Performance Analysis of Trade off in SE-EE in Cooperative Spectrum Sensing

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Abstract - *A cognitive cellular network, which integrates conventional licensed cellular radio and cognitive radio into a holistic system, is a promising model for the fifth-generation mobile communication systems. Understanding the trade-off between energy efficiency, EE, and spectral efficiency, SE, in cognitive cellular networks is of fundamental importance for system design and optimization. In fifth generation mobile communication we need to implement cognitive radio system over the existing system, the reason behind that is cognitive radio technology are more efficient in use of spectrum. In cognitive radio system the spectrum sensing is playing major role. Because of spectrum sensing the cognitive radio can get the idea of free spectrum. In fifth generation mobile communication the spectrum needs to be used in a specific manner. For that we require the spectrum efficiency and energy efficiency trade-off. The trade-off between energy efficiency and spectrum efficiency is playing major role in the communication system. So, by finding the better trade off value we can improve the usage of spectrum.*

Key Words: **Cognitive Radio, Cooperative Spectrum Sensing, Energy Efficiency, Spectrum- Efficiency and Energy- Efficiency Trade – off.**

1. INTRODUCTION

Increasing Spectrum-Efficiency (SE) as well as Energy-Efficiency (EE) has attracted much attention recently due to the fact that the future wireless networks need to address the issues of high throughput and low power consumption. However, the objective for optimizing SE sometimes conflicts with the one for optimizing EE, and the methods for improving EE may result in a decrease in SE. [5] Cooperative spectrum sensing suffers from large overhead due to multiple secondary users who are working in cooperation with each other. Hence, energy efficiency in cooperative spectrum sensing is a challenging concern in cognitive radio. [4] A cognitive cellular network, which integrates conventional licensed cellular radio and cognitive radio into a holistic system, is a promising paradigm for the fifth-generation mobile communication systems. Understanding the trade-off between energy efficiency, EE, and spectral efficiency, SE, in cognitive cellular networks is of fundamental importance for system design and optimization. [5] The main objective is to find the best algorithm for the finding the best trade-off between SE and EE. This helps for improving the use of spectrum in better way.

2. THEORETICAL BACKGROUND

2.1 Spectrum sensing

Spectrum sensing is defined as a task to finding the spectrum holes by sensing the spectrum. After finding the spectrum hole and if the found band is additionally used by a licensed user, the CR user find another spectrum hole and moves to the next spectrum hole.

2.2 Spectrum Efficiency

Cognitive radio cooperative spectrum sensing occurs when a group or network of cognitive radios share the sense information they gain. This provides a better picture of the spectrum usage over the area where the cognitive radios are located. In cognitive radio applications where a cognitive radio network is present, cooperative spectrum sensing is not only advantageous, it becomes essential if the network as a whole is to avoid interference with any primary users.[12]

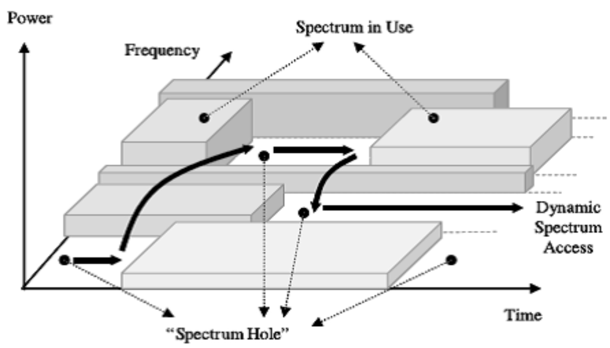

Fig -1: Illustration of spectrum white space [8]

2.3 Energy Efficiency

An increase in energy efficiency is possible if the total power consumed at each stage of CSS is decreased. The EE of a communication system is closely related to its power consumption. It is reducing the amount of energy required to transmit the data signal from transmitter to receiver.

Energy Efficiency Techniques are Local Sensing, Reporting, Decision Fusion, Network organization.

2.4 Probability of Detection

Probability of Detection (Pd) is the detection probability of the signal at Receiver side. Total probability of detection of transmitted signal at receiver side. It is given by:

$$P_{di} = Q\left(\frac{\lambda_i - N(1+\gamma_i)}{\sqrt{2N(1+2\gamma_i)}}\right) \quad (1)$$

2.5 Probability of False Detection

Probability of False Detection (Pfd) is the probability of false signal detection. That means at receiver side the signal is detected without it is transmitted. So, this cause an error at receiver side. It is given by:

$$P_{fi} = Q\left(\frac{\lambda_i - N}{\sqrt{2N}}\right) \quad (2)$$

2.6 Fusion Rules

Cooperative spectrum sensing is classified as hard decision or soft decision schemes according to the way the presence of PU is determined at the FC with the composed reported decisions from the individual selected SUs. Every SU will make its own decision and transmits one-bit decision to FC that makes a final cooperative decision by fusing the data collected from SUs. In hard decisions AND & OR schemes are present.

AND Fusion Rule and OR fusion Rule

AND decision rule states that the PU is present when all the selected SUs at FC detect the PU. And OR decision rule states that when at least one of the network users detects the primary signal, the FC will state that the PU is present.

$$P_{dAND,i} = \prod_{i=1}^{k} P_{d,i}$$

$$P_{dOR,i} = 1 - \prod_{i=1}^{k}(1 - P_{d,i}) \quad (3)$$

Where, $P_{d,i}$ is the probabilities of detection and false alarm for each individual SU. It should be noted that k is bounded as $1 \leq k \leq M$since the network size is M.

3. SIMULATION WORK

3.1 EE-SE Trade off

Figure 2 is the one of the trade-offs of EE and SE. In which the SE versus the threshold of EE requirement for various values of target detection probability is shown. So, there are few methods which are used to see the trade-off. These are the parameters on which the work is prepared. For EE-SE trade off we require one parameter to compare with. The EE-SE trade off can give by many parameters. Like SNR, Sensing time, Probability of Detection and Probability of False Detection, etc... SNR and Sensing Time is selected for the analysis the trade-off in CSS. Through these parameters we can see the behavior of EE and SE. As both EE and SE are measured with same parameter so it is easy to check the trade-off between them. The basic trade-off is shown and from that it can be concluded that when SE increases the EE is Decreasing. Or in other words it can say that when EE increases the SE is decreases. So, this is the basic trade-off between EE & SE. And this trade-off is of the PCMs from this there are value at which the EE-SE both is at their maximum values. Now the chosen parameters for analysis are SNR and Sensing Time (Ts).

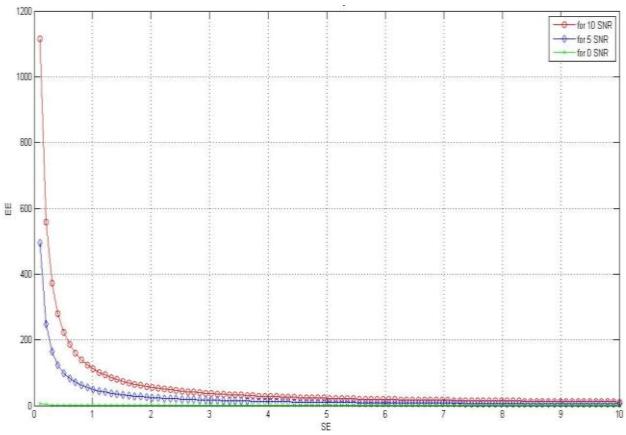

Fig -2: EE-SE trade-off for Realistic Power Consumption Models (PCMs)

3.2 EE and SE vs SNR

For the analysis it needs to create an environment through which the analyse the behaviour of signals at real time. For creating such environment this assumption and values are preferred.

Distance is taken in Km, Rayleigh channel is selected, Number of secondary users are 5, Number of samples taken is 2000, SNR is in DB, signal transmitted is QPSK

Results for EE and SE vs SNR

The results of the EE and SE tradeoff with respect to SNR according to the chosen environment and values are shown in figure 3 and figure 4.

In figure 3 the relation of SE and EE is clearly visible for Cooperative Spectrum Sensing. As seen in figure 4-6 SE and EE are inversely proportional to each other. Number of samples in 0.1 to 0.15 are higher than remaining graph. So, from this it is said that the EE is stared decreasing after certain value of SE. And as the relation between SE and EE is inversional, the system and environment are for cooperative spectrum sensing.

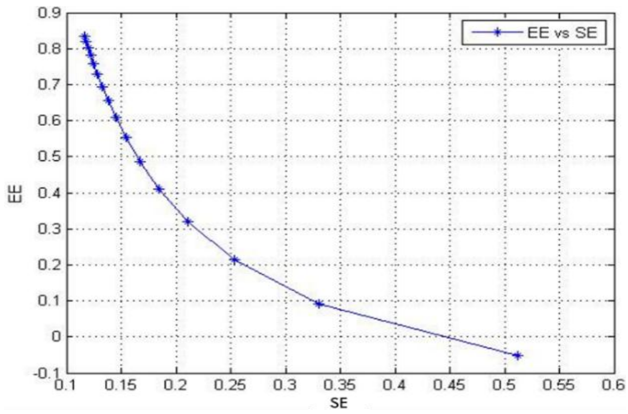

Figure 3 EE-SE trade-off for various Values of SNR

For achieving the figure 4, the values of some parameters are constant like number of SU which is 5, Sensing time is 0.01 s. from this graph optimum values of both parameters can be measured, so from the graph the optimum values are occurred at around -14 dB and the optimum value is 2.5. For the chosen environment and chosen values of different parameters.

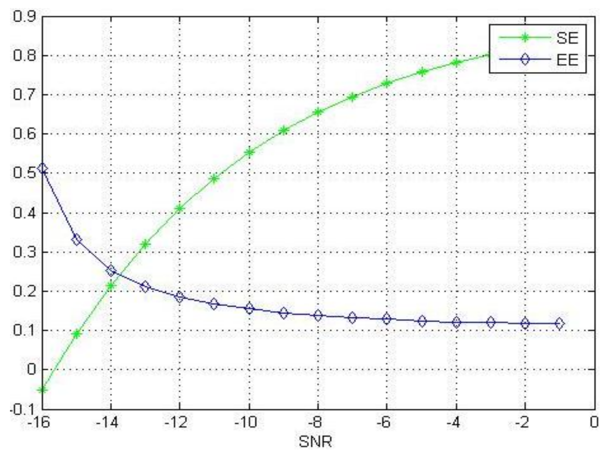

Figure 4 EE-SE Trade-Off using SNR

3.3 EE and SE vs Sensing Time

For the analysis it is mandatory to create an environment through which it is possible to analyze the behavior of signals at real time. For creating such environment this assumption and values are preferred.

Frame Duration is (T) is 100 ms, Number of SU (K) is 8, Sensing Power (Ps) is 40 mW, Transmit Power (Pt) is 1.8 W, Circuit Power (Pc) is 80 mW, Reporting Power (Pr) is 10 mw, Secondary link SNR(γs) is 5dB, SNR(γ) is -10dB

The frame structure designed for the CR network with periodic CSS where each frame consists of a spectrum sensing block, a reporting block and a data transmission block. Suppose the frame duration is T, the sensing duration is ts, and the reporting duration for each SU is tr. In the spectrum sensing block, the K cooperating SUs sense the PU's status simultaneously. In the reporting block, the K sensing results are sent to the FC sequentially via a common control channel (CCC). Then, according to some fusion rules, the FC makes a final decision to indicate that the PU is present or absent. If the PU is absent, one of the secondary users is allowed to conduct data transmission. However, if the PU is present, the secondary users will not be able to utilize the spectrum. Now consider that the primary signal is Quadrature phase-shifted keying (QPSK) signal, the noise is real-valued Gaussian variable with zero mean and variance, and energy detection is employed to detect the PU's status in the local sensing stage. The detection probability and false alarm probability at each SU can be calculated as,

$$P_d = \mathbb{Q}\left(\left(\frac{\epsilon}{\sigma^2} - \gamma - 1\right)\sqrt{\frac{T_s f_s}{2(2\gamma+1)}}\right)$$

$$P_f = \mathbb{Q}\left(\left(\frac{\epsilon}{\sigma^2} - 1\right)\sqrt{\frac{T_s f_s}{2}}\right) \quad (4)$$

Where, ϵ is the threshold of energy detection, γ denotes the SNR of PU's signal at each SU when the PU is present, fs is the sampling frequency. SUs is close to each other such that they experience almost similar path loss. So that the PU signal reaches all SUs with the same power level. However, the design methodology can be extended to case when the received powers are different. By combining (3) and (4), it is derived that

$$P_f = \mathbb{Q}\left(\sqrt{2\gamma+1}\,\mathbb{Q}^{-1}(P_d) + \gamma\sqrt{\frac{T_s f_s}{2}}\right) \quad (5)$$

The SU transmits data in the following two cases:

When the PU is absent, and it is correctly detected to be absent; When the PU is present, and it is falsely detected to be absent. In the former case, the SE (measured in bits/s/Hz) of the CR network can be formulated as,

$$\frac{T - T_s - KT_r}{T} log_2(1 + \gamma_s) \quad (6)$$

In the latter case, the SE of the CR network can be presented as

$$\frac{T - T_s - KT_r}{T} log_2\left(1 + \frac{\gamma_s}{\gamma + 1}\right) \quad (7)$$

Where γ_s is the SNR for the SU link. The final detection probability and final false alarm probability can be computed by,

$$Q_D = \sum_{i=M}^{K} B(i;K,P_d) \quad (8)$$

$$Q_D = \sum_{i=M}^{K} B(i;K,P_f) \quad (9)$$

Where, M is the final decision threshold,

$B(i;K,P_f) = \binom{m}{l} p^l (1-p)^{m-l}$ is the probability that there are l success results in successive m Bernoulli trials each trial with a probability of success p. The average SE of the CR network is given by

$$\eta_{SE} = \widetilde{\eta_{SE}} + \overline{\eta_{SE}} \quad (10)$$

Where,

$$\widetilde{\eta_{SE}} = \lambda(1-Q_F)\frac{T-T_s-KT_r}{T}\log_2(1+\gamma_s) \quad (11)$$

$$\overline{\eta_{SE}} = (1-\lambda)(1-Q_D)\frac{T-T_s-KT_r}{T}\log_2\left(1+\frac{\gamma_s}{\gamma+1}\right) \quad (12)$$

In equations (11) and (12) λ is the probability that PU is absent and 1- λ is the probability that PU is present.

Procedure for EE

Considering the energy consumption of the CR network, let us define P_s, P_r, P_c and P_t as the sensing power consumed by each SU, the reporting power consumed by each SU, the circuit power consumed by electronic devices, and the transit power by the SU transmitter, respectively.

Four scenarios will be considered. 1)The CR network correctly detects PU's presence. 2) The CR network falsely detects PU's presence (missed detection). 3) The CR network correctly detects PU's absence. 4) The CR network falsely detects PU's absence (false alarm). The average energy consumption is

$$E = KT_sP_s + KT_rP_r + K(T_s+T_r)P_C + [\lambda(1-Q_F) + (1-\lambda)(1-Q_D)] \times (T-T_s-KT_r)(P_t+P_c) \quad (13)$$

The EE (measured in bits/Joule/Hz) of the CR network can be expressed as

$$\eta_{EE} = \widetilde{\eta_{EE}} + \overline{\eta_{EE}} = \frac{\eta_{SE}T}{E} \quad (14)$$

Where,

$$\widetilde{\eta_{EE}} = \frac{\widetilde{\eta_{SE}}T}{E} \quad (15)$$

$$\overline{\eta_{EE}} = \frac{\overline{\eta_{SE}}T}{E} \quad (16)$$

Results for EE and SE vs Sensing Time

In figure 5 relation between SE and EE is shown, as it is inversely proportional to each other. In figure 4-10 SE is decreasing as EE is increasing. For the chosen range of sensing time, graph in figure 5 is achieved. As per the terms and values of parameter EE lies from 0.6 to 1.5 for the value of SE at 0.5 to 0.95.

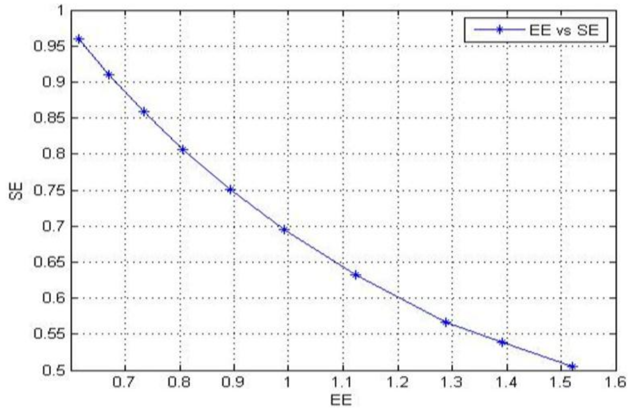

Figure 5 EE vs SE for Sensing Time

In figure 6 SE and EE tradeoff is given with respect to Sensing time.as seen in the figure, 0.8 is the optimum value at 20ms. From that point onwards EE is getting increased and SE is decreasing. From the chosen values tradeoff of SE and EE is achieved.

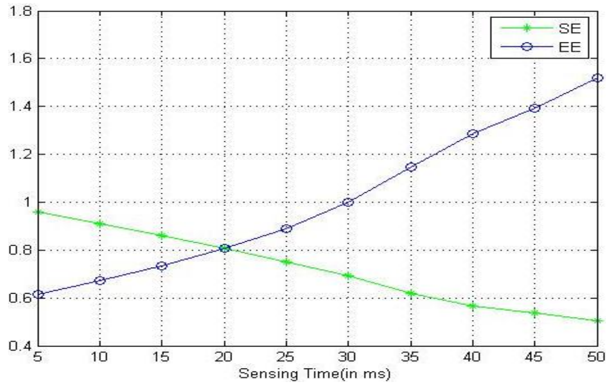

Figure 6 EE vs SE for Sensing Time

Now for our selected environment and values the simulated and theoretical results are compared to each other.in figures 7. And relation between PF and OR Fusion Rule is shown.

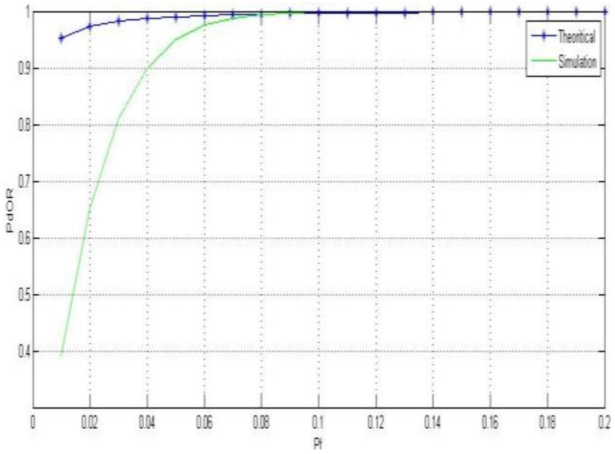

Figure 7 Comparison of theoretical values and simulation values of PdOR vs PF

Figure 7 shows the comparison of theoretical and Simulation values of OR fusion rule. From the figure it is clear that simulation values are very close to the theoretical values of OR fusion rule. Values of simulation is started from 0.39 and it is decreasing with increasing PF values, and it approaches to 1 after 0.1 PF value.

Observations

- For CSS simulation as well as analytical results for Pd vs Pf are obtained. Both results are matching to each other. at the FC, AND fusion rule and OR fusion rules are used for Detection.
- Pd is increasing with SNR.
- The mathematical analysis for EE and SE has been carried out for various values of SNR (-16 to 0) for the cooperative environment. The Trade-off has been formed between EE and SE, which is helpful in predicting suitable value of SNR.
- The mathematical analysis for EE and SE has been carried out in respect to Sensing time (5-50ms) and trade-off between EE and SE has been observed. This compression will be helpful for choice of suitable sensing time.
- Also, theoretical and simulated analysis for EE and SE has been carried out with respect to Sensing time and SNR. Trade-off between EE and SE has been observed. Optimum value of sensing time is achieved at 20ms.
- EE and SE are optimized at the SNR value of -17dB which is fair for energy efficient networks.

Conclusions

CSS is suitable technique for Spectrum Sensing in CR, especially for low SNR ranging (SNR<-10dB). Pd above 0.8 is obtained in CSS environment. Sensing time is critical issue when CSS is performed. The proposed work has come out with some reasonable values of sensing time, EE-SE trade-off is a well-known problem in CSS. The analysis of EE-SE trade-off is carried out based on the two important parameters, SNR and Sensing time. This work helps in predicting suitable values for SNR and sensing time to achieve desirable EE and SE. In the proposed work, OR fusion rule is used to obtain the trade-off of EE and SE for different values of sensing time and SNR.

Here EE and SE are optimized to the value 0.8 for the values of Sensing time and SNR are 20ms and -17db respectively. Also, EE(SE) can be maximized by satisfying the minimum requirement of SE(EE). An accurate energy efficient metric for cognitive radio networks can be determined in order to reduce the Sensing time and Energy consumption while achieving a certain high level of sensing performance.

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