy in presence of Imperfect Spectrum Sensing. Imperfect Spectrum Sensing is the spectrum sensing with errors like low Signal to Noise Ratio (SNR), multipath fading or uncertainty of noise. These errors subjected to the miss detection or false alarm. There are two important metrics in spectrum sensing: 1) detection probability Pd and 2) false alarm probability Pf [2]. The higher the Pd, the better the PUs are protected; the lower the Pf, the more efficiently the channel can be reutilized by SUs.

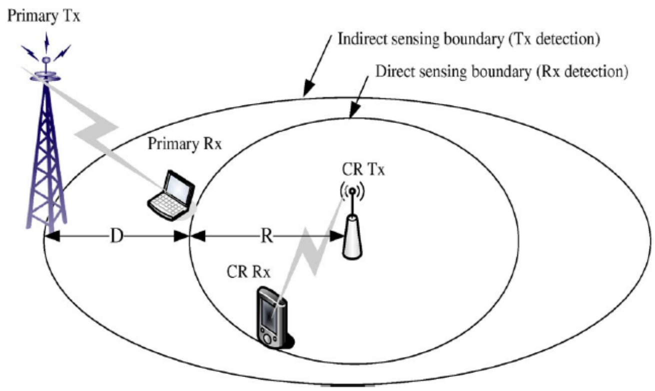

Fig 1:- Principle of Sensing [7]

In figure shows the Primary Transmitter (PT) and Primary Receiver (PR) with region distance D as well as Secondary Transmitter (ST) and Secondary Receiver (SR) with region distance R. Total boundary region is D+R. When D<R it become direct sensing at transmission side and D>R then it become indirect sensing at receiver side.

However, in recently years, the evaluation metric of energy efficiency had been paid much attention to. Besides the effective spectrum utilization, the overall energy efficiency of a wireless network has been recognized as the key paradigm of the future 5th generation (5G) radio communication systems [5]. The impact of sensing duration on Energy Efficiency (EE) of cognitive transmission is significant, which measures the number of transmitted bits normalized by total energy consumption. Hence the different sensing duration may lead to different number of transmitted bits in data transmission phase. This will cause different energy consumption in one cognitive transmitting phase of certain wireless devices.

In addition, different transmit power level of Cognitive Transmitter (CT) also occur different number of transmitting bits and energy consumption in the cognitive system. A higher transmit power corresponds to a larger number of transmitted bits and more energy consumption. Thus the tradeoff between transmission power at CT and the EE of cognitive transmission is exists [3-7].

- The work studied on impact of imperfect spectrum sensing and average EE maximization problem in fading channel, in consideration of average transmit power constraint and average interference power constraints.
- 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 cognitive radio cooperative transmission model as shown in figure 2 where Cognitive Radio (CR) helps to transmit the data. As shown in figure the pair of secondary transmitter and receiver i.e. ST and SR accesses a frequency band licensed to a pair of primary transmitter and receiver i.e. PT and PR, with transmission link between ST to SR having fading coefficient h and interference link between ST to PR having fading coefficient g.

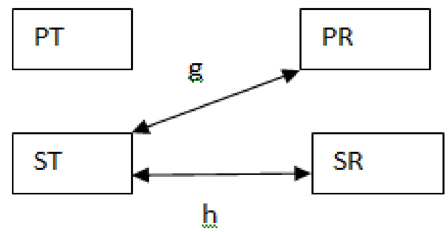

Fig 2:- System Model Cognitive radio setup

However, EE does not form a close loop expression and hard to maximize directly. Based on solver of two problem constraint it has been solved by search algorithm It is based on two hypothesis based on activeness of primary users. The hypothesis denoted by the probability 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.

We consider the spectrum sensing with the error in it due to miss detection or low SNR of secondary users which is called imperfect spectrum sensing. 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. Here $P_r(.)$ represent the probability function. Hence, by conditioning on the two hypotheses, probabilities of the detection and false-alarm 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 corresponding conditional probabilities are (From (1) and (2)):

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

The channel is considering block flat fading with coefficient g and h. In spectrum sharing cognitive radio system spectrum-holes utilized by secondary transmitter and receiver pair. Here, spectrum-holes can be defined as unused frequency band or intervals at certain location at particular time. Secondary users are assumed to transmit under both idle and busy sensing decisions. It is assumed that sensing performed in τ duration and

the total frame duration is T. Therefore the data can be transmitted in remaining duration of T-τ.
The rate of secondary user can be defined as:

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

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

III. OPTIMAL POWER ALLOCATION

The optimal power allocation strategy can be obtained by maximization energy efficiency with respect to allocated average transmission power i.e. idle channel power and busy channel power. The EE is defined as total data rate of secondary user per total transmission power, i.e. total transmitted bits per joule. Maximization of energy with average power constraint P_{avg} and interference constraint Q_{avg} 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,

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

$$E_{g,h}\{[(1-P_d)P_0(g,h) + P_d P_1(g,h)]|g|^2\} \leq Q_{avg} \quad (8)$$

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

Here Pc is a circuit power at transmitter side like D-to-A converter or mixer or filters etc. Here, P_{avg} is total maximum average transmitting 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].

Now we consider the linear search method and compare with exhaustive search method in terms of computational complexity. Although the given algorithm is much simpler, a small step size may need to reach the goal. As a result it gives the pair of (P_0,P_1) that is power of idle channel and power of busy channel; which have maximum energy. The calculation shows the EE is so optimum for channel power constraint for idle as well as busy channel. The result shows the EE can be improved by every value of average power and by optimization toolbox we can obtain the 3-D plots which have pair of (P_0, P_1).

IV. NUMERICAL RESULT

The result is initialized by 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 it consider imperfect sensing decisions with *P*d = 0.9 and *P*f = 0.1 (For perfect it should $P_d = 1$ and $P_f = 0$).

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

Table 1:- Initialization Parameters

The each values of P_{avg} we get the pair of (P_0, P_1) at which the energy will be maximum. And the same on optimization tool box with scripting we get the pair of (P_0, P_1) where energy is maximum.

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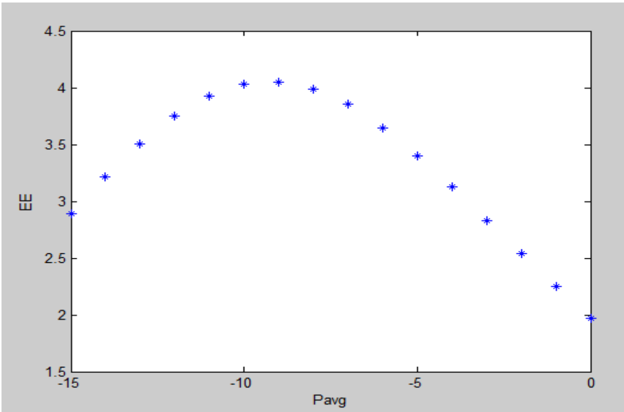

Fig 3:- Energy Efficiency vs. Average Power Constraint

Here Fig.3 shows the power allocation strategy assuming imperfect channel sensing can exploit higher transmission power is allocated to the channel, which satisfied all constraint of objective functions. Here, the value of Q_{avg} is -25dB. 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.

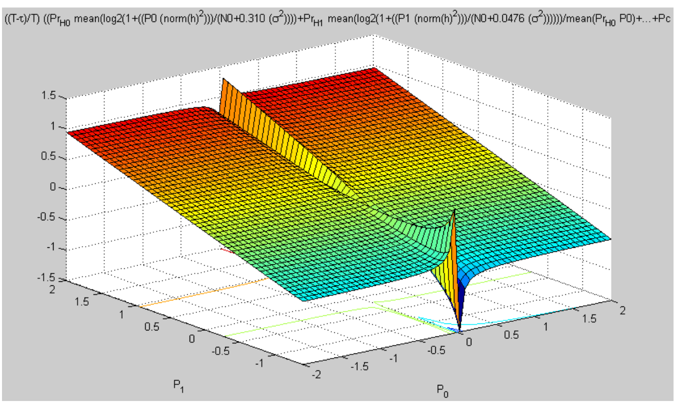

Fig 4:- A maximization 3-D plot of EE and (P_0, P_1)

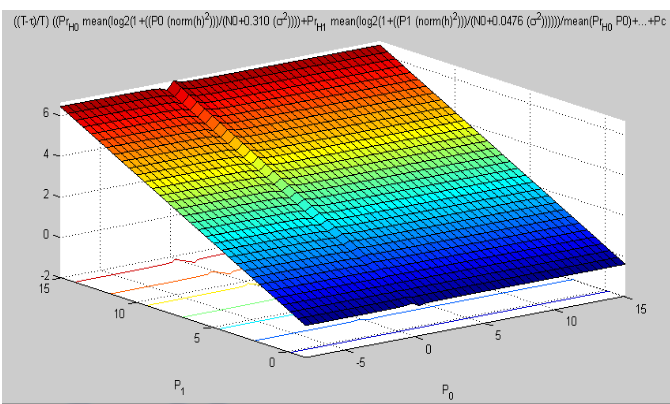

Fig 5:- Maximum EE at point (P_0, P_1)

Figures 4 shows the same values of (P_0, P_1) by interior point method. It shows the every time with change of each value in iteration it would change the value of EE with respect to (P_0, P_1). Hence iterative solution give the better result in real world scenario compare to any search method in computational complexity.

P_{avg} *in dB*	Maximum P_0	Maximum P_1	Achievable Rate R_a	Maximum EE
-15	0.0631	0.0088	1.4178	2.8924
-14	0.0794	0.011	1.4596	3.2154
-13	0.1000	0.0140	1.5076	3.5074
-12	0.1259	0.0176	1.5620	3.7502
-11	0.1585	0.0222	1.6227	3.9278
-10	0.1995	0.0279	1.7616	4.0289
-9	0.2512	0.0352	1.8389	4.0483
-8	0.3162	0.0443	1.8389	3.9876
-7	0.3981	0.0557	1.9189	3.8545
-6	0.3981	0.1448	2.0017	3.6482
-5	0.3981	0.2569	2.0582	3.4003
-4	0.3981	0.3981	2.0862	3.1237
-3	0.3981	0.5758	2.1289	2.8315
-2	0.3981	0.5758	2.1674	2.5357
-1	0.3981	0.7096	2.1984	2.2461
0	0.3981	1.0812	2.2636	1.9704

Table 2:- Determined Variables

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

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 done easily in low energy level and cost. Thus, the optimization problem is formulated and optimum values of energy efficiency are carried out for average power of channel for idle and busy.

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