Dynamic Spectrum C0-Access (DSCA) With Dirty Paper (DPC) For Cognitive Radio Networks

Nashib Acharya, Nanda B. Adhikari

Department of Electronics and Computer Engineering, IOE, Central Campus, Pulchowk, Tribhuvan University, Nepal

Corresponding Email: nashibacharya@gmail.com

Abstract: In the current architecture of dynamic spectrum access, which is also known as opportunistic spectrum access, secondary user can only access the spectrum when there is no existence of primary carrier. The resurgence of primary user compels the secondary user to vacate the spectrum so that communication of primary user shall not be disturbed. Eventually, this disrupts the secondary user results the poor Quality of Service. In this thesis, architecture for dynamic spectrum access, termed as Dynamic Spectrum Co-Access (DSCA) is developed, to enable the primary user and the secondary user to simultaneously access licensed spectrum. With DSCA, secondary users transparently incentivize primary users through increasing the primary user performance, so that secondary users can access spectrum simultaneously with primary users. This is realized by using the special pre coding techniques called Dirty Paper Coding (DPC) to preserve signal over the interference. For that, a mathematical model is formulated to determine the minimum incentives for the spectrum co-access, computational analysis of region of co-access is done to determine where the secondary users that can co-access with a given primary user.

Keywords: Dynamic spectrum Co-Access; simultaneous access of spectrum; cognitive radio network; resurgence.

1. Introduction

Broadcasting is done through Radio. Thus, large number of users coexists in same frequency band which interfere each other. As numbers of users increased exponentially over last few decades, the availability of spectrum becomes severely constraint. This shows that almost all the frequency bands have been assigned. On the other hand, user demands are increasing exponentially.

In recent years, significant effort has been applied to better utilize the wireless communications spectrum. The existing model for spectrum allocation by Federal communication commission (FCC) has been to give licenses for the major part of usable spectrum to the commercial licensed user and named them as primary user. As Primary user pay for the spectrum, the total right over this spectrum will be of primary user. However many studies have shown that a large portion of licensed spectrum is underutilized. There exist abundant spectrum opportunities in the temporal, spatial, and frequency domains. The exploitation of these spectrum opportunities is currently an area of significant research known as Dynamic Spectrum access (DSA) or Cognitive Radio Network (CRN). Researchers consider cognitive radio as the best solution for the problem of spectrum scarcity, since a large portion of spectrum in the UHF/VHF bands are becoming available on a geographical basis after analog to digital TV switchover [1]. There exist very little new bandwidth available for emerging wireless products and services. Cognitive radio is born as the idea to solve this spectrum scarcity problem. "A cognitive radio is a Wireless communication system that intelligently utilizes any available side information about the (a) activity, (b) channel conditions, (c) codebooks or (d) messages of other nodes with which it shares the spectrum" [2] . This is the most famous and widely proposed Cognitive radio Cycle. However, it is the concept which is basically used in opportunistic cognition. The Cognitive Radio devices will utilize advanced radio and signal processing technology along with new spectrum allocation policies to support new user in existing crowded spectrum without degrading the Quality of Service (QoS) of the existing users of the spectrum. A cognitive Radio must pose advanced sensing and processing capabilities. Thus, CR needs the intelligence software which can sense, gather and process all the information about the spectrum that exists around it. Thus cognitive radio is a novel concept that allows wireless system to sense the environment, adapt, and learn from previous experience to improve the communication quality.

Though, dynamic spectrum access solve spectrum scarcity problem to some extent, but secondary user opportunistically access the licensed spectrum of Primary User, whereas PU has privileged access of the licensed band. The compulsion to vacate the band immediately by Secondary user after resurgence of primary user traffic in the band made ongoing communication of secondary user to be disrupted. The requirement that Secondary users cannot access spectrum simultaneously with Primary users results in significant overhead on spectrum sensing and spectrum handoff, which in turns results poor performance for cognitive radio networks.

In this paper, A novel architecture is developed for dynamic spectrum access, termed as Dynamic Spectrum Co-Access (DSCA), which enables both SU and PU simultaneously access licensed spectrum. It is well understood that PU does not allow SU to co-access without incentive. Thus PU is incentivized by SU to motivate in participation for co-access. The novelty of DSCA is that the secondary user communication can provide a significant performance improvement to the PUs communication as incentive. Hence PU is incentivized to welcome the Co-Access of spectrum with SU [3]. It differs than Opportunistic Spectrum Access (OSA) in a way that it allows simultaneous spectrum access not time based sharing. DPC is incorporated with cooperative cognitive radio to implement this.

2. Literature Review

The concept of cognitive radio was first proposed by J. Mitola in 1998 in the seminar of Royal Institute of Technology of Stockholm [4]. He had described that if the network is intelligent enough to gather the information about the co-users then the radio resources can be adaptively change to need user need and demands.

In the past, there have been extensive studies on opportunistic spectrum access architecture and cognitive radio networks [5]-[12] .Good general overview can be found in paper published by K. Shin et.al, [13] and paper published by M. Song et.al. [14].

Different paradigm of the cognitive network is briefly discussed and concluded various aspects of the paradigm. Underlay and Overlay allows concurrent transmission of both primary and secondary user. Along with it, this paper also explains various encoding techniques and error control techniques for the interference cancellation during concurrent transmission. This suggests dirty paper coding as the best candidate for encoding in the cognitive radio network in known interference scenario [2].

The authors in [3] proposed a scheme that exploits the network coding technique to incentivize PUs to cooperate with SUs in spectrum access, so that SUs can access spectrum even when PUs are active. Nevertheless, the spectrum access of SUs is not transparent to PU in this scheme. The PU must have the knowledge of SU, and need to listen to the packets from SU. Contrary to the scheme in [3], the spectrum access of SU in DSCA architecture in this thesis is transparent to PU, i.e. PU does not need to have any knowledge of SUs DPC technique is utilized to achieve transparent incentivizing of PU.

DPC was first introduced by Costa as a proof for maintaining signal to interference plus noise ratio (SINR) at the receiver given the transmitter had prior knowledge of the interference state [15]. It was shown that DPC could achieve the largest known capacity region for cognitive radio networks in a channel model with one PU node pair and one SU node pair, as long as the SU transmitter had a priori knowledge of the PU messages . Several later studies have shown that SU can coexist with PU without degrading the PU channel capacity. However the success of DPC in a cognitive radio network relies on the SU transmitter having a priori knowledge of the PU transmitted packet. This is a non-trivial problem and there have been several proposed methods for achieving this. In traditional one-hop infrastructure networks the authors proposed using DPC for interference reduction between base stations, by leveraging the high bandwidth of the wired backbone to obtain a priori knowledge of base stations downlink data. However the PU is unlikely to share a wired high-bandwidth backbone with SU [16].

More importantly, Dirty Paper Coding is explained and implemented for the cognitive users. In their architecture primary codebooks are known to the secondary base station and interference cause by the primary base station on the secondary users is canceled using dirty paper coding (DPC)[17].

In this Paper, Dynamic Spectrum Co-Access (DSCA) is implemented for transparent incentivizing of primary user by secondary user. Primary user need not to be aware of existence of secondary user. This now enables Primary and secondary user to have simultaneous access of the spectrum which significantly reduces the sensing and handoff overhead. This finally improves the Quality of Service of cognitive radio network.

3. System Modeling

In this section, DSCA architecture is described. With DSCA when PU is not transmitting, SU freely access the spectrum, similarly to the opportunistic spectrum access architecture. On the other hand, when PU is active, SU provide incentives to PU so that simultaneous transmission by SU is allowed. In the following, operation of DSCA in the latter case is focused, i.e., how the SU incentivize the PU to enable spectrum co-access. At first a simple network with one PU node pair and one SU node pair is considered. Three key components of DSCA is used, Portion of SU power used to relay the PU message, Co-access incentives and region of Co-access. The co-access incentives ensure that both PU and SU are benefit from the spectrum co-access. The region of co-access is the region where SUs can co-access spectrum with PUs. Figure 1 show the basic architecture of an incentivized network with one SU node and one PU node with normalized Gaussian channel with pass loss (1, a, b, 1). The legend on a link indicates the path loss.

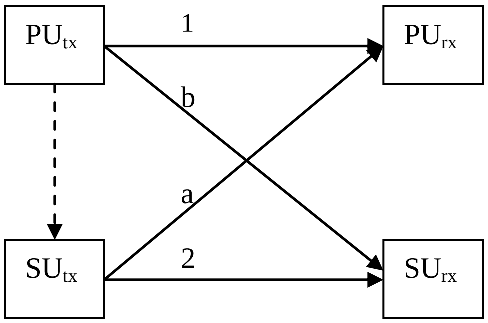

Figure 1: Basic Incentivized Architecture

3.1 A PU Node Pair and SU Node Pair

In above given basic architecture of incentivized network, let X_p and X_s be the codeword transmitted by PU and SU respectively. (1, a, b, 1) is assumed as a normalized path loss between the links. Assume that SU knows the PU packet priori through a side information path. To provide incentives to the PU so that the PU allows simultaneous spectrum access from the SU, the SU transmitter uses a portion of its power to boost the SINR at the PU receiver. Let $\gamma \in [0, 1]$ denote the portion of the SU power used to transmit the PU code word and $(1-\gamma)$ the portion of power used to transmit its own code word. Let P_p and P_s denote the transmit power of the PU and SU transmitters, respectively. In addition, let X_p and X_s be a single transmitted code word for the PU and SU, respectively. The major notations are listed in Table 1. Over a large set of code words, the PU transmit power at the PU transmitter is $P_p = |X_p|^2$. The SU code word is generated using DPC such that:

$$\boldsymbol{X_s = \widetilde{X_s} + X_p\sqrt{\frac{\gamma P_s}{P_p}}} \tag{1}$$

Where $\boldsymbol{\widetilde{X_s}}$ is the code word to carry the SU packet and $\boldsymbol{X_p\sqrt{\gamma P_s/P_p}}$ is the code word to carry the PU packet. These codeword's are chosen in such a way that they are statically independent. Table 1 shows major notations summary used in this chapter.

Table 1: Major Notations for section 3

a,b	Normalized path losses as shown in Figure 1
γ	Portion of the SU power used to relay the PU code word
P_p,P_s	Transmit Power of the PU and SU transmitter respectively
S_P,S_S	Received codeword by PU and SU receiver respectively
Q_p,Q_s	Received signal power (excluding interference) at the PU and SU receivers, respectively
X_p, X_s	Transmitted code word of PU and SU transmitters
$\widetilde{X_s}$	Code word of SU transmitter to carry SU packet
R_p, R_s	Achievable rate of PU and SU respectively
N_p, N_s	Noise plus interference Power at PU and SU

3.1.1 At PU transmitter

As stated earlier, this DSCA architecture transparently incentivized the PU i.e. PU don't need to be aware of the existence of SU, so no difference will be seen in the nature of PU transmitter then it was without the SU. So the transmit power of the Primary User can simply be given as:

$$P_P = |X_p|^2 \tag{2}$$

3.1.2 At SU transmitter

The codeword transmitted by the SU transmitter consist the two code word separately. One its own code word and another to relay the codeword of Primary User. This is given by the 1. So total power transmitted by the SU transmitter is:

$$P_s = \boldsymbol{\left(\widetilde{X_s} + X_p\sqrt{\frac{\gamma P_s}{P_p}}\right)^2}, \tag{3}$$

$$P_s = \left[\widetilde{X_s}\right]^2 + 2\widetilde{X_s}X_p\sqrt{\frac{\gamma P_s}{P_p}} + X_p{}^2 . \frac{\gamma P_s}{P_p}, \tag{4}$$

$$P_s = \left[\widetilde{X_s}\right]^2 + \gamma P_s, \tag{5}$$

$$\left[\widetilde{X_s}\right]^2 = (1-\gamma)\, P_s, \tag{6}$$

3.1.3 At PU receiver

The received signal at PU receiver will be the sum of signal transmitted by PU and the sum of code word transmitted by SU. Received code word will be:

$$\boldsymbol{S_p = X_p + a\left(\widetilde{X_s} + X_p\sqrt{\frac{\gamma P_s}{P_p}}\right)}, \tag{7}$$

$$\boldsymbol{S_p} = \underbrace{\boldsymbol{(X_p + aX_p\sqrt{\frac{\gamma P_s}{P_p}})}} + \underbrace{\boldsymbol{a\widetilde{X_s}}} . \tag{8}$$

Desired Code Noise

The total desired signal power can be calculated from the equation 8 by squaring the desired code word and is given by:

$$Q_p = (X_p + aX_p\sqrt{\frac{\gamma P_s}{P_p}})^2, \qquad (9)$$

$$Q_p = (X_p + a\sqrt{\gamma P_s})^2 \qquad (10)$$

$$Q_p = (\sqrt{P_P} + a\sqrt{\gamma P_s})^2 . \qquad (11)$$

Where Q_p is the total signal power at the PU receiver.

At PU receiver, total noise at the receiver will be the addition of normalized Gaussian noise 1, and noise due to the secondary transmission. So total noise at PU receiver is given by:

$$N_p = (1 + (a\check{X}_s)^2. \qquad (12)$$

Where N_p is the total noise at the PU receiver. a is path loss, $\widetilde{X_s}$ is the codeword that carries SU packet.

Achievable rate for Primary User can be calculated using the formula

$$R_p = log(1 + SINR). \qquad (13)$$

Using Equation 11 and Equation 12 we can have above equation as:

$$R_p = log(1 + \frac{(\sqrt{P_P} + a\sqrt{\gamma P_s})^2}{(1 + (a\check{X}_s)^2}). \qquad (14)$$

This equation can be finally used to determine the achievable rate of the primary user while Co-Access with secondary user. However the value of γ should be chosen in such a way that SINR of the primary user increases.

3.1.4 At SU receiver

The received signal at SU receiver will be the sum of signal transmitted by SU and the sum of code word transmitted by PU. Received code word will be:

$$\boldsymbol{S_s = \widetilde{X_s} + X_p\sqrt{\frac{\gamma P_s}{P_p}} + bX_p} \qquad (15)$$

The desired codeword is $\boldsymbol{\widetilde{X_s}}$ and SU receiver non causally knows that interference to the SU receiver would be $\boldsymbol{X_p\sqrt{\gamma P_s/P_p} + bX_p}$. This is cancelled by DPC i.e. coding is done in such a way that $\boldsymbol{X_p\sqrt{\gamma P_s/P_p}}$ will be cancelled by $\boldsymbol{bX_p}$. This is already stated in the paper published in [17] which shows that DPC will be success to cancel the interference. So only the normalized noise is remaining in SU receiver.

Achievable rate can be given as:

$$\boldsymbol{R_s = log(1 + SINR)}, \qquad (16)$$

$$\boldsymbol{R_s = log(1 + |X_s|^2)}, \qquad (17)$$

Using Equation 6 in above Equation we can derive:

$$\boldsymbol{R_s = log(1 + (1 - \gamma)\, P_s)} \qquad (18)$$

This equation can be used to determine the achievable rate of secondary user when SU Co-Access with the PU.

3.2 Co-Access Incentive

Without SU the SINR of the Primary user will be given as:

$$SINR = \boldsymbol{P_p/1}, \qquad (19)$$

With SU, changed SINR is given as:

$$SINR = \frac{\boldsymbol{(\sqrt{P_P} + a\sqrt{\gamma P_s})^2}}{\boldsymbol{(1 + (a\check{X}_s)^2}}, \qquad (20)$$

For primary user to be incentivized,

$$\frac{(\sqrt{P_P} + a\sqrt{\gamma P_s})^2}{(1 + (a\check{X}_s)^2} \geq P_p + K, \qquad (21)$$

Where K is the PU co-access incentive in terms of increased SINR of the Primary user. After some manipulation in above Equation we can derive:

$$\gamma \geq \left(\frac{\sqrt{\left((P_P+K)\left(1-P_P+a^2P_s(P_P+K+1)\right)\right)} - \sqrt{P_s}}{a\sqrt{P_s}\,(P_p+K+1)}\right)^2 . \qquad (22)$$

This Equation can be used to calculate the portion of power to be used to relay for given amount of PU Co-Access incentive to the PU user.

3.3 Acceptable SU SINR

Let λ be the minimum SINR that is desired to be received in SU receiver. Then we can write:

$$((1 - \gamma)\, P_s) \geq \lambda \qquad (23)$$

3.4 Region of Co-Access

If the PU co-access incentive K is not able to be offered by the SU, then the PU does not allow the SU to co-access the licensed spectrum with it. Therefore it is necessary to be able to find an area within the PU network that if the SU is located within it, it would be able to provide enough incentive for co-access. In contrast to that while calculating Region of Co-Access Acceptable SU SINR should also be guaranteed for given γ which is used to incentivize PU by amount K. Using appropriate path loss model and Equation 22, 23 bound for the Region of Co-Access can be calculated.

4. Results and Discussion

We know that achievable rate varies with the portion of SU power that is used to relay the PU packet. So using Equation 14, 18, following results is drawn.

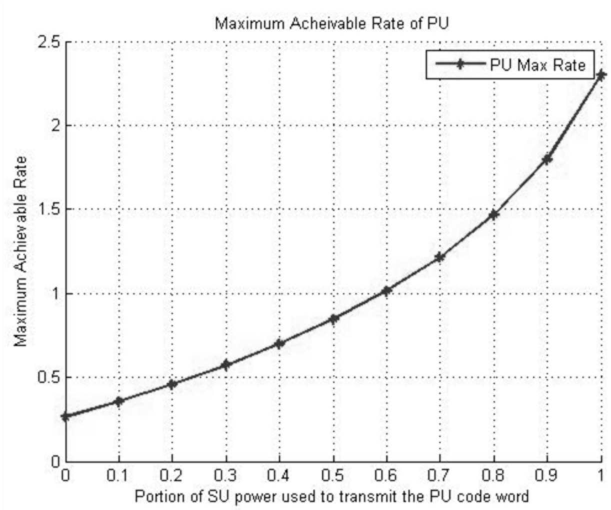

Figure 2: Achievable PU rate increasing γ

Figure 2 shows that the variation in achievable rate of PU with the variation in γ. The transmit power of PU is considered as 5 Watt, and that of SU is considered as 7 Watt. When SU does not assist PU then, the performance of PU will even degrade because of the interference produces by the SU. As the portion of power of SU use to relay PU packet increases, the interference starts to overcome and after certain point performance of PU will be increased. If total power of SU is given to the PU then, it simply act as a repeater for PU hence, PU rate will be maximum when whole power of SU is used to relay the PU packet.

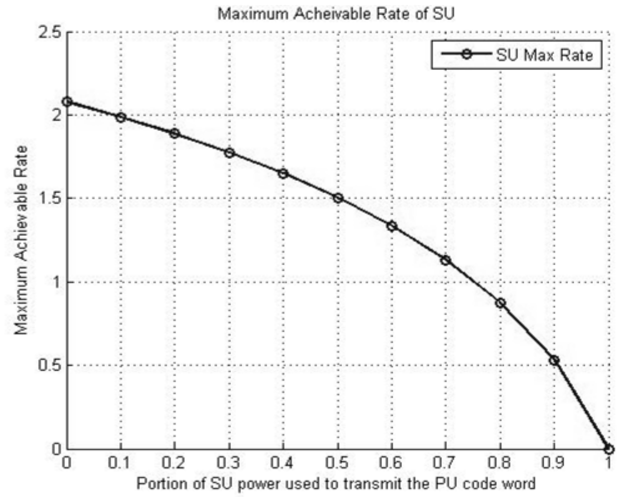

Figure 3: Achievable SU rate increasing γ

Figure 3 shows that the variation in achievable rate of SU with the variation in γ. The transmit power of PU is considered as 5 Watt, and that of SU is considered as 7 Watt. When SU does not assist PU then, the performance of SU will be maximum. As the portion of power of SU use to relay PU packet increases, the achievable rate of SU starts to degrade. If total power of SU is given to the PU then, it simply act as a repeater for PU hence, and achievable SU rate will be zero at that time.

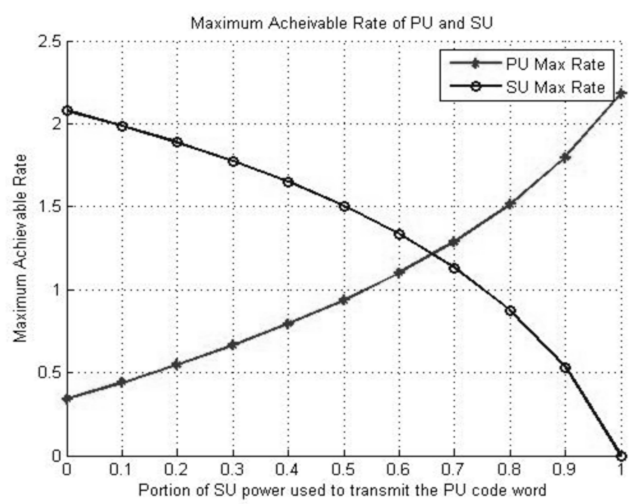

Figure 4: Achievable PU and SU rate increasing γ

Figure 4 shows that the variation in achievable rate of PU and SU with the variation in γ. The transmit power of PU is considered as 5 Watt, and that of SU is considered as 7 Watt. Here rates of both SU and PU are combined and plotted in the same graph. Here we can see when 65% of SU's power is used to relay the PU codeword then the achievable rate for both SU and PU during Co-Access is exactly the same. So according to the requirement any value of power split can be chosen is both PU and SU are satisfied with the achievable rate provided with that value.

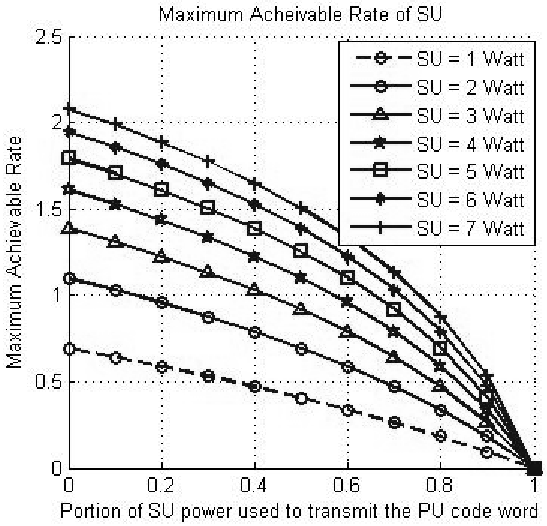

Figure 5: Achievable SU rate increasing γ with fixed PU transmit power and variation in SU transmit power

Figure 5 shows the variation in maximum achievable rate of SU with variation in portion of SU power used to relay the PU codeword. Here PU transmit power is Considered as constant with value 5Watt, and SU power is ranged from 1 Watt to 7 Watt, as SU transmit power goes on increasing, the maximum achievable rate of SU also increases, however all the curve end up with zero value when all SU power is use to relay the PU packet.

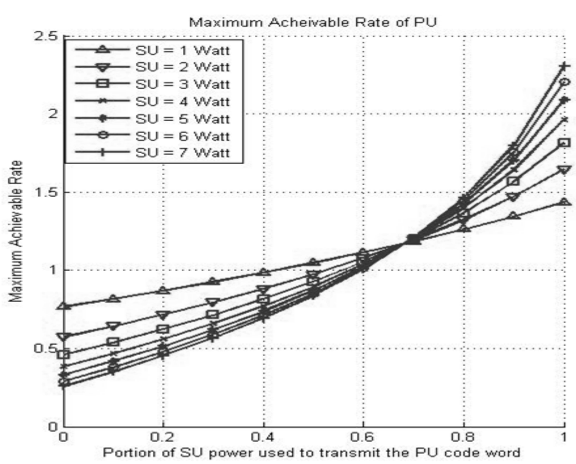

Figure 6: Achievable PU rate increasing γ with fixed PU transmit power and variation in SU transmit power

Figure 6 shows the variation in maximum achievable rate of PU with variation in portion of SU power used to relay the PU codeword. Here PU transmit power is Considered as constant with value 5Watt, and SU power is ranged from 1 Watt to 7 Watt, as SU transmit power goes on increasing, without assistance for PU, the maximum achievable rate of PU decreases, it also shows that whatever value is use by SU transmitter, the PU achievable rate depends only on the portion of SU power used to transmit PU codeword. And if 60% of SU power is given to PU, then achievable rate of PU is fixed for every value of SU transmit power.

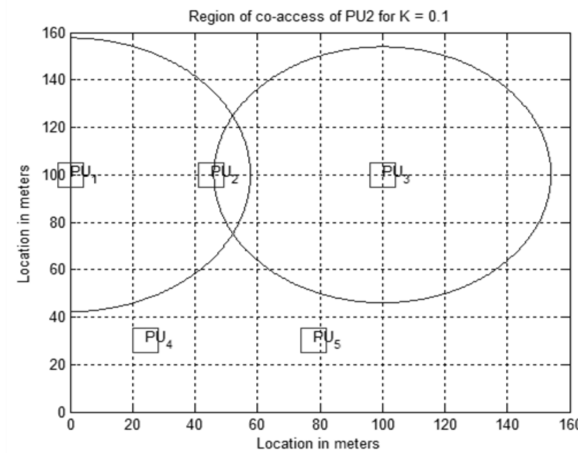

Figure 7: Region of Co-Access

Region of Co-Access is defined as the geographical location around the Primary user where secondary can be located and incentivize the Primary user also finding some space for itself. How region of Co-Access is calculated is already discussed, so using Equation 22 and Equation 23 following result is drawn and interpreted. Figure 7 shows the region of Co-Access around the second primary user, where SU can be located to Co-Access with the Primary User. Here result shows that PU can be located between approx. 50m to 65m distance from the primary user. This region of Co-Access may change according to the model of path loss assumed in that given model and value of incentive given to the primary user. If it is located nearer than it, it will cause more interference and if it is located beyond that it may not able to relay the PU packet.

4. Conclusions

This paper concludes that a new architecture of dynamic spectrum access termed as Dynamic spectrum Co-Access can be implemented to enable the Co-Access. Furthermore, the incentive to the PU can be guaranteed by the SU and also finding some space for itself. The region of Co-Access even gives the more geographical conclusion that where SU can be located around the PU. The most important terminology in this research is the power split and prior knowledge of PU to the SU. Power split should be chosen in such a way that both PU as well SU are benefitted, however the SU has to use more power as a pay for the spectrum.

The numerical results shows that DSCA architecture can significantly increase the performance of PU and also finding some space for SU.

References

[1] S.Sun.,Y. Ju.,"Overlay Cognitive Radio Ofdm System For 4g Cellular Network" , IEEE Wireless Communication, April 2013.

[2] Goldsmith et al., "Breaking Spectrum Gridlock With Cognitive Radios: An Information Theoretic Perspective," Proc. IEEE, Vol. 97, No. 5, May 2009, pp. 894–914.

[3] Xin, et al., "An Incentivized Cooperative Architecture For Dynamic Spectrum Access Networks," IEEE Trans. Wireless Communications., Vol. 12, No. 10, pp. 5154–5161, Oct. 2013.

[4] J. Mitola, "Cognitive Radio," Licentiate Proposal, KTH, Stockholm, Sweden,Dec. 1998.

[5] M. Pan, C et al., "Joint Routing And Link Scheduling For Cognitive Radio Networks Under Uncertain Spectrum Supply," in Proc. IEEE Infocom, 2011.

[6] Y. Liu et al., "Spectrum-Aware Opportunistic Routing In Multi-Hop Cognitive Radio Networks," IEEE J. Sel. Areas Commun., Vol. 30, No. 10, pp. 1958–1968, 2012.

[7] Y. Zhang et al., "Etch: Efficient Channel Hopping For Communication Rendezvous In Dynamic Spectrum Access Networks," in Proc. IEEE Infocom, 2011.

[8] Qing Zhao et al., "A Survey of Dynamic Spectrum Access," IEEE Signal Processing Magazine, pp. 79 – 89, May 2007.

[9] Paul J. Kolodzy, "Cognitive Radio Fundamentals," SDR Forum, Singa- pore, April 2005.

[10] Rui Zhang and Ying-Chang Liang, "Exploiting Multi-Antennas for Opportunistic Spectrum Sharing in Cognitive Radio Networks," IEEE Journal of Selected Topics in Signal Processing, Vol. 2, pp. 88–102, February 2008.

[11] N. Devroye et al., "In- formation Theoretic Analysis of Cognitive Radio Systems," Cognitive Wireless Communications, Springer, 2007.

[12] N. Devroye et al., "Cognitive Multiple Access Networks," IEEE International Symposium on Information Theory, pp. 57–61, September 2005.

[13] K. Shin et al., "Cognitive Radios For Dynamic Spectrum Access: From Concept To Reality," Wireless Communications, IEEE, Vol. 17, No. 6, pp. 64–74, 2010.

[14] M. Song et al., "Dynamic Spectrum Access: From Cognitive Radio To Network Radio" , Wireless Communications, IEEE,Vol. 19, No. 1, pp. 23–29, 2012.

[15] M. Costa, "Writing in a Dirty Paper (corresp.)", IEEE Transaction On Information Theory, Vol 29, No.3, pp. 439-441, 1983.

[16] X. Guan et al., "Exploiting Primary Retransmission To Improve Secondary Throughput By Cognitive Relaying With Best-Relay Selection," IET Communications, Vol. 6, No. 12, pp. 1769–1780, 2012.

[17] M. Mohammadin, S. seltine., "Joint Interference Cancellation And Dirty Paper Coding For Cog- Nitive Cellular Networks," in Wireless Communications and Networking Conference (WCNC), 2011 IEEE. IEEE, 2011, pp. 1972–1976.

[18] R. Zhang, Member, IEEE, and Y-C Liang, Senior Member, IEE.,"Investigation on Multiuser Diversity in Spectrum Sharing Based Cognitive Radio Networks".

[19] T. cover, "Broadcast Channels", IEEE transaction on Information Theory, Vol 18, pp. 2-14, 1972