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An incentive-based dynamic energy efficient spectrum allocation for cognitive radio networks

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ABSTRACT
Cognitive radio is a successful technique for utilizing the unused and under-used spectrum, and dynamic spectrum access is one of the major facilitators in making this happen. When a secondary user (an unlicensed user) interferes with the licensed user, the idea of using unused or under-utilized spectrum offers a challenge. Therefore, effective spectrum sensing is necessary to ensure the primary user's protection and the successful transmission of data by the secondary user. An Optimal Incentive algorithm is suggested to meet this need. It effectively uses the available idle channel based on the joint optimization of sensing time and transmission time without interfering with the primary user. The proposed work also contributes to a significant increase in energy efficiency with minimal interference. Simulation results show an increase in efficiency when compared with the algorithms, namely, exhaustive search and sub-optimal algorithms.

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KEYWORDS
Cognitive radio; optimal incentive algorithm; energy efficiency

1. Introduction

Spectrum being a valuable resource there is a need to utilize that properly. But in most cases, it is evident that a lot of spectrum holes are available. To avail these spectrum holes FCC proposes the concept of cognitive radio (CR) coined by Joseph Mitola. Cognitive radio deals with the primary and secondary users, giving foremost importance to the primary users because they are licensed users. Researchers have come up with different concepts for detecting whether the spectrum is occupied or not.

Most of the work is concentrated on increasing the detection rate but it increases the sensing time. If the sensing time is more, then the possibility of successful transmission by the secondary users will be small. To enhance throughput the need for more transmission time also increases. Increasing the transmission time will surely cause interference to the primary user. To keep interference within the limit the concept of dynamic spectrum allocation is used. Also, the spectrum requirement varies for each and every secondary user available in the network hence to maximize the throughput the SU has to sense the appropriate channel. This can be done by a cooperative spectrum sensing process. The process of sensing and transmission imposes challenges in formulating different optimization schemes. Thus several researchers have taken fixed sensing periods to design the transmission period accordingly. In some of the works sensing time and reporting time are taken into account to keep the success rate maximum. In practice, the SUs don't have the same spectral need. By fixing sensing time there are more changes of increased probability of false alarm. In the literature, works have been done to increase the detection probability and also throughput maximization is attained. If interference trade-off is considered then there is a need for a minimum transmission period which turns out to be unaccountable. To overcome this issue, incentive-based optimization of sensing and transmission time is proposed. When the SU correctly predicts channel availability then the incentive will be given as one ensuring it doesn't introduce any interference with the primary user and accordingly the optimized values of sensing and transmission time will be calculated which, in turn, results in energy efficiency maximization.

2. Related work

Cognitive radio makes use of opportunistic spectrum sensing which allows the utilization of underused and unused spectrum in an efficient way [1,2]. To ensure proper sensing, cooperative spectrum sensing is beneficial, at the same time it is important to pay attention to the overheads associated with it [3]. Enhancing energy efficiency under different power capacity has been studied and numerical results show the impact of transmission power, sensing time and transmission time

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in improving energy efficiency [4]. Researchers have been working on the joint optimization of transmission and sensing time by fixing the probability of detection, probability of false alarm and threshold [5–7]. To achieve maximum efficiency, joint optimization of different parameters, namely, sensing time, transmission time and transmit power are considered in the literature [8–10] and [11]. The primary user protection should not be affected by the secondary user data transmission, hence minimum tolerable interference is also needed. While increasing the energy efficiency there may be chances of interfering with the primary user, hence in this work authors have formed tolerable interference limits [12–16] and [17]. In this work [9], the sensing time is optimized based on the available transmission power which is explicitly defined. The localization algorithm based on priority to the secondary user lying within the predefined range of the primary user is used in [18] to optimize the sensing time. Optimization of different parameters demands priority to perform convergence effectively. Hence, the concept of adding weight to each parameter is used to enhance the importance of the particular QoS parameter. A weight-based Genetic Algorithm is proposed to achieve the QoS parameters, namely, minimum bit error rate, minimum power consumption and maximize the data throughput. The priority is given to the minimum bit error rate by setting the emergency value of weight to 0.8023 [19]. For multidimensional optimization in cognitive radio networks, weight-based techniques help to maximize the convergence speed [20]. In this work, the Pareto method is used to optimize the network's power consumption, global exposure and spectrum use [21]. In this work, the authors have studied the impact of transmission power on energy efficiency by considering a flat-fading channel environment [22]. The concept of reinforcement learning is proposed by researchers to enable multiple users' environments in a device-to-device communication [23]. In [24], the authors proposed a mixed Markov decision process for identifying single secondary users in the given time for allocating the spectrum. To automate the spectrum sensing process machine learning concepts are utilized to identify the spectral availability [25]. To enhance energy efficiency, [26] proposes a time frame split into three slots: two slots for sensing time and one slot for transmission. The second slot of sensing time is used to store the details of the first slot whether the spectrum is free or occupied. The trade-offs between sensing and transmission times are considered for reducing energy utilization in [27]. The authors have proposed an excellent mathematical framework for maximizing the probability of detection by considering the trade-off offered by sensing time and throughput [28]. By the motivation from the literature, an optimal incentive algorithm, which jointly optimizes the transmission time and sensing time without violating the interference limit, is proposed. The remaining work is organized as follows: The system model for a single PU and CU environment is developed in Section 2. Problem formulation is given in Section 3. The solutions for the proposed work are discussed in Section 4. The results and their interpretations are detailed in Section 5 and the conclusion is given in Section 6.

2.1. System model

In this work, single PU and single SU are considered for designing the algorithm which finds optimal values of sensing time and transmission time, respectively. The system model considered for this work is given in Figure 1 and the list of acronyms used further is depicted in Table 1. The total time taken is a combination of sensing and transmission. The time frame format considered in this work is represented in Figure 2. At given T_{total}, Figure 3 demonstrates the following key facts:

(i) SU predicts the PU activity based on periodical sensing and if PU is absent, then SU will start its transmission.

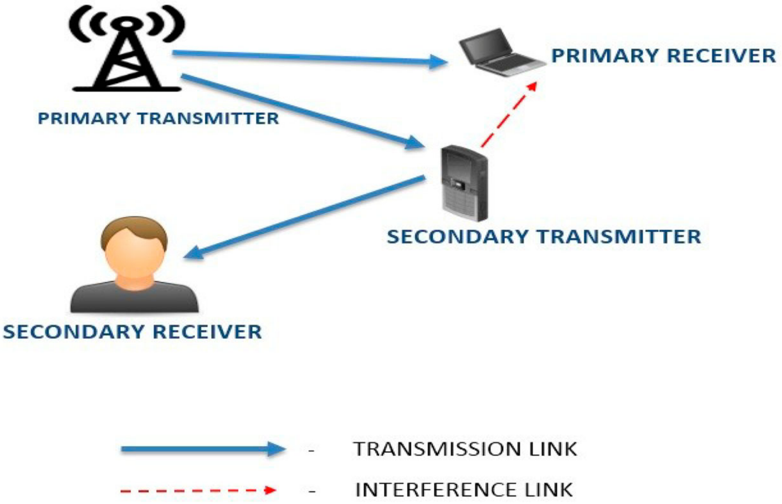

Figure 1. System model.

Table 1. Acronyms used.

Acronym	Definition
PU	Primary user
SU	Secondary user
t_{sn}	Sensing time
t_{trn}	Transmission time
P_{sn}	Sensing power
P_{trn}	Transmission power
α_{idle}	Probability of the idle channel
α_{busy}	Probability of the busy channel
thresh	Threshold
γ_{PU}	Signal-to-noise ratio of PU
P_d	Probability of detection
P_{fa}	Probability of false alarm
X_{sense}	Spectrum status sensed by SU
X	Actual spectrum status

On the other hand,

(ii) if SU senses PU is active, then it has to wait and repeat the process of sensing and transmission.

From the above-mentioned facts, during transmission either PU or SU is utilizing the available channel.

The total time required for sensing and transmission time is calculated using Equation (1)

$$T_{\text{total}} = t_{sn} + t_{trn} \tag{1}$$

T_{total} defines the time taken by the system to periodically detect the presence or absence of the PU. Based on this detection, there are two possible outcomes:

(a) If PU is absent at a particular T_{total}, then SU will get an opportunity to occupy the channel.

(b) If PU is present at the given time, SU has to wait for its turn.

From the above said factors it is clear that SU will never interfere in case (b) hence we need to take case (a) into account and check the possibilities of interference that may affect the PU. For example, if PU reoccupies the channel then it will cause interference to CU transmission and hence proper knowledge about t-sense and t-transmit is needed for successful transmission by CU. The maximum allowable interference is given in terms of t_{trn}

$$P_{\text{int}} = 1 - \exp^{-t_{\text{trn}}/\alpha_{\text{idle}}} \tag{2}$$

where P_{int} = interference probability, α_{idle} = the mean value of idle time of PU, α_{busy} = the mean value of busy time of PU, both α_{idle} and α_{busy} are exponentially distributed. If SU wants to occupy the time frame T_{total} it is important to identify the probability density functions when PU is occupied or vacant. Equations (3) and (4) are used to facilitate the calculation of the probability of idle state, $P_i(t)$ and the probability of busy state $P_b(t)$, respectively

$$\begin{aligned} P_i(t) &= 1/\alpha_{\text{idle}} exp^{-t/\alpha_{\text{idle}}} u(t), P_b(t) \\ &= 1/\alpha_{\text{busy}} \exp^{-t/\alpha_{\text{busy}}} u(t) \end{aligned} \tag{3}$$

To avoid more complications, the probabilities defined in the literature [7] are adopted for modelling the PU as busy or idle it can be given in terms of individual

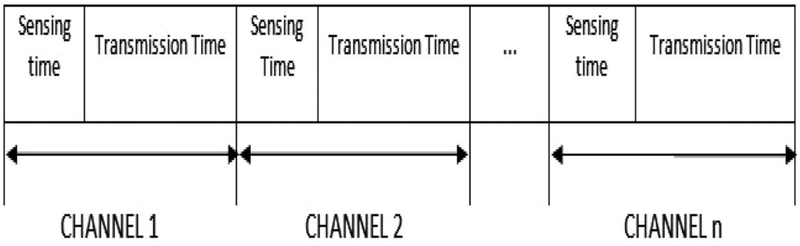

Figure 2. Time frame structure.

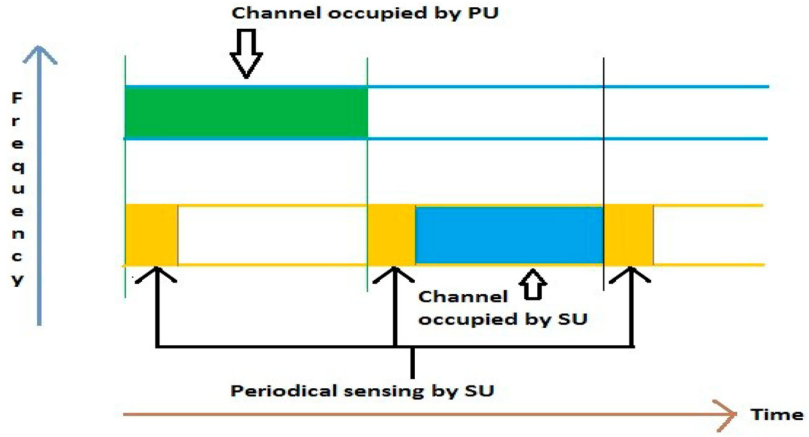

Figure 3. Channel occupancy by users.

probabilities as follows:

$$P_b = \alpha_{\text{busy}}/(\alpha_{\text{idle}} + \alpha_{\text{busy}}), P_i = \alpha_{\text{idle}}/(\alpha_{\text{idle}} + \alpha_{\text{busy}}) \tag{4}$$

To ensure proper sensing of PU's state by SU two parameters are taken into account, namely,

probability of detection

$$P_d(t_{sn}, \text{thresh}) = Pr(X_{\text{sense}} = 1|X = 1)$$

probability of false alarm

$$P_{fa}(t_{sn}, \text{thresh}) = Pr(X_{\text{sense}} = 1|X = 0)$$

both these terms depend on t_{sn} and thresh simultaneously where

$$\text{thresh} = \sqrt{(2/L) * (1 + 2\gamma_{PU})} \tag{5}$$

is used to define the threshold for detection. Based on energy detection

$$\begin{aligned}\text{thresh} = \sigma_{n^2} * \sqrt{(2/L) * (1 + 2\gamma_{PU})} * Q^{-1}(P_d^0) \\ + 1 + \gamma_{PU}\end{aligned} \tag{6}$$

Based on these values of X_{sense} and X, the four different probabilities of finding PU's state are defined.

2.1.1. State 1

In this state, SU correctly detects the absence of PU and it has the chance of occupying the channel given by $Pr(X = 0, X_{\text{sense}} = 0) = \alpha_{\text{idle}}(1 - P_{fa}(t_{sn}, \text{thresh}))$

2.1.2. State 2

In this state, SU correctly detects the presence of SU and it has to wait until the PU leaves the channel. Hence, it does not initiate transmission and no interference will be introduced by SU to the PU. $Pr(X = 1, X_{\text{sense}} = 1) = \alpha_{\text{busy}}(P_d(t_{sn}, \text{thresh}))$

2.1.3. State 3

This state defines false detection of PU's state as busy with probability $Pr(X = 0, X_{\text{sense}} = 1) = \alpha_{\text{busy}}(P_d(t_{sn}, \text{thresh}))$. It does not contribute any reward for transmission.

2.1.4. State 4

When SU falsely detects that PU's state is idle with probability $Pr(X = 1, X_{\text{sense}} = 0) = \alpha_{\text{idle}}(1 - P_{fa}(t_{sn}, \text{thresh}))$. This state is similar to state 2 and hence no reward for transmission.

3. Problem formulation

The motivation of this work is to reduce the interference of SU while utilizing the channel when PU reoccupies and also to maximize the energy efficiency which will result in the successful transmission of SU data. This can be done by adding incentives to the correct detection of spectrum availability. To increase energy efficiency it is proposed that jointly optimizing the transmission and sensing time by considering the importance of t_{sn} and t_{trn} times over maximizing the throughput.

3.1. Data rate

In this model, the data transmitted by SU are considered to be valid only in state 1 because SU has identified the absence of PU and also the data transmission will be initiated whether in remaining states no rewards are given for data transmission. The AWGN channel is considered for testing the proposed algorithm. Considering this factor, the total number of data bits transmitted in the CR system is represented in Equation (7)

$$R_{\text{total}} = \alpha_{\text{idle}}(1 - P_{fa}(t_{sn}, \text{thresh}))t_{trn}(1 - P_{int}) * R0 \tag{7}$$

3.2. Energy consumption

The energy needs to be considered for all the cases since the transmission is successful or not but the amount of energy invested needs to be included. Hence, the energy consumed for all four states in the given time frame T_{total} can be calculated using Equation (8).

$$\begin{aligned}E_{\text{total}} = P_{sn} * t_{sn} + P_{trn} * t_{trn}(P_i(1 - P_{fa}(t_{sn}, \text{thresh}))) \\ + P_b(1 - P_d(t_{sn}))\end{aligned} \tag{8}$$

3.3. Energy efficiency

The energy efficiency of the single CRNs can be calculated as follows:

$$E_{\text{effi}} = \frac{R_{\text{total}}}{E_{\text{total}}} \tag{9}$$

$$E_{\text{effi}} = \frac{\alpha_{\text{idle}}(1 - P_{fa}(t_{sn}, \text{thresh}))t_{trn}(1 - P_{int})R0}{\begin{array}{l}P_{sn} * t_{sn} + P_{trn} * t_{trn}(P_i(1 - P_{fa}(t_{sn}, \text{thresh}))) \\ +P_b(1 - P_d(t_{sn}))\end{array}} \tag{10}$$

The maximization problem statement for energy efficiency can be formulated as per Equation (11)

$$\begin{aligned}&\max_{t_{sn}, t_{trn}, P_{int}, p_d(t_{sn})} E_{effi}(t_{sn}, t_{trn}) \qquad (11)\\ &s.t.\ t_{se0} < t_{sn} < t_{se1},\\ &\quad t_{tr0} < t_{trn} < t_{tr1},\\ &\quad P_{int} < \alpha_1,\\ &\quad p_d(t_{sn}) > p_d^0\end{aligned}$$

where $\alpha_1 = 0.1$ and $p_d^0 = 0.9$ are taken as explicit values that ensure maximum allowable interference imposed on PU by the SU. The probability of a false alarm is denoted by $P_{fa}(t_{sn})$ and its corresponding equation is

$$P_{fa}(t_{sn}) = Q(\sqrt{(2 * \gamma_{PU} + 1)}Q^{-1}(p_d^0) + \gamma_{PU}\sqrt{(t_{sn}fs)} \tag{12}$$

where fs = sensing frequency and γ_{PU} = SNR introduced by SU data transmission.

3.4. *Finding limits for sensing and transmission times*

To ensure $P_{fa}(t_{sn})$ below 0.5, t_{sn} must satisfy the following condition.

$$t_{sn} > \left(\frac{Q^{-1}(p_d^0)\sqrt{(2\gamma_{PU})+1)}}{\gamma_{PU}\sqrt{fs}}\right)^2 \tag{13}$$

The lower limit for ts is given by

$$t_{se0} = \left(\frac{Q^{-1}(p_d^0)\sqrt{(2\gamma_{PU})+1)}}{\gamma_{PU}\sqrt{fs}}\right)^2 \tag{14}$$

To achieve the maximum allowable interference level then the maximum t_{trn} is given by Equation (15)

$$t_{tr1} = -\alpha_0 \log(1-\alpha_1) \tag{15}$$

where α_0 is defined as the interference constraint and is explicitly defined. Now the maximization problem for E_{effi} can be modified as

$$\max_{t_{sn}, t_{trn}, P_{int}, P_d(t_{sn})} E_{\text{effi}}(t_{sn}, t_{trn}) \tag{16}$$

$$s.t.\ t_{se0} < t_{sn} < t_{se1},$$

$$t_{tr0} < t_{trn} < t_{tr1},$$

4. Proposed system

The parameters t_{sn}, t_{trn}, P_{tr} and P_{int} are used for solving EE maximization problem. The relationship between sensing time and false alarm is crucial to maintain minimum miss detection the p_f should follow the above equation. To witness lower interference the value of t_{trn} should satisfy Equation (15). By using these values of t_{trn} and t_{sn}, an optimal incentive search algorithm, in turn, maximizes the EE that is proposed.

4.1. *Solving for t_{sn}*

To solve t_{sn} we take partial differentiation of $E_{\text{effi}}(t_{sn}, t_{trn})$ with respect to t_{sn} and put it to zero by fixing t_{trn}

$$\frac{\partial}{\partial t_{sn}} E_{\text{effi}}(t_{sn}, t_{trn}) = 0 \tag{17}$$

$$\frac{\partial}{\partial t_{sn}}\left(\frac{\begin{array}{c}\alpha_{\text{idle}}(1-P_{fa}(t_{sn},\text{thresh}))\\ \times t_{trn}(1-P_{\text{int}}) * R0\end{array}}{\begin{array}{c}P_{sn} * t_{sn} + P_{trn} * t_{trn}(P_i(1-P_{fa}\\ \times(t_{sn},\text{thresh}))) + P_b(1-P_d(t_{sn}))\end{array}}\right) = 0 \tag{18}$$

For simplicity let us assume $P_{fa}(t_{sn}, \text{thresh})$ as P_{fa}, $P_d(t_{sn})$ as P_d in Equation (18). Now the equivalent form can be represented as

$$P_{sn}P_{fa} - [t_{trn}P_i(1-P_d)P_{trn} + P_{sn}t_{sn}]P'_{fa} = 0$$

$$t^*_{sn} = -\frac{1}{{P_{fa}}'} - \frac{t_{trn}P_i(1-P_d)P_{trn}}{P_{sn}} + \frac{P_{fa}}{P'_{fa}} \tag{19}$$

Hence, for the limits of t_{sn} ranging between $t_{se0} < t_{sn} < t_{se1}$ the value of P_{fa} decreases and $P'_{fa}(t_{sn})$ increases and negative, hence P_{fa} is the convex function and $P''_{fa}(t_{sn})$ is positive.

4.2. *Solving for t_{trn}*

To solve t_{sn} we take partial differentiation of $E_{\text{effi}}(t_{sn}, t_{trn})$ for t_{trn} and put it to zero by fixing t_{sn}

$$\frac{\partial}{\partial t_{trn}} E_{\text{effi}}(t_{sn}, t_{trn}) = 0 \tag{20}$$

$$\frac{\partial}{\partial t_{trn}}\left(\frac{\alpha_{\text{idle}}(1-P_{fa})t_{trn}(1-P_{int}) * R0}{\begin{array}{c}P_{sn} * t_{sn} + P_{trn} * t_{trn}(P_i(1-P_{fa}))\\ +P_b(1-P_d(t_{sn}))\end{array}}\right) = 0 \tag{21}$$

By solving the above equation we get

$$t^*_{trn} = \frac{P_{sn}t_{sn} - \sqrt{\begin{array}{c}P_{sn}^2 t_{sn}^2 + 4a_0 P_{sn}t_{sn}[(P_i(1-P_{fa}(t_{sn})))\\ \times P_b(1-P_d)]t_{sn}\end{array}}}{-2P_{trn}[(P_i(1-P_{fa}(t_{sn})))P_b(1-P_{de})]} \tag{22}$$

Using Equation (22), the optimal value of t_{trn} can be calculated. Within the range of $0 < t_{trn} < t^*_{\text{transmit}}$, the energy efficiency attains a maximum value which tends to be unique. Further increase in $t_{trn} > t^*_{\text{transmit}}$ results in the $\frac{\partial}{\partial t_{trn}} E_{\text{effi}}(t_{sn}, t_{trn}) < 0$; therefore, the value of $\frac{\partial}{\partial t_{trn}} E_{\text{effi}}(t_{sn}, t_{trn}) > 0$ only for the range $0 < t_{trn} < t^*_{\text{transmit}}$ for each fixed value of t_{sn}.

4.3. *Optimal incentive algorithm*

To maximize the energy efficiency we propose the suboptimal weighted search algorithm, which makes use of the reward for the correct prediction of PUs' availability under predefined interference levels. This reward is included as weight in Equation (10) and the modified equation can be written as follows:

$$E_{\text{effi}} = \frac{\begin{array}{c}\alpha_{\text{idle}}(1-(1+\omega)P_{fa}(t_{sn},\text{thresh}))\\ \times t_{trn}(1-P_{int})R0\end{array}}{\begin{array}{c}P_{sn} * t_{sn} + P_{trn} * t_{trn}(P_i(1-P_{fa}(t_{sn},\text{thresh})))\\ +P_b(1-P_d(t_{sn}))\end{array}} \tag{23}$$

This algorithm starts with the initial values of E_{effi}, t_{trn} as zero and $t_{sn} = t_{s0}$, the energy efficiency is calculated based on Equation (22) if rules are violated, reward will be given as $\omega = 0$. The iteration process begins from $k = 0$ and continues to $k + 1$ till it meets the stopping criterion $E_{\mathrm{effi}}(k + 1)$-$E_{\mathrm{effi}}(k) < \Delta E$ The pseudo-code for the proposed algorithm is given as follows:

Optimal incentive Algorithm:

```
Step 1: Initialize k = 0, $t_{s0}$, $\Delta E$,$E_{\mathrm{effi}} = 0$,$t_{trn}(0) =$
    $0$,$\Delta E_{effi} = 0$
Step 2: while $\Delta E_{\mathrm{effi}} > = \Delta E$
Step 3: Set k = k + 1
Step 4: calculate $t_{trn}(k)$ and corresponding $P_{int}$
Step 5: Calculate $t_{sn}(k)$ and corresponding $P_{fa}$.
Step 6: if $P_{fa} < 0.5$ and $P_{int} < 0.1$
Step 7: Choose a reward as 1.
Step 8: else, a reward as 0.
Step 9: Compute efficiency $E_{\mathrm{effi}}(k + 1)$-$E_{effi}(k) < \Delta E$
Step 10: Return $E_{\mathrm{effi}}$,$t_{trn}$,$t_{sn}$.
```

The algorithm is implemented in such a way that the optimal values of sensing time and transmission time are calculated by which the EE value is maximized.

5. Implementation and results

In this section, the results obtained by making use of the incentive algorithm are discussed. The parameters used for optimization are sensing time and transmission time. The need for optimization increases when

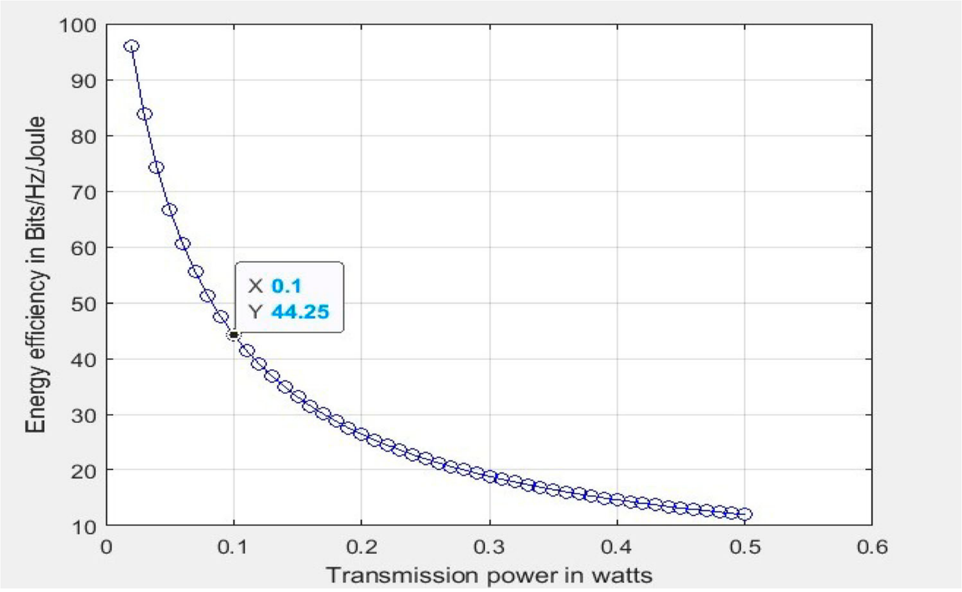

Figure 4. Proposed algorithm.

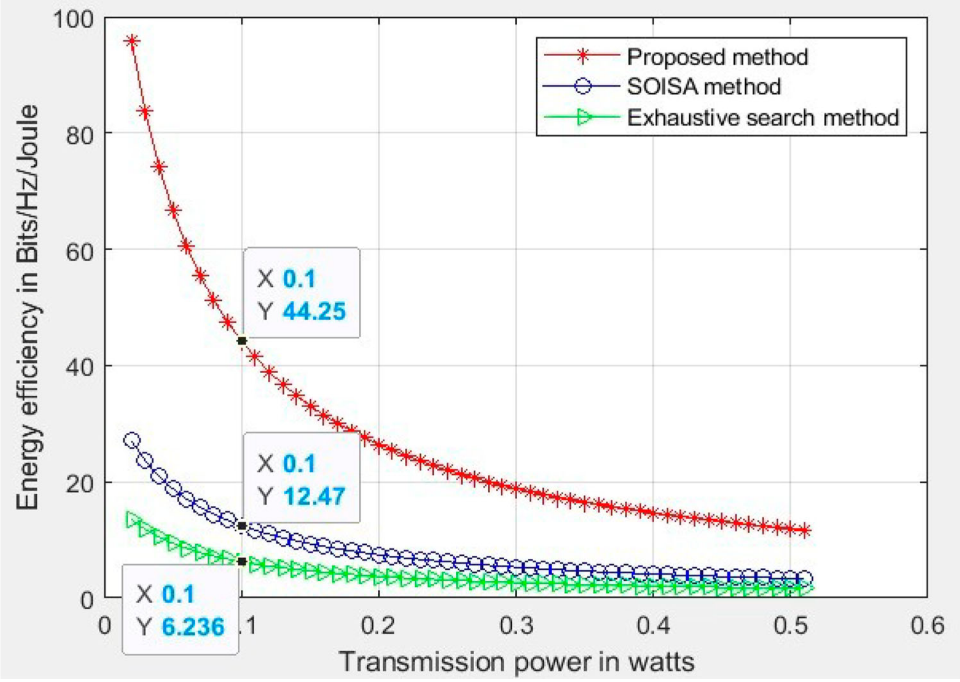

Figure 5. EE comparison with the existing methods.

Table 2. Simulation parameters.

Parameters	p_d^0	α_1	P_{sn}	α_{idle}	α_{busy}	BW	R0	γ_{PU}
Values	0.9	0.1	0.11 W	0.652 S	0.348 S	6 MHz	10 Mbps	−20 dB

the increase in sensing time results in better detection probability but the transmission time becomes so small that may not be feasible for successful data transmission. To achieve better transmission time trade-off with interference needs to be considered. In this model, a single PU and SU are taken to analyse the efficiency of the incentive algorithm. The performance of the proposed method by comparing with the methods stated in [16] and [7] by providing numerical results obtained through simulation using MATLAB software is demonstrated. The parameters used for simulation are given in Table 2.

Figure 4 shows the impact of transmission power on energy efficiency by the optimal incentive algorithm. By choosing transmission power as 0.1 W, the energy efficiency is 44.25 bits/Hz/Joule. Due to the probability of false alarms, an increase in transmission power will reduce the data rate. This, in turn, results in increased sensing time. Because of this effect energy efficiency falls with an increase in transmission power.

Figure 5 shows that the proposed algorithm outperforms the exhaustive search method and the sub-optimal iterative search algorithm by yielding the highest EE. For comparison the transmission power is chosen as the same as stated in [?], $P_{trn} = 0.1$ W the E_{effi} for the proposed method is 44.25 bits/Hz/Joule, for SOISA is 12.47 bits/Hz/Joule and the exhaustive search method is 6.236 bits/Hz/Joule. The optimized values of sensing time and transmission time predicted by this

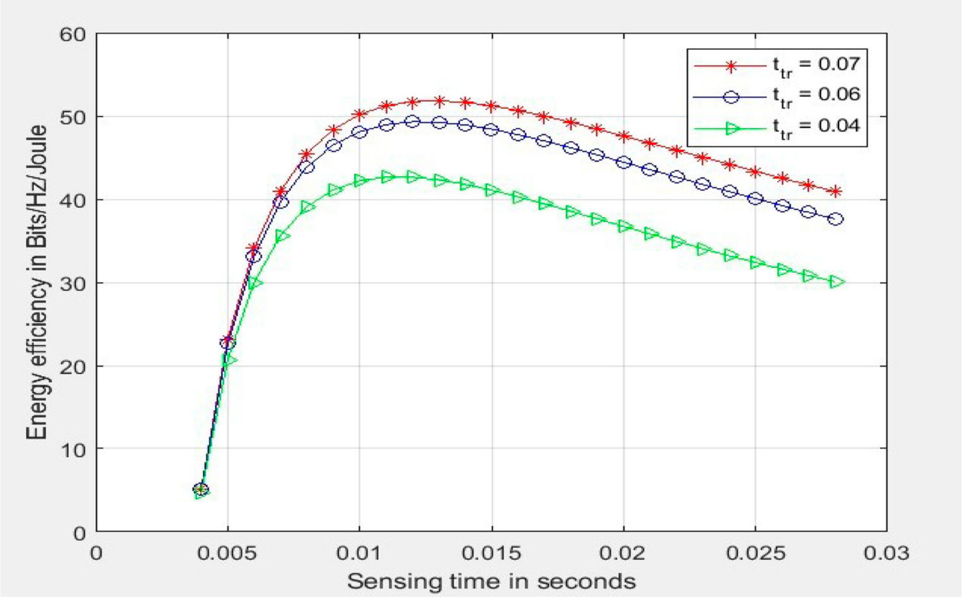

Figure 6. Energy efficiency versus sensing time with fixed transmission time.

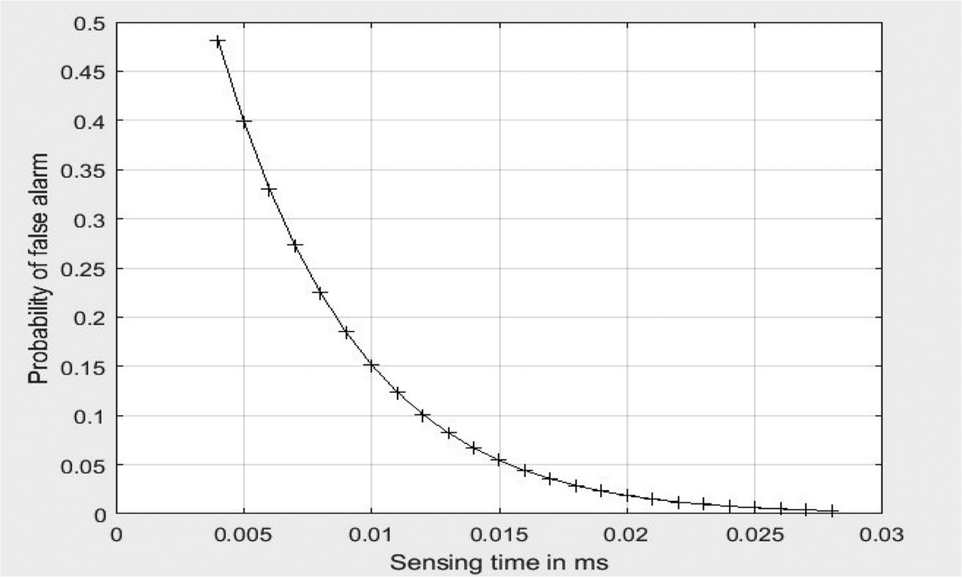

Figure 7. Probability of false alarm vs sensing time.

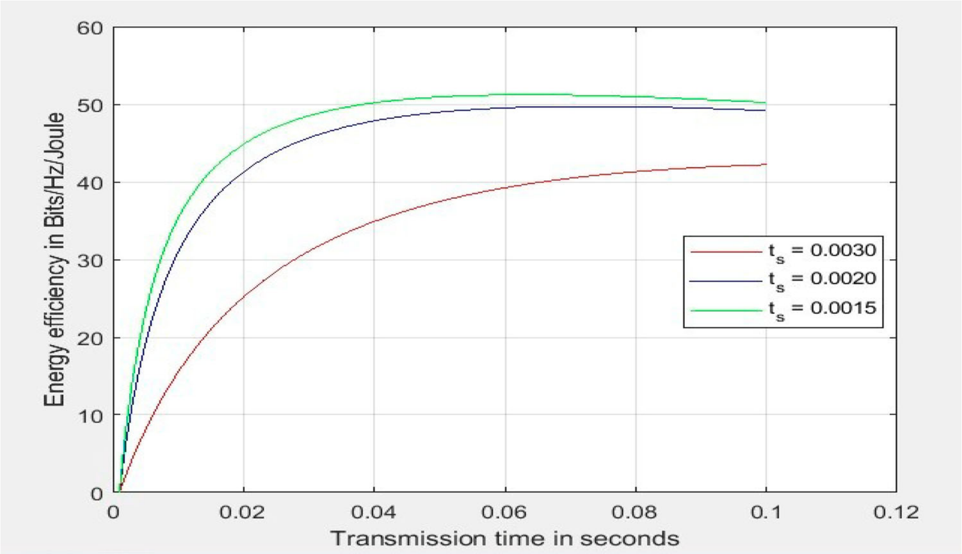

Figure 8. Energy efficiency vs transmission time.

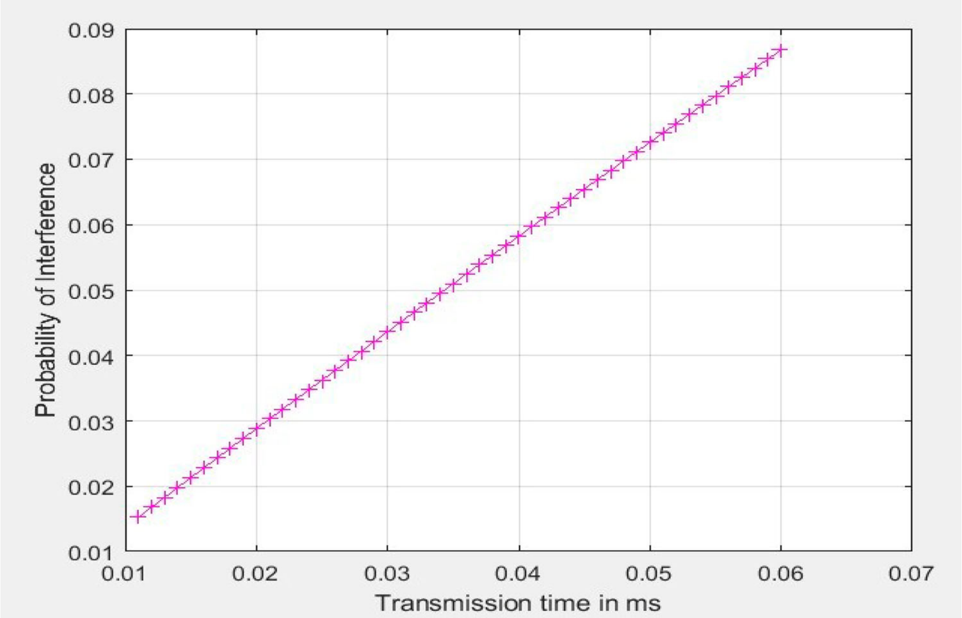

Figure 9. Probability of interference vs transmission time.

algorithm are 0.0025 and 0.0615 s, respectively, which play a crucial role in maximizing the energy efficiency to 44.25 bits/Hz/Joule. The probability of interference also remains within the specified range ensuring PU protection in the CR system.

By taking fixed values for transmission time the energy efficiency attains maximal value for optimal sensing times. Figure 6 depicts that the energy efficiency reaches a maximum value for t_{ns}^* value and afterwards starts decreasing.

Figure 7 shows that the false alarm is within the predefined range as mentioned in the algorithm.

Figure 8 shows that the energy efficiency attains the maximum value for the optimal value of transmission

Table 3. Comparison of the proposed algorithm with the existing methods.

Algorithm	Parameter optimized	QoS	Maximum energy efficiency in bits/Hz/Joule	Inference
Exhaustive Search [4]	Sensing time and transmission time	Power constraint	6.236	Power limitations
Sub-optimal iterative search algorithm [16]	Sensing time and transmission time	Interference probability	12.47	Increased detection probability and the minimum false alarm rate
Optimal Incentive algorithm	Sensing time and transmission time	Power constraint	44.25	Increased transmission time with minimum interference to the PU and the maximum energy efficiency

time for different values of sensing time, there exists a unique maximal value for energy efficiency.

Calculated transmission time imposes only tolerable interference to the PU as inferred from Figure 9.

Table 3 shows that the algorithms available in the literature are taking either the power consumption or the probability of interference as their QoS parameters. In the proposed system the trade-off between transmission time and probability of interference is taken as one of the constraints and simulation results show an appreciable increase in energy efficiency as well.

6. Conclusion

In this paper, the problem statement is modelled by considering single PU and single SU and multiple users' environments. The solution is derived in such a way that the energy efficiency is maximized by taking appropriate values of sensing and transmission times. The impact of providing incentives over energy efficiency maximization in the CR system is studied. The optimization problem is designed with parameters, namely, sensing time, transmission time and probability of interference. This model enables joint optimization of sensing time and transmission time contributing to an appreciable increase in energy efficiency. It is also witnessed that the proposed optimization algorithm protects PU data transmission without enhancing the tolerable interference value. From simulation results, the proposed algorithm shows better performance than the exhaustive and sub-optimal iterative search algorithms with a remarkable increase in energy efficiency.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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