Reliable Transmission and Energy Efficient Cooperative Spectrum Sensing in Multicarrier Cognitive Radio

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Abstract: In the era of wireless communication technologies RF (Radio Frequency) spectrum is the most wanted but limited resource, but due to the diversified use of RF Spectrum it is congested. Allocating new RF spectrum to the new wireless system is a major challenge for us since most of the spectrum is licensed and costly. "Cognitive Radio" is the adverse alternative spectrum access technique to improve the spectral efficiency, but with great energy losses. In this paper we propose an efficient energy harvesting technique for multi carrier cognitive radio based on cooperative spectrum sensing. We employ the concept of cooperative spectrum sensing with the help of efficient band width allocation and band width of each subcarrier is divided as spectrum sensing bandwidth, energy harvesting bandwidth and transmission bandwidth, thus cooperative spectrum sensing, energy harvesting and data transmission can be implemented simultaneously within transmission time. Our proposed joint optimization technique will achieve maximum throughput of the secondary users by preserving the maximum channel capacity. We have extended the same joint optimization technique using amplify and forward concept also.

Index Terms **- Cognitive Radio, Bandwidth allocation, Cooperative Spectrum sensing, amplify and forward techniques.**

I. INTRODUCTION

Continuous increment in demand for wireless applications and services has created huge need for additional radio frequency spectrum and it is complex to provide the required spectrum to every user since the frequency spectrum in fixed and limited. Spectrum allocation is done by government organizations such as Federal Communications Commissions and these people allowed some of the people to use only some specific frequency bands by using license. These licensed peoples are Primary users of frequency spectrum. Now a days sharing the spectrum without interfering the other coexisting networks becomes a great challenge, since most of the available spectrum is already assigned to licensed users or primary users. There is lot of unused spectrum is available at every time since all the primary users are not in operational in all the times. Therefore a new technology Cognitive Radio is proposed in order to allow to use the temporarily unused frequency spectrum known as Spectrum Hole (SH) or white space which is depicted in figure 1 by unauthorized or unlicensed users called as Secondary users.

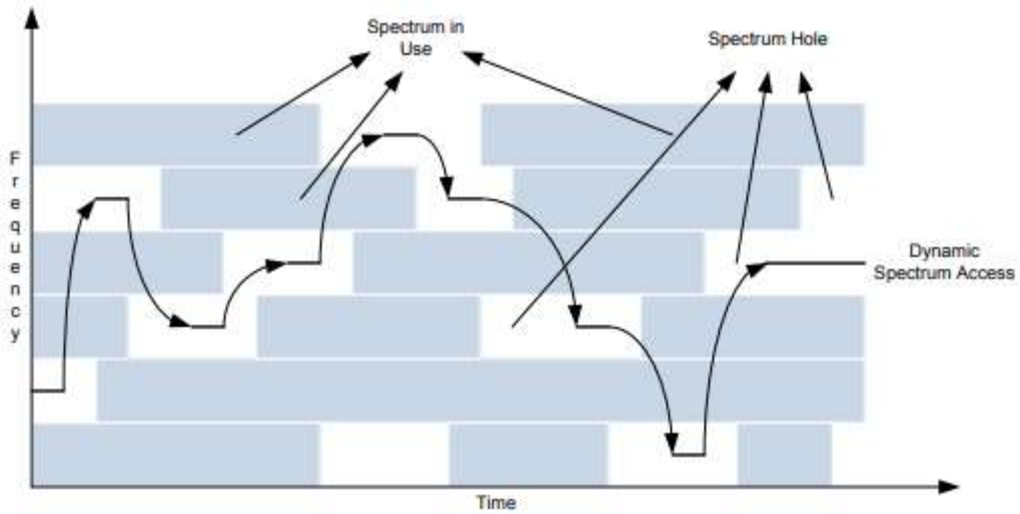

Figure 1: Concept of Spectrum Hole (SH)

A Spectrum Hole is defined as a band of A SH is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being used by that user.

Since most of the spectrum is already assigned, the challenge is to share the spectrum with coexisting networks without interfering with their transmission. For this the cognitive radio enables the usage of temporarily unused spectrum, which is referred in the literature as Spectrum Hole (SH) or white space, which is depicted in Figure 1.1. In [13], the definition of SH was given: A SH is a band of frequencies assigned to a primary user, but, at a particular time and specific geographic location, the band is not being used by that user. If this SH where the CR is operating starts also to be used by another secondary user, then the CR moves to another SH or stays in the same, altering its transmission power level or modulation scheme to minimize interference. Therefore the CR is a very advanced and effective technique for the efficient use of available spectrum and it is possible to;

- To determine free available spectrum
- Choose the efficient available channel
- Coordinate selected channel to other users to avoid unwanted interference effects.
- Vacate it when the channel conditions worsen.

Cognitive Radios allows the secondary users whenever the spectrum allocated to primary user is available and this scheme is known as avoid cognitive radio scheme or spectrum interweave scheme. Besides this interweave scheme, spectrum cooperative scheme also works simultaneously to avoid interference losses.

Most generally there should be the presence of fading effect between the primary users and secondary users, additionally due to the effect of weak received signal strength at PU causes the detection performance may greatly reduce. The probability of detection performance may increase using the concept of spectrum sensing. Cognitive radios requires more energy in order to perform spectrum detection and sensing operations, and therefore the sensing energy consumption grows as sensing time and sensing bandwidth increases. Therefore in this thesis we propose an energy harvesting scheme based on simultaneous cooperative spectrum sensing using dynamic bandwidth allocation for multicarrier cognitive radio. Amplify and forward is one of the advanced technique used to amplify the signal power levels whenever the signal power reaches under the threshold levels.

II. System model

Multi carrier cognitive radio is an advanced intelligent wireless transceiver system detects which communication channels are in use and which are not, and instantly move to vacant channels while avoiding occupied ones. This optimizes the use of available radio frequency spectrum while minimizing the interference to other users. Cognitive radios are broadly categorized as *Full Cognitive radio and Spectrum sensing Cognitive Radio.* In full cognitive radio is like classical radio a wireless node will observe every parameter in the network whereas Spectrum sensing cognitive radio only considers radio frequency spectrum. As already we discussed in previous section in order to transfer the data secondary users are harvest the energy of the existing primary user signal and noise. In this proposed system model we will achieve the energy harvesting for spectrum sensing and data transmission by dividing the each subcarrier of the Secondary user into three sub bands as *Spectrum Sensing Sub band, Energy harvesting sub band and data transmission sub band.*

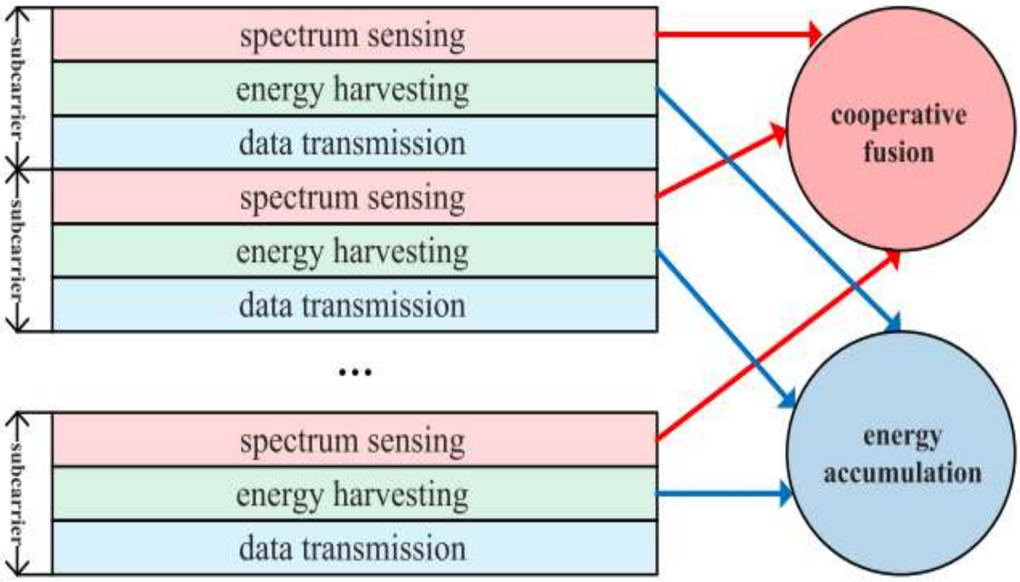

Figure 2. Simultaneous cooperative spectrum sensing and energy harvesting model

Figure 2 represents the proposed simultaneous cooperative spectrum sensing and energy harvesting model.

Spectrum sensing

All the major functionalities of cognitive radio such as spectrum decision, spectrum sharing and spectrum mobility are depends on spectrum sensing function. Therefore spectrum sensing will greatly affects the performance of spectrum efficiency (SE) and energy efficiency (EE) of the cognitive radio. Spectrum Sensing is the ability of secondary users to efficiently utilize the UN used primary user spectrum and energy efficiency is defined as the ration of spectrum efficiency to the total consumed power by the secondary user.

The local sensing observation of an SU can be formulated as a binary hypothesis problem and the received sensing signal is described as

$$r(m) = \begin{cases} n(m), & H_0 \\ h(m)s(m) + n(m), & H_1 \end{cases}, \quad m = 1,2,\dots,M \tag{1}$$

Where H0 denotes the absence of primary user signal and H1 denotes the presence of primary user signal, s(m) is the sampled primary user signal with the power spectral density ζ_s, n(m) is the sampled Gaussian noise with the power spectral density ζ_n, h(m) is the subcarrier gain from the PU to the SU, and M is the number of the sampling nodes. SS detection techniques can be classified as coherent or non-coherent [6]. With coherent detection, prior knowledge of the PU signal characteristics is required. In non-coherent detection, no prior knowledge is required for PU detection. Energy detection (ED) is a non-coherent detection technique [6] and is used in this thesis.

Energy statistic of sensing signal is described as

$$\Phi(R) = \frac{1}{M}\sum_{m=1}^{M}|R(m)|^2 \tag{2}$$

R(M) is the FFT of the r(m) and M=2TW, where T is sensing time and W is spectrum sensing bandwidth.

By comparing $\Phi(R)$ to a prefixed decision threshold λ, false alarm probability and detection probability are respectively given as follows

$$P_f = P_r(\Phi(R) > \lambda|H_0) = Q\left(\left(\frac{\lambda}{\zeta_n W} - 1\right)\sqrt{2TW}\right) \tag{3}$$

$$P_d = P_r(\Phi(R) > \lambda|H_1) = Q\left(\left(\frac{\lambda}{\zeta_n W(\gamma+1)} - 1\right)\sqrt{2TW}\right) \tag{4}$$

Where the function Q(x) is described as

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} exp\left(-\frac{z^2}{2}\right)dz \tag{5}$$

There are two schemes are available depends on either fixing the false alarm probability or fixing the detection probability

Condition 1: if the spectrum access to the secondary user is guaranteed. Then the sensing threshold can be selected by fixing the false alarm probability as follows

$$\lambda = \left(\frac{Q^{-1}(P_f)}{\sqrt{2TW}} + 1\right)\zeta_n W \tag{6}$$

Condition2: If the interference to the PU has to be controlled by the SU, the sensing threshold can be chosen by fixing the detection probability as follows

$$\lambda = \left(\frac{Q^{-1}(P_f)}{\sqrt{2TW}} + 1\right)(\gamma+1)\zeta_n W \tag{7}$$

Based on OR Rule, the best detection performance is achieved if the presence of PU is detected to be in any of the sub carried. Therefore the probability of false alarm and detection probability are defined as

$$Q_f = 1 - (1 - P_f)^N$$
$$Q_d = 1 - (1 - P_d)^N \tag{8}$$

N is the number of sub carriers.

Optimization Model

Throughput of the secondary users and the efficiency of data transmission is good whenever the absence of primary user is detected without false alarm. And the through of the secondary user is give as

$$R(\rho_s, \rho_h, \{p_n\}) = W(1 - \rho_s - \rho_h)(1 - Q_f)P_r(H_0) \times \sum_{n=1}^{N}\log\left(1 + \frac{p_n g_n^2}{\zeta_n W \rho_t}\right) \tag{9}$$

ρ_s is defined as spectrum sensing bandwidth ratio, ρ_h is energy harvesting bandwidth ratio and ρ_t is data transmission bandwidth ratio. Transmission power in subcarrier n with the channel gain gn is defined by p_n.

The overall harvested power over N subcarriers is given as follows

$$p_H = N\mu(\zeta_s P_r(H_1) + \zeta_n)\rho_h W \tag{10}$$

μ is the energy harvesting efficiency and it is 0< μ<1

We order that the harvested power adding the initial power should supply the consumed sensing power and the transmission power. We suppose that the initial power supplied by the battery is pB, the maximal transmission power is pmax and the sensing power for unit bandwidth is pu. Then we can get

$$p_H + p_B \geq p_{max} + Np_u\rho_s W \tag{11}$$

Number of subcarriers

Though the sensing performance may improve with the increasing of the number of the subcarriers, the consumed energy will also increase due to cooperative overhead. Thus, we choose the optimal number of the subcarriers to achieve better cooperative sensing performance with less energy consumption. In cooperative spectrum sensing, the sensing time includes the local sensing time T and the cooperative overhead time Nτ . From (10), Qd can be denoted by Qf as follows

$$Q_d = 1 - \left(1 - Q\left(\frac{Q^{-1}\left(1-(1-Q_f)^{\frac{1}{N}}\right) - \gamma\sqrt{2TW}}{\gamma+1}\right)\right)^N \tag{12}$$

Define sensing energy efficiency ξ as detection probability to sensing energy ratio. In the optimization problem, we seek to maximize the sensing energy efficiency as follows

$$\max_{N} \xi = \frac{Q_d}{(T+N\tau)p_u} = \frac{Q_d = 1 - \left(1 - Q\left(\frac{Q^{-1}\left(1-\left(1-Q_f\right)^{\frac{1}{N}}\right) - \gamma\sqrt{2TW}}{\gamma+1}\right)\right)^N}{(T+N\tau)p_u} \quad (13)$$

We have extended the same cooperative spectrum sensing using amplify and forward technique , it allows Cooperative communication exploits the broadcast nature of the wireless medium and allows terminals to jointly transmit information through relaying. Amplify and forward method is often used when the relay has only limited computing time/power available or the time delay, caused by the relay to decode and encode the message, has to be minimized. Of course when an analogue signal is transmitted Assuming that the channel characteristic can be estimated perfectly, the gain for the amplification can be calculated as follows.

$$[|y_r^2|] = E[|h_s r|^2]E[|x_s r|^2] + E[|z_s r|^2] = |h_s|^2\zeta + 2\sigma^2 \quad (14)$$

where s denotes the sender and r the relay. To send the data with the same power the sender did, the relay has to use a gain of

$$\beta = \frac{\sqrt{\zeta}}{|h_s r|^2\zeta + 2\sigma_{s,r}^2} \quad (15)$$

III. RESULTS AND DISCUSSIONS

We have implemented the proposed scheme using MATALB simulator, here we have considered unity band width, power spectral density of 5 mW/Hz with absence and presence of primary user probability are mutually exclusive with the probability of 0.5, energy harvesting ratio is 0.5, sensing time T=10s,maximum Transmission power is 50mW and with Rayleigh distribution carriers.

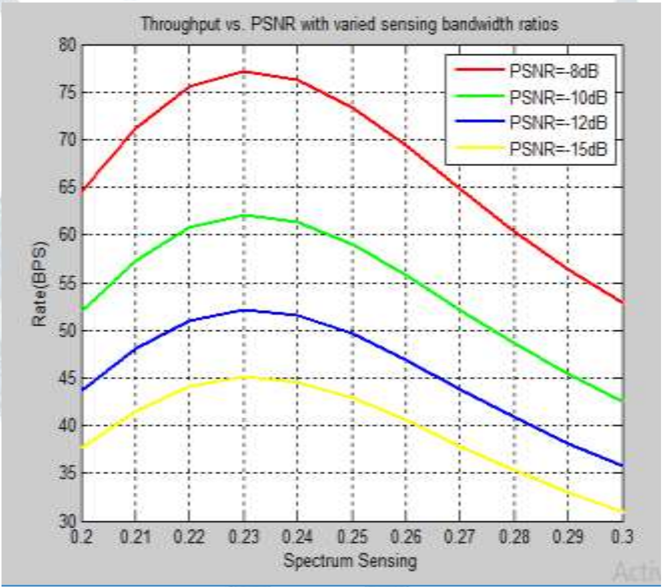

Figure3: Throughput VS PSNR

Figure 3 represents the simulation results of throughput with respective to peak signal to noise ratio with varying sensing bandwidth ratio. Since we have consider the absence alarm probability and presence alarm probability is mutually exclusive, probability of access opportunity is too less in the presence of false alarm environment. In other hand the transmission bandwidth will decreases gradually whenever the probability of spectrum access opportunity increases. It is also seen that R improves obviously with the increasing of PSNR.

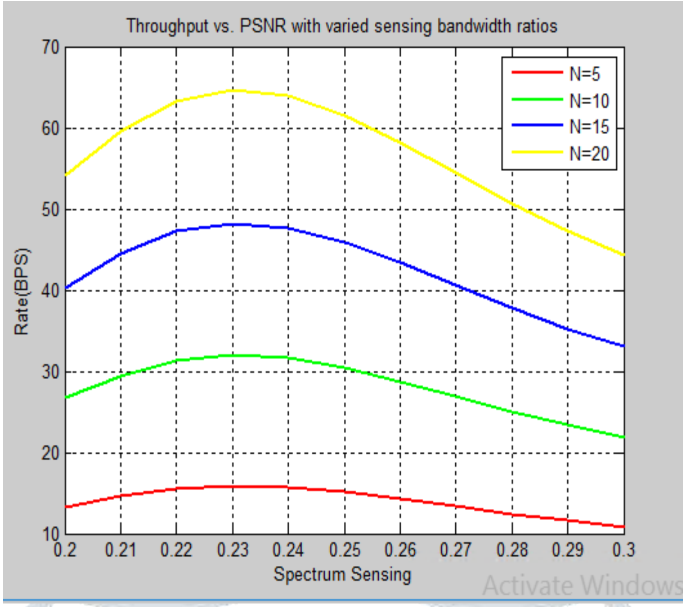

Figure. 4. Throughput vs. number of subcarriers with varied sensing bandwidth ratios.

From the figure 4 we have proved that R will increases gradually with the increase in N. as we have used cooperative spectrum sensing improvement techniques the accessibility of spectrum sensing also increases gradually.

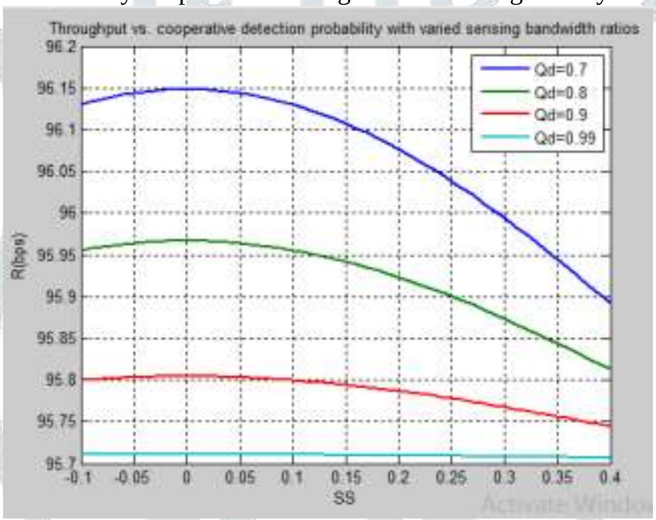

Figure. 5. Throughput vs. cooperative detection probability with varied sensing bandwidth ratios.

Figure 5 shows the relation between R with respective to cooperative detection probability with varied sensing ratio. We have observed that whenever the Qd decreases R will improves.

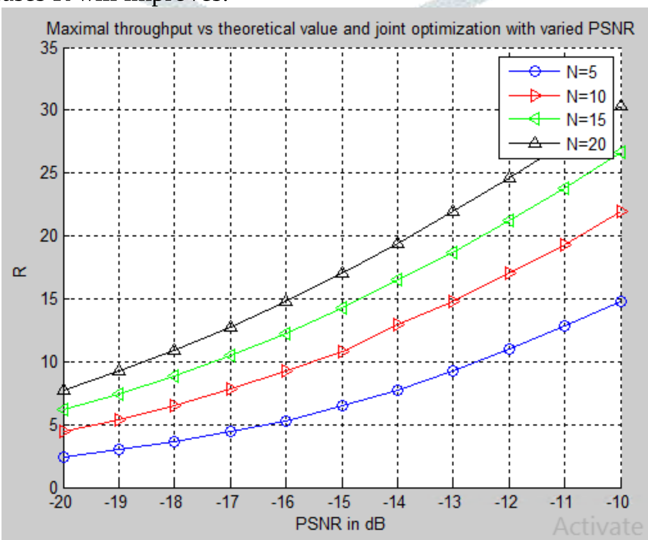

Figure 6. Maximal throughput vs theoretical value and joint optimization with varied PSNR.

Above results indicates the achieved maximum throughput with respective to joint optimization of varied PSNR.

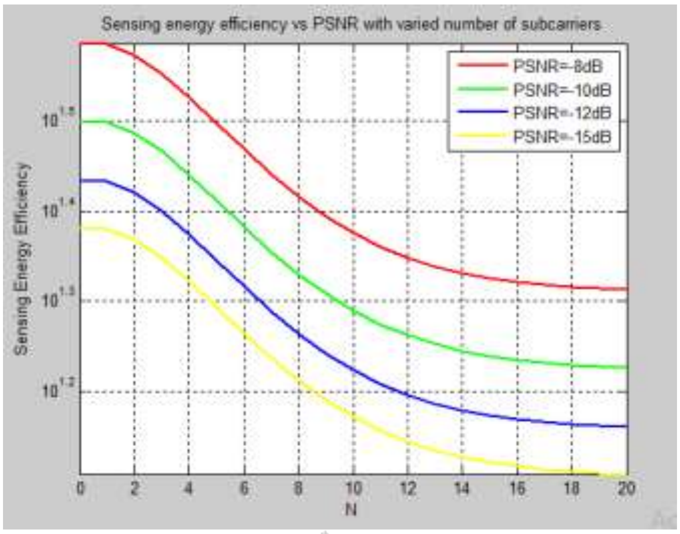

Figure 7. Sensing energy efficiency vs PSNR with varied number of subcarriers.

Figure 7 shows the sensing energy efficiency, ξ , vs. PSNR with varied N. It is seen that there exists an optimal N that makes ξ achieve the maximal value. When N is small, the sensing performance is very low; however, when N increases, though the cooperative detection probability improves, the cooperative overhead also increase.

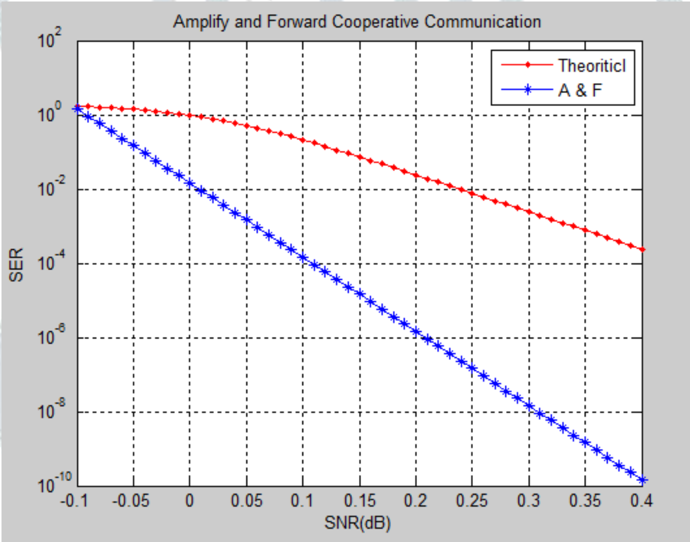

Figure 8. SNR vs SER of amplify and forward

Figure 8 represents the cooperative spectrum sensing and bandwidth allocation using amplify and forward concept. Our simulation results depicts that whenever SNR is increasing then the SER decreases gradually, here we have implemented amplify and forward technique in order to increase the signal strength whenever the signal strength goes under the threshold levels.

IV. Conclusion

This paper describes about the advanced energy harvesting model for multi carrier cognitive radio network system using bandwidth allocation scheme. We have extended this thesis to amplify and forward scheme. There is a great scope to extend this schema to maintain high reliability with availability in wireless technologies.

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