CHAPTER 4: HYBRID SPECTRUM SHARING SCHEMES FOR COGNITIVE RADIO NETWORKS

In the earlier works, the focus was on opportunistic spectrum access where secondary user will access the primary user band if PU is idle. In cognitive radio environment the secondary users sense the primary user bands and based on the decision they access the spectrum for communication. Most commonly used spectrum access models [87] [88] [89] are interweave mode and joint interweave underlay mode. In the interweave mode secondary users transmit the information when primary users are sensed to be idle. Due to sensing errors primary user may get interfered by secondary user transmission. In the joint interweave underlay mode, secondary users will transmit the information irrespective of primary user transmission, but without interfering and maintaining the Quality of service of primary users.

In 5G networks [90] cognitive radio is one among the emerging technologies to improve the spectrum access efficiently. Small cell technology is promising in 5G networks because it can offload traffic from primary marcocells and it can increase the spatial reuse and coverage. By having cognitive small cell deployments in the network resource allocation, spectrum access and interference mitigation are maintained optimally [91-93]. Therefore system performance can further be improved by having small cell network coexisting with a macro cell network [94]. The three potential ways of sharing primary macrocell spectrum by small cell network are: 1) Spectrum sharing, primary macrocells spectrum is shared by small cell 2) opportunistic spectrum access, secondary small cell can access the primary macro cell spectrum if it is sensed idle 3) Hybrid spectrum sharing, depending on the spectrum sensing result of Enhanced spectrum sensing secondary small cell senses channel status and optimize the allocation of power[95].

In [96], for perfect sensing case authors studied throughput tradeoff between only interweave and combination of interweave underlay mode. In [96]-[99] authors hasn't considered any cooperation between users transmission. In [100]-[102] under information theoretic framework authors discussed about benefits in cooperation between users. In [103] SU's receiving packets from two PU's relaying them using superposition coding method when PU is idle. In [104], cooperative relaying is discussed where the failed packets of PU are transmitted by SU relays which has finite queue length. Coming to survey on sharing techniques, in [105], a theoretically derived stochastic geometry model was investigated for spectral sharing scheme between macrocell(Primary network) and small cell(Secondary network). In [106], a stochastic dual control approach was presented to analyse different interfering forces within small cell networks, without involving centralized and global control efforts. In [107], a stackleberg game in cognitive femto cells was studied for energy efficient power allocation and spectrum sharing. A power adaptation game was studied to decrease energy consumption in [108]. The existing works discussed so far used conventional energy detectors at sensing stage due to which false alarms and missed detections will increase and has not been well tested on improvement of spectral efficiency by having power control optimization.

Later power control optimization for secondary users known as Hybrid spectrum sharing is used for further improvement of spectral efficiency. Furthermore, the failed packets of Primary users are taken care by high ranked relays which in turn decrease the average Primary user packet delay.

In this chapter, different from the existing works, at spectrum sensing stage, enhanced spectrum sensing, in combination with hybrid spectrum sharing (HSS) is used for enhancing the primary and secondary user spectral efficiency. Later power control optimization for secondary users is used to avoid interference with the primary user. Furthermore, the failed packets of Primary users are taken care by high ranked relays, which in turn decrease the average Primary user packet delay.

In recent times, the efforts are towards secondary network helping to relay primary user packets by continuing data transfer of their own. This is motivated because of joint interweave underlay mode. With various constraints and objectives, extensive research is done in the literature [109][110][111]. Hence we considered the influence of having a group of buffered relay nodes with cognitive capabilities on Primary and secondary user Spectral efficiency. Relay nodes will help in delivering unsuccessful packets at primary destination nodes. When both primary and secondary nodes are silent the relay nodes will send the unsuccessful packets. We start with describing the system model that was used for simulations.

4.1 System Model

The figure 4.1 is the block diagram of cognitive ofdm network. In this work We have considered an OFDMA cognitive network. The focus is on resource allocation in the downlink of the cognitive small cell.

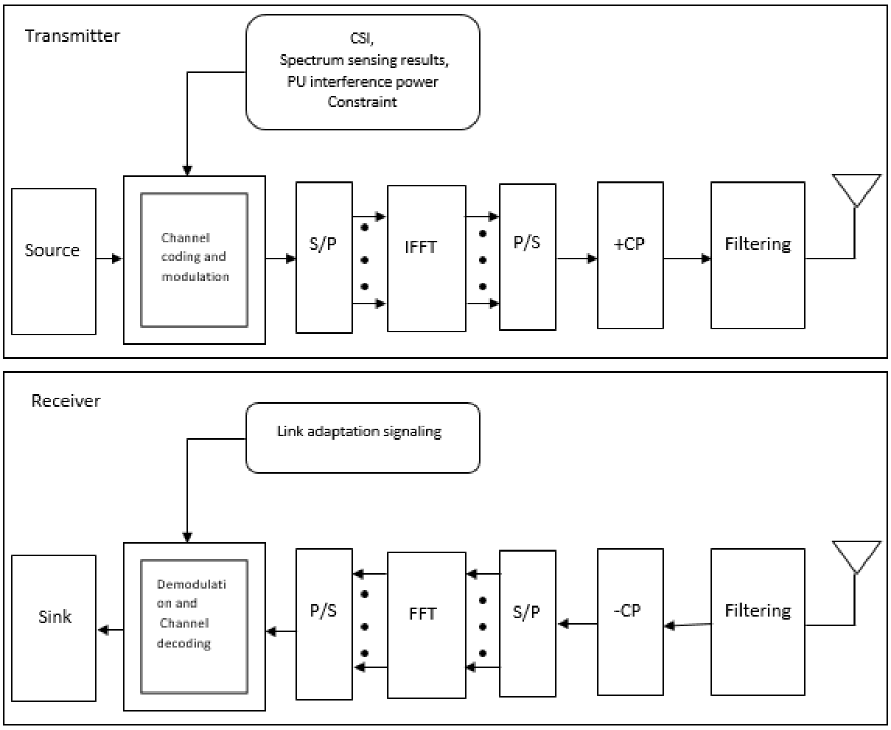

Figure 4-1 Generic Block diagram of Cognitive OFDM network

The OFDMA system has a bandwidth of B, which is divided into N subchannels. Not all the subchannels are used for communication by Pus. Some of the subchannels can be considered for cognitive user communications. Before CU accesses the spectrum licensed to primary user, CU performs spectrum sensing to determine the status of the subchannels. In each time frame, the cognitive user can sense N subchannels by enhanced spectrum sensing method. Then the cognitive user adapts the transmit power based on the spectrum sensing result. It should be noted that Primary user communication should not get disturbed.

In a cognitive heterogeneous network which consists of a cognitive user and primary user, imperfect spectrum sensing by cognitive user will cause cochannel interference to primary user and thus degrade the performance of heterogeneous network. Where both cognitive user and primary user throughput will get affected. Hence spectrum sensing plays an important role. Our proposed enhanced energy detector will help in improving the spectral efficiency.

4.2 Hybrid Spectrum Sharing

As shown in the figure below [112] the frame structure of cognitive small cell network is designed. It is observed from the figure that a sensing time τ is assigned in the beginning of each frame. The cognitive small cell (CSC) adapts it's transmit power at the beginning of each frame dependent on the sensing result.

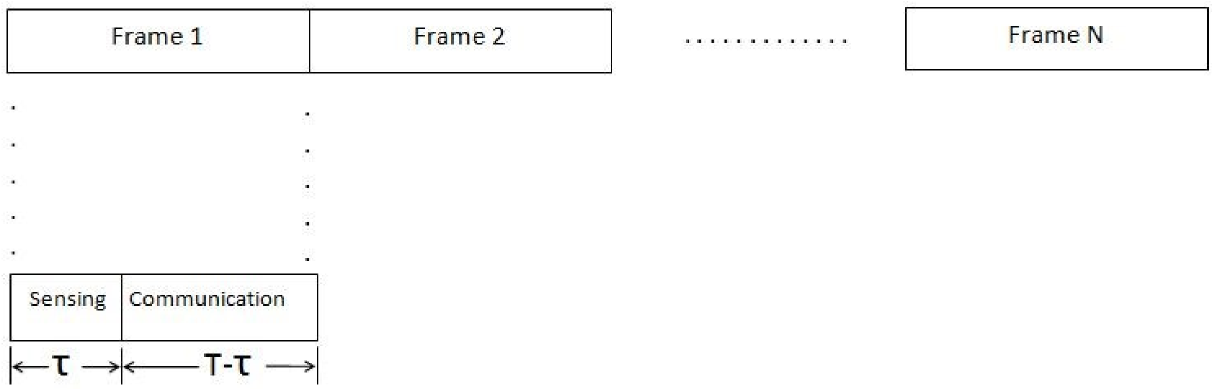

Figure 4-2 Frame structure of CSC network

If the subchannel is detected idle, CSC can transmit with high power $P^{v}_{s,n}$, if not CSC can transmit with low power $P^{o}_{s,n}$. This method is termed as "Hybrid Spectrum Sharing". Based on shannons capacity formulae the feasible capacity of sub channel n when sensing outcome is idle and when it is active in small cell is given by [95]

$$R_{v,n} = \log_2(1 + \frac{g_{ss,n} \cdot p^{v}{}_{s,n}}{\sigma^2}) \quad (4.1)$$

$$R_{o,n} = \log_2(1 + \frac{g_{ss,n} \cdot p^{0}{}_{s,n}}{g_{ms,n} \cdot p^{0}{}_{m,n} + \sigma^2}) \quad (4.2)$$

Where $g_{ss,n}$ is the channel gain of subchannel n between small cell user and Cognitive small cell base station, $g_{ms,n}$ where is the channel gain of subchannel n between macrocell basestation and Cognitive small cell base station and ${p^0}_{m,n}$ is the transmit power of macrocell basestation on sub channel n.

4.3 Formulation of Interference and Transmit Power Constraints:

In this section the optimal powers of CSC's which overcome the interference mitigation is determined. From [95], [107], [114] average interference and transmit powers are considered and can be formulated as follows

$$E_{g,h}\{ p(H_0)(1-p_{fa})\,p + p(H_1)(1-p_d)\,p \} \le p_{av} \tag{4.3}$$

$$E_{g,h}\{ p(H_1)(1-p_d)\,h\,p \} \le \Gamma \tag{4.4}$$

Where p_{av} *is* the maximum average transmit power of CSC users and Γ is the maximum average interference power which can be tolerated by PU. The enhanced spectrum sensing is considered as method of detection, the detection and false alarm probability are given by Eq 4.3 and Eq 4.4 Now the formulation for average interference and transmit power constraint of CSC users for the combination of Hybrid spectrum sharing [113] and enhance spectrum sensing is given as

$$maximize\{ p, {p^{EED}}_d \};\; C(p, {p^{EED}}_d) = E_{g,h}\left\{ p(H_0)(1-{p_{fa}}^{EED}).\log_2(1+\frac{gp}{\sigma^2}) + p(H_1)(1-{p_d}^{EED}).\log_2(1+\frac{g\,p}{{\sigma^2}_n+{\sigma^2}_p}) \right\}$$

(4.5)

Where g and h are instantaneous channel gains. ${\sigma^2}_n$ and ${\sigma^2}_p$ are variance of noise and signal. $p(H_0)$ and $p(H_1)$ are probability of PU present or not present.

By letting similar average interference power constraint in cognitive networks [115], the $p_d{}^{EED}$ becomes an optimization variable for maximizing the achievable spectral efficiency. By observing Eq (4.5) it is evident that the formulation is convex with transmit power P but not with respect to $p_d{}^{EED}$, because of dependency on probability of false alarm $p_{fa}{}^{EED}$ on the probability of detection.

Hence, the optimal detection probability cannot yield from convex optimization techniques. In this case for minimization of spectral efficiency of the proposed HSS and ESS the detection probability is considered in the range [0,1]. By doing so the optimal power allocation can be determined for a detection probability p_d=$p_d{}^{EED}$.

Lagrangian can be determined for detection probability p_d=$p_d{}^{EED}$ in accordance with transmit power P is given by [113]

$$L(p,\nu,\mu) = E_{g,h}\left\{p(H_0)\left(1 - p_{fa}{}^{EED}\left(\mathbb{P}_d{}^{EED}\right)\right).\log_2(1+\frac{gp}{\sigma^2}) + p(H_1)\left(1-\mathbb{P}_d{}^{EED}\right).\log_2(1 + \frac{g\,p}{\sigma^2{}_n+\sigma^2{}_p})\right\} - \lambda\left\{E_{g,h}\left[p.p(H_0)\left(1-p_{fa}{}^{EED}\left(\mathbb{P}_d{}^{EED}\right)\right) + p(H_1)\left(1-\mathbb{P}_d{}^{EED}\right)p\right] - p_{av}\right\} - \mu\{E_{g,h}\left[p(H_1)(1-\mathbb{P}_d)h\,p\right] - \Gamma\} \tag{4.6}$$

Now the lagrange dual optimization problem is given as

$$minimize\ \nu \geq 0, \mu \geq 0, \quad g(\nu,\mu) \tag{4.7}$$

Where $g(\nu,\mu)$ is lagrange dual function and given as

$$g(\nu,\mu) = \sup_{P} L\,(p,\nu,\mu) \tag{4.8}$$

From [116] the primal optimization problem, Eq 4.5 can be solved by Eq 4.7 with respect to transmit power P. Hence the focus is to solve lagrange dual optimization problem (Eq 4.5). The Supremum of lagrangian $L\,(p,\nu,\mu)$ is to calculate the lagrange dual function $g(\nu,\mu)$ with respect to transmit power P as in Eq 4.8. With the help of KKT conditions [116] the optimal power allocation P for multipliers ν *and* μ [113] can be obtained by

$$p = [\frac{A+\sqrt{\Delta}}{2}]^{+} \tag{4.9}$$

The parameters A and Δ are given as follows and the whole term $[X]^{+}$ denotes max(o,x). The proofs are considered from [113]

$$A = \frac{\log_2 e\left[p(H_0)\left(1-p_{fa}{}^{EED}\left(\mathbb{P}_d{}^{EED}\right)\right)+p(H_1)\left(1-\mathbb{P}_d{}^{EED}\right)\right]}{\nu\left[p(H_0)\left(1-p_{fa}{}^{EED}\left(\mathbb{P}_d{}^{EED}\right)\right)+p(H_1)\left(1-\mathbb{P}_d{}^{EED}\right)\right]+\mu\; p(H_1)\left(1-\mathbb{P}_d{}^{EED}\right)h} - \frac{2\sigma^2{}_n+\sigma^2{}_p}{g} \tag{4.10}$$

$$\Delta = A^2 + \frac{4}{g}\left\{\frac{\log_2 e\left[p(H_0)\left(1-p_{fa}{}^{EED}\left(\mathbb{P}_d{}^{EED}\right)\right)(\sigma^2{}_n+\sigma^2{}_p)+p(H_1)\left(1-\mathbb{P}_d{}^{EED}\right)\sigma^2{}_n\right]}{\nu\left[p(H_0)\left(1-p_{fa}(\mathbb{P}_d)\right)+p(H_1)(1-\mathbb{P}_d)\right]+\mu\; p(H_1)\left(1-\mathbb{P}_d{}^{EED}\right)h} - \frac{\sigma^2{}_n\left(\sigma^2{}_n+\sigma^2{}_p\right)}{g}\right\} \tag{4.11}$$

4.4 Results and Analysis

Spectrum sensing on the sub channels is done with the help of enhanced spectrum sensing algorithm so that the probability of false alarms will be less. Based on the spectrum sensing result the powers are allocated. If spectrum sensing gives PU is present then CU will coexist with PU but send its data with less power. In converse, if spectrum sensing output gives PU absent then CU will send data with high power. While CU is coexisting with PU it has to maintain a certain interference threshold so that PU communication will not get interfered. As the network is dynamic reliable CUs are always available. Failed packets in PU communication can be transferred by high ranked CU nodes which eventually increases the throughput of PU. This way the throughput of both primary and secondary user networks are improved and presented in the results.

In this chapter the focus is on downlink of cognitive small cell. In order to access the bandwidth of licensed primary macro cell, cognitive small cell has to perform spectrum sensing to determine the status of the primary sub channels. Cognitive small cell can sense N-subchannels by enhanced spectrum sensing in each time frame. The cognitive small cell will adapt the transmit power based on the spectrum sensing result .To evaluate the performance of the proposed method the simulation results of the network consisting of cognitive small cell and macrocell networks is presented. The comparison results are between HSS+ESS, OSS (Oppurtunistic spectrum sensing) +ESS [114] and CSS [88][89]. From the following results it is evident that by having optimal powers in Hybrid spectrum sharing [95] with the involvement of Enhanced energy detection [82] will yield better results. The parameters considered are, sampling frequency, f=6MHz, T=0.1 sec, and number of nodes in the network, N=50, variance σ^2= 1x10^{-4} and channel gains are considered as block faded and distributed exponentially with 0.1 mean. On each channel of primary macrocell the transmit power is set as 10 mW. The assumptions are, the detection probability is considered as 90% if it is not stated and 0.3bps/Hz is the minimum data requirement for better Quality of Service. It can be observed from figure 4.3 that by having efficient enhanced spectrum sensing scheme at sensing unit and optimal power allocation for secondary users with the help of Hybrid spectrum sharing will eventually increase spectral efficiency when compared with Opportunistic[112] and

Conventional Spectrum sensing[88][89], in the environment with parameters considered above. As the enhanced spectrum sensing scheme will have minimum false alarms and missed detections the true free channels are identified properly and allocated to secondary users and with the help of power optimization in hybrid spectrum sharing the interference caused by secondary users to primary users is also minimized and hence spectral efficiency will increase. One more reason for increment in spectral efficiency is the failed packets of PU are taken care by a set of high ranked SU relays. Hence the Spectral efficiency of PU has increased compared to other methods [99][100][101][102]. It is also observed form the graphs that after certain average number of relays the spectral efficiency is constant because if there are more number of relays available then spectrum decision and spectrum mobility becomes easier.

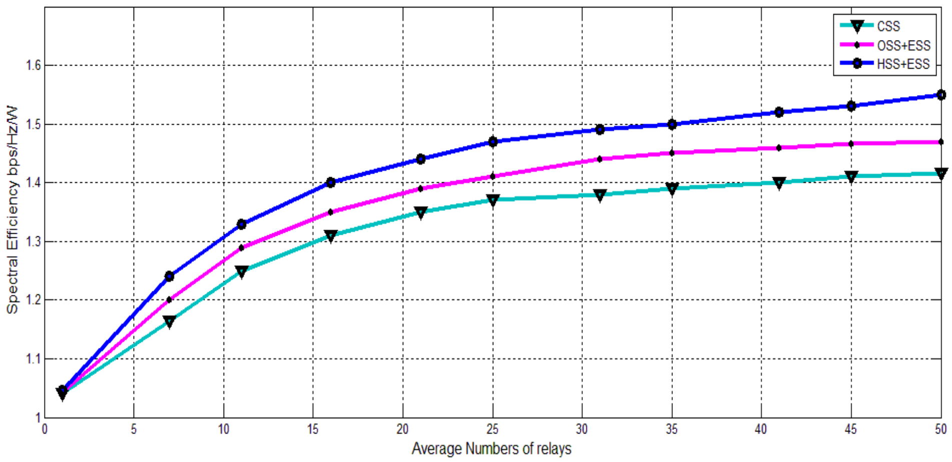

Figure 4-3 Comparison of average number of relays and its impact on PU Spectral Efficiency between different methods

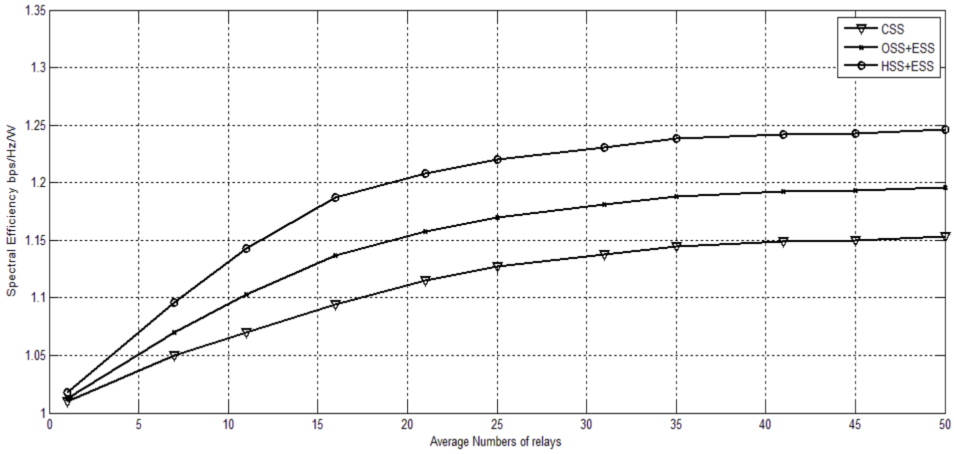

Figure 4-4 Comparison of average number of relays and its impact on SU Spectral Efficiency between different methods

Figure 4.4 displays that by choosing optimal powers to SU's and increase in the number of relays will increase its spectral efficiency without causing interference to PU's. If we observe the SU's who opportunistically access the PU spectrum (Conventional Spectrum Sensing (CSS)) [88][89] with conventional energy detector and Enhanced spectrum sensing (OSS+ESS)[114], the former has low spectral efficiency compared to the proposed method (HSS+ESS) because of not assigning optimal powers

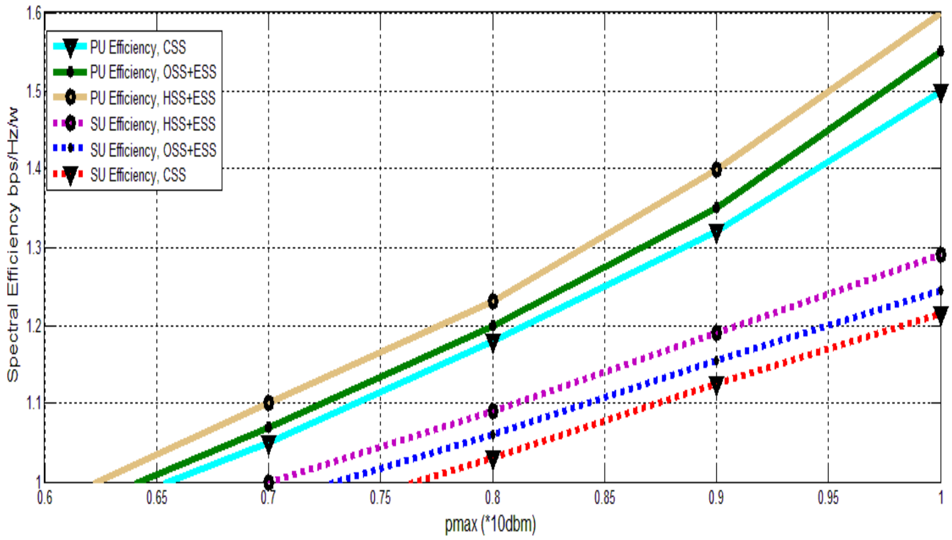

*Figure 4-5 Spectral Efficiency vs. Pmax (*10dbm) in both Primary macrocell and Cognitive small cell*

Figure 4.5 provides the spectral efficiency comparison between proposed method and the other methods of primary macrocell and cognitive small cell. By implementing the proposed method and working in complete environment where primary macrocell and cognitive small cell nodes are participating in communication. The spectral efficiency of HSS+ ESS method of secondary user network has increased from 1.21 bps/Hz/w to 1.29 bps/Hz/w, and for primary user network it has increased from 1.5 bps/Hz/w to 1.6 bps/Hz/w. In both the networks the improvement is due to power optimization from Hybrid spectrum sharing plus enhanced spectrum sensing. The improvement is also evident because of SU relay nodes helping PU failed packet transmission. This is possible because of finding out the perfect spectrum for communication and interference avoidance of Secondary user to primary user.

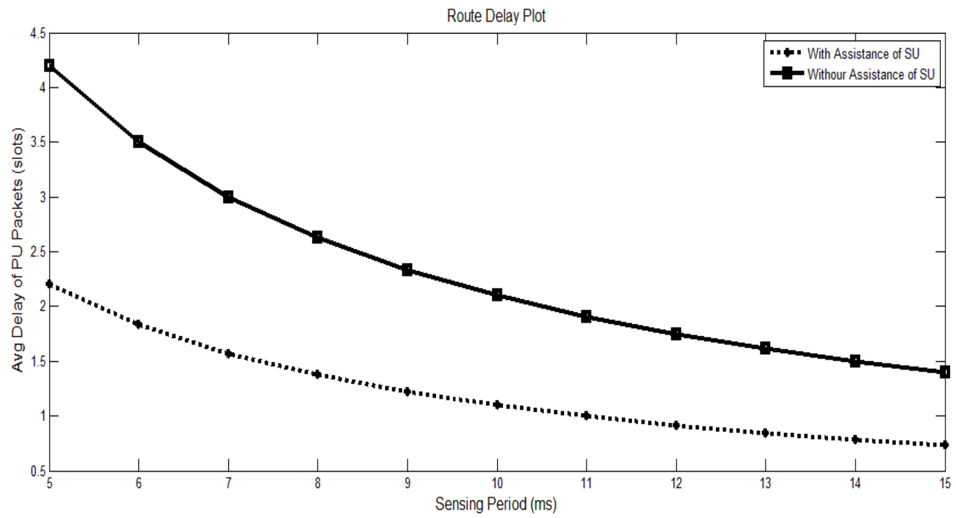

Figure 4-6 Average Delay of PU packets with respect to time with and without assistance of Cognitive small cell relays

Figure 4.6 indicates the relation between Sensing Time and average delay of PU packets with and without assistance of SU relays. One of our objective was if any failed packets are there from PU, the high ranked SU relays in cognitive small cell will help PU's to transfer the packets which actually avoids the PU resending the data packets and reroutings. By doing so it is observed from fig 4.6 that the average delay of PU packets has decreased by 20%. Hence we can say that our proposed scheme's spectral efficiency is better when compared with other methods and the average packet delay is also decreased.

4.5 Conclusions

In this chapter, an efficient method is proposed which allocates an optimal power to SU's in order to mitigate interference for PU's. We also have investigated a cooperation method where a cognitive small cell nodes (SU's) will help Primary macro cell nodes (PU's) in transmission of failed packets. We have analysed spectral efficiencies and average PU packet delay. It was observed from the results that the proposed method's spectral efficiency is improved for primary macrocell and cognitive small cell. The average PU packet delay of assisted SU method is decreased by 20% when compared to non-assisted SU method.

In this chapter, we have worked on all the important parameters which are helpful for building a cognitive radio network and have seen improvement in the results. In the final chapter we wanted to simulate Cognitive radio enabled IoT network, and in a network, routing metrics play an important role for defining quality of service of a network. New routing metrics are proposed for estimating spectrum quality and availability.