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GEOLOCATION AWARE RESOURCE ALLOCATION IN CELLULAR BASED COGNITIVE RADIO NETWORKS WITH GREEN COMMUNICATION PERSPECTIVE

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Abstract

This paper puts forward a Geolocation aware spectrum and power allocation scheme for cellular-based cognitive radio network using the principle of sensing free spectrum access. The problem formulation to test the feasibility of deploying the secondary system within Terrestrial Trunked Radio (TETRA) based cellular primary system is carried out to maximize the served Secondary Users (SU) while keeping the interference to Primary Users (PU) under a predefined threshold. A novel model called Primary Mobility Contour (PMC) for the avoidance of harmful interference to PU is proposed, which will consider the velocity of PU, the time taken by the secondary base station for transmission and Geolocation information. Using this model sensing free spectrum and power allocation algorithm is developed for cellular-based cognitive radio network to maximize the served SU to enhance system throughput and achieve an enhanced energy efficiency of the system to attain green communication. Simulation results confirm that the proposed scheme maximizes the served SUs per cell, throughput and energy efficiency.

Keywords: Cognitive radio networks, Energy efficiency, Green communication, Resource allocation, Spectral efficiency, TETRA.

1. Introduction

The Radio Frequency (RF) electromagnetic spectrum has become very scarce in certain bands due to dramatically increased demand for wireless spectrum in recent times. Adoption of static spectrum allocation policy also adds to spectrum crowding in certain bands and sparse usage in certain bands. As a result of constantly increasing demands for wireless spectrum in modern communication, most of the usable spectrum has been allocated to PUs by now and very less spectrum is available to devise and deploy new wireless services.

Recent spectrum occupancy measurements carried out reveals that a vast number of these allocated spectrum bands are rarely occupied by services assigned to them and vast temporal and geographic variations in the use of the allocated spectrum was found with utilization varies from 15% to 85% [1, 2]. It was observed that spectrum utilization in UHF and VHF bands in a suburban area in India was 7.22% and 3.55% [3].

Cognitive Radio (CR) has emerged as a possible solution to the problem of spectrum scarcity where it is possible for an SU to make use of the spectrum resources unoccupied by the PU opportunistically [4]. Based on the policies of spectrum usage imposed by regulatory bodies, the spectrum sharing approaches can be classified as either overlay-based where the SUs can utilize the spectrum only when the PU is inactive or underlay-based where the SUs are allowed to share the spectrum with the PU. Cognitive radio is considered to be next-generation wireless systems [5]. A Cognitive radio engine using a genetic algorithm is proposed for optimal Resource allocation in cognitive radio [6].

The intelligence of CR is proportional to the amount of information it can get from the environment. Therefore, if the additional feature of location awareness is included in the CR system, it will become more intelligent and its ability to effectively manage the resources will be enhanced for an underlay CR network, it is of utmost importance that interference caused by a CR node should be below the interference threshold of the primary receivers at all times. Geographical location becomes highly important in this aspect, as it can be used to predict received power at primary receivers, given a signal propagation model. In [7] optimal spectrum, sensing threshold was derived to maximize a cognitive radio network capacity by utilizing location awareness, which consists of prior information concerning the geographical location of PUs. The awareness capability of CR can have multi-dimensions, which may include information regarding transmitted waveform, RF spectrum, communication network, geography, locally available services and the user needs, various methods for obtaining the Geolocation information can be found in [8]. The location information available in CRN can be classified as Full Location Aware (FLA), Partial Location Aware (PLA) and No Location Aware (NLA) [9]. Various techniques exist in the literature for the acquisition of location information in the case of FLA.

In Geolocation database, the primary transmitters are equipped with location estimation devices; information about the location and the operating frequency are updated in a central database so that any secondary radio system can access this central database and acquire the concerning information [10]. Rawat et al. (2014) proposed algorithm for radio resource management based on Geolocation for CRN by using the cloud to store Geolocation database. A cooperation protocol, which allows cooperation between PUs and SUs was introduced, which can acquire location information of PU transmitters from the primary network via cooperation

[11]. The path loss exponent is an important parameter to be known, as it varies from place to place depending upon the geographical environment. For example, in urban areas, due to a large number of buildings present, the radio waves undergo a tremendous loss in their energy as compared to the rural environment, where there are higher chances of getting Line of Sight (LOS) communication [12].

In [13], an algorithm with associated performance bounds was introduced for estimating a primary transmitter's position and path loss exponent of the propagation environment using Received Signal Strength (RSS).A PU detection scheme was proposed, which relies on PU's communications with SUs to provide information such as location and frequency occupancy [14]. During the process of reception, the primary receiver's RF front-end tends to leak power. Wild et al. [15] proposed an architecture, which utilizes sensors capable of detecting this leakage from local oscillators to estimate Geolocation based on the received leakage power and inform CR regarding location information along with spectrum information. A power control algorithm known as Graph Colouring based Dynamic Power Allocation (GCDPA) to carry out channel allocation under interference avoidance conditions for a cellular-based CRN to improve the power efficiency and throughput of the network was proposed [16]. Tong et al. [17] proposed a channel and power allocation scheme for a CRN based on interference violation test to maximize the energy efficiency of a network by utilizing space and frequency opportunities. It has proved that power consumption can be reduced by avoiding unnecessary spectrum sensing.

Although many policies exist for the purpose of spectrum sensing alone, in very recent literature, a sensing free approach for CR is making its way. One of the ways by which, it can bring into practice is by using location-aware networks. The major benefits of this sensing free approach are energy efficient networks and increased network capacity by continuous operability of the secondary networks. However, in order to acquire location awareness, we need to bear an additional cost in terms of system complexity. The system should be able to either estimate parameters of interest (locations, channel parameters, etc.) and process them independently, or acquire them via cooperation with the PU network. In both cases, an additional cost due to system complexity or additional overhead needs to be borne. Such a cost is only justified when there is a significant increase in performance (increase in network throughput). Therefore, there is a need to quantify the performance gains offered by location awareness, with reference to the overhead incurred.

All the aforementioned work discussed above concentrates on enhancing spectral efficiency using Geolocation information, which is limited by interference caused to the primary system. To avoid harmful interferences to PU most of the opportunities for spectrum sharing remains unexploited due to lack of efficient PU interference avoidance mechanism. Very little work is done on Energy efficient CRNs using Geolocation information, which is highly required to achieve green communication along with achieving high spectral efficiency. The limitations concerning TETRA were listed out by [18], one of that was the under-utilization of spectrum in TETRA network. This is the motivation for deploying a secondary network to maximize the usage of the spectrum in TETRA network and to develop spectrum and power allocation scheme, under location-aware network conditions. For both wired and wireless communication systems, power and bandwidth are the important parameters, which are responsible for its performance. Especially when it comes to wireless communication systems, these parameters attain some more important because in open medium surrounding radios are affected due to the way in which, these resources are utilized.

The first contribution of this paper is to devise problem formulation to test the deployment of the secondary system (cognitive radio network) within TETRA based primary system considering Geolocation information. To propose an efficient spectrum allocation scheme for SUs in downlink based on TETRA wireless communication standards, using the principle of sensing free spectrum access. The proposed scheme aims at serving a maximum number of SUs while obeying specific regulatory conditions, which ensure that the PU's are not harmfully interfered hence preserving the Quality of Service of this PUs.

The second contribution of this paper is to propose a novel model called Primary Mobility Contour for the avoidance of harmful interference to PU, which will consider the velocity of PU and time taken by the secondary base station for transmission along with Geolocation information. Using this model sensing free spectrum and power allocation algorithm is developed for cellular-based cognitive radio networks to maximize the served Sus, which enhances system throughput and achieves enhanced energy efficiency of the system.

The organization of the paper is as follows: Section 2 presents the System Model and Problem Formulation in TETRA based cellular cognitive radio networks. In Section 3, the proposed Primary Mobility Contour is discussed. Section 4 presents the Algorithm developed using Primary Mobility Contour. , Section 5, simulations results are presented. Section 6 concludes the paper.

2. System Model and problem formulation

The system model considers a commercial Private Mobile Radio (PMR) network utilizing TETRA standards, operating within the 450-470 MHz band as PU (PU) network. Cellular configuration for PMR system is considered in this work, which involves the use of multiple cell sites with a frequency re-use scheme in place as it is mostly deployed in applications where large capacity is used and a large area is required to be served by PMR systems.

The Geolocation based CRN architecture is shown in Fig. 1. It consists of two types of users the PUs and SUs. The Primary User Mobile Station (PUMS) can access primary base station (PUBS) on licensed bands of TETRA standards operating in 450-470MHz. The cellular configuration is adopted as shown in Fig. 1. The Secondary User Mobile Station (SUMS) can access secondary user base station (SUBS) on the unutilised spectrum, opportunistically. As depicted in Fig. 1, SU network is also a cellular structure, which is placed at the boundary of the primary cell. SBS can have links with other SBS on licensed or unlicensed band. The SU is considered to be a cellular network, which coexists with the PMR network under the limited interference to the primary network. The assumptions made for the primary network are that it operates in an urban area having a cellular structure having cluster size 7, path loss exponent n = 3.5 and receiver sensitivity -104 dBm [19]. The secondary network is assumed to be a cellular network, which is placed at the edges of one of the cells of the primary network, as illustrated in Fig. 1. The cell radius of the PU cell was estimated using a Hata path loss model for the urban environment [20].

For simplicity, log-normal shadowing is not considered. Although the receiver sensitivity of the mobile station is -104 dBm, minimum power required at the receiver must be -85 dBm [19]. Therefore, the distance for which, the received power becomes -85 dBm becomes the radius of the cell. The transmission power of the primary base station considered for this work is 44 dBm. Putting these parameters into the known equation of Hata model, the required radius comes out to be 1.755 km. The SUs need to have extra sensitivity, as the secondary base station will have to transmit at low powers sometimes, as there may be a PU in the vicinity. Therefore, the sensitivity of SUs for this scenario is considered to be -147 dBm.

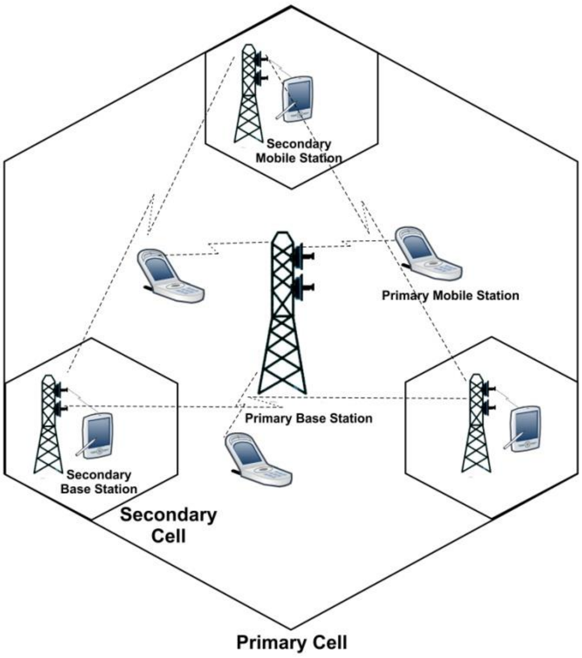

Fig. 1. Geolocation based CRN architecture.

The cell radius of the SU is assumed to be 146 m. From this information, the secondary base station can transmit as low as 7 dBm of power, so that the SU at the edge of the cell will be able to receive successfully. Free space path loss model [21] is used for this purpose.

In a given a wireless cognitive cellular network, P_m^i belongs to P_b , S_m^i belongs to S_b^i in *ith* cell for all stations $\in P_b \cup P_m \cup S_b^i \cup S_m^b$, the geographic location of j is given, for $l \in P_b \cup P_m$, the channel usage of l is given by L_l, for $m \in P_m$, the velocity of physical movement of m is given and for $n \in S_b^i$, the transmission time τs on channel $k \in L_l$ is given. An optimization problem is formulated for channel allocation to maximize the served SUMSs, such that for each served SUMS, the following conditions are satisfied.

The SINR of the downlink (SUBS → SUMS) is at least γs.

The SINR at the downlink (PUBS → PUMS) is at least γ p.
Maximize $\sum_{y \epsilon S_m^b} \sum_{k \epsilon L_i} c_y^k$ (1)

Subject to conditions:

$$C1{:}\sum_{k\in L_y} c_y^k \le 1 \ \forall y \in S_m^b, k \in L_i \tag{2}$$

$$c_y^k \in \{0,1\} \quad \forall y \in S_m^b, k \in L_i \tag{3}$$

$$C2{:}\sum_{y\epsilon S_m^b} \sum_{k\epsilon L_i} c_y^k \le |L_i| \tag{4}$$

$$C3{:}\quad P_b^k \le P_s^{max} \cdot \sum_{y:\{y\in S_m^b\}} c_y^k\,;\, b \in S_b^i, k \in L_i \tag{5}$$

$$C4{:}\, P_i^k \ge \gamma_P \left(N_0 + \sum_{b\in S_b^i} I_{b,y}^k\right) \quad \forall i \in P_b, x \in P_b, y \in P_m^i, k \in L_i \tag{6}$$

$$C5 \quad g_{x,y}^k P_i^k \ge \gamma_s \left(N_0 + \sum_{i\in P_b^i} I_{i,y}^k\right) \ \forall i \in P_b, x \in S_b^i, y \in S_m^b, k \in L_i \tag{7}$$

$$C6. \quad R_{b,m,i} \ge R_{b,m,i}^{min} \quad b \in S_b^i, k \in L_i \tag{8}$$

The parameters are listed and explained in Table 1. The aim of this work is to maximize c_y^k. As shown in (1), subject to conditions as C1, Eqs. (2) and (3) is a channel assignment constraint, which guarantees the assignment of at most one channel to each secondary mobile terminal for reception. C2, Eq. (4) is upper bound on c_y^k, C3, Eq. (5) is power control constraint, which keeps the transmission power of SUBS for those SUMS who are assigned a channel to receive on below a maximum level and zero level for those, which are not, assigned a channel. C4 and C5, Eqs. (6) and (7) are linked reliability constraints, which guarantee downlink reliability for each PUMS and SUMS that has been assigned a channel to receive respectively. This condition allows safe operation of the mobile stations of the respective systems by keeping the power level of their respective transmissions above the power level of unwanted transmission by the predefined SINR. C6, Eq. (8) is a minimum rate guarantee for SUMS this condition states that the rate on the channel between the secondary base station and the secondary mobile station should not be less than the predefined rate in order to satisfy the QoS of the secondary mobile user.

3. Primary Mobility Contour (PMC)

CR system is expected to exploit every opportunity it founds in an effective way by keeping the interference caused to PU under a predefined threshold. In Geolocation based channel allocation, the interference constraint may be violated, if the location of PUMS is considered only at the time of channel assignment due to the mobility of the MS. In the case undertaken, an ideal operation can be delivered, if the location information of PUs can be provided in the SU controller at all time instances. Hence, this would be impractical, as it would incur a huge amount of overhead traffic.

Recently in [16] interference quantification model named Cognitive Interference Ring in the cellular CRN was proposed, which relies on spectrum sensing to estimate strong interference area around SU. In [17], a model named Interference Violation Test was proposed, which uses SU's location to avoid unwanted spectrum sensing. In both of these models, energy efficiency enhancement is limited owing to the use of spectrum sensing. However, sensing free interference avoidance model based on the Geolocation information of SU as well as PU, further needs to be explored, which is not yet addressed in the literature.

In contrast to aforementioned models, the idea of PMC is introduced in this paper where SU controller obtains the Geolocation information of the PUMS along with the velocity of the PUMS only at the time of the channel allocation request. The direction information is not considered since it is highly subject to change and its estimation is a highly challenging task.

The proposed model Primary Mobility Contour (PMC) is shown in Fig. 2. It shows PUBS, SUBS and PUMS in one geographical plane and their Geo-locations are available to the controller. The circle shown around PUMS is the PMC of radius *R2* in which, it is going to experience the interference from SUBS transmitter. The circular arc shown in PMC having radius *R1*, which can be calculated using Geolocation and its maximum value is the coverage area of the PUBS which is 1.755 km as explained in Section 2. The velocity of PUMS is calculated using its current Geolocation and GPS tracking. The transmitting time of the SUBS is calculated based on receiving requests for channel allocation by SUMS. The PMC is defined as the Contour of radius *R2* around the PUMS, which is calculated by:

$$R2 = v \cdot \tau s \tag{9}$$

where v is the velocity of PUMS under consideration and τs is the transmission time of SUBS.

The coordinates of PUMS are denoted by (*h2, k2*), PUBS are (*h1, k1*) and the two points on PMC, which are equidistant from PUBS are d1 (*x1, y1*) and *d2* (x2, y2). For the avoidance of harmful interference to PU, as depicted in Fig. 2 the coordinate geometry is used to find the point on the PMC for which, the SINR of PUMS would be minimum. The point *d1* is taken such that PUMS will be at the same distance from the PUBS as it was when the PUMS is at the centre of PMC. Thus, the following is the formulation of the method used to estimate the Geolocation on PMC of the above-mentioned conditions.

From the knowledge of geometry, we have the equation of circle as:

$$\sqrt{a^2 + b^2} = c \tag{10}$$

where *a* and *b* form locus of the circle with radius c. Similarly, our problem can be written as:

$$(x - h_1)^2 + (y - k_1)^2 = r_1^2 \tag{11}$$

and

$$(x - h_2)^2 + (y - k_2)^2 = r_2^2 \tag{12}$$

In the above equations, units on both sides must be obviously made same. On LHS we have Geolocation coordinates in degrees and on RHS we have the distance in km. Therefore, the LHS should be converted to km by multiplying LHS by:

$$\left(\frac{\pi}{180}\right)^2 6371^2$$

where, 6371 is the radius of the earth in km. In these equations, *x* and *y* are the unknown coordinates on the PMC, which are found by solving above equations simultaneously to find the distance between SUBS and point *d1* on the PMC for which, the SINR at PUMS would be minimum.

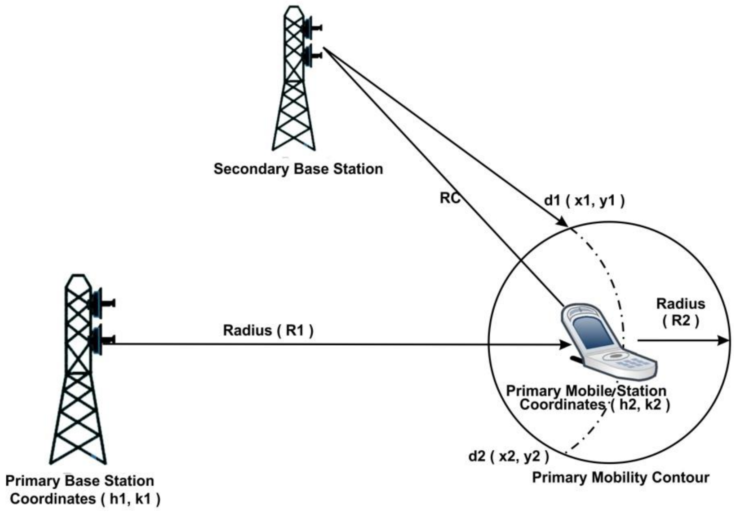

Fig. 2. Primary mobility contour.

Change in link reliability constraint due to PMC

To test the reliability constraint of PUMS link (or in other words, not to harm the pre-existing primary link,) with mobility constraint, the terminal has to be assumed at the edge of PMC, such that it is closest to the SUBS making the interference maximum and farthest from the PUBS making the signal strength minimum. At that point, SINR has to be calculated and if it is above the predefined value, then the channel can be used by SUBS for transmission. In order to incorporate this change in the mathematical model, interference in the PUMS link reliability constraint in Eq. (6) needs to be increased. This can be done by reducing the distance between PUMS and SUBS under consideration.

Effectively the interference at PUMS is increased in Eq. (6) and can be denoted by the following equation:

$$P_i^k \geq \gamma_P \left(N_0 + \sum_{b \in S_b^i} \left(I_{b,y}^k + \widehat{I_{b,y}^k}\right)\right) \ \forall i \in P_b, x \in P_b, y \in P_m^i, k \in \ L_i \tag{13}$$

where

$$\widehat{I_{b,y}^k} = P_b^k(\widehat{g_{x,y}^k} - g_{x,y}^k) \tag{14}$$

where $\widehat{g_{x,y}^k}$ Is the power gain between SUBS x and PUMS y for new distance

$$\hat{d} = Rc - R2 \tag{15}$$

where *Rc* is the original distance between SUBS x and PUMS *y*.

4. Proposed Algorithm

This is in order to maximize the number of SU served to enhance, throughput and energy efficiency without causing harmful interference to PU. An algorithm is based on the proposed PMC, which is explained in Table 1.

Table 1. Proposed algorithm.

Input	$L; P_b; P_m^i; S_b^i; S_m^b; G_{PB}\ ; G_{PM}^i; G_{SB}^i\ ; G_{SM}^b\ ; v_p\ ; \tau_s\ ; P_i^k$
Output	Channel allocation to SUMS $L_{(r)}$; transmission power
1	// Phase 1:estimation of distance
2	Using G_{PB} and G_{PM}^i, estimate distance between P_b and their respective P_m^i.
3	Using G_{PB} and G_{SM}^b, estimate distance between P_b and their respective S_m^b.
4	Using G_{SB}^i and G_{SM}^b, estimate distance between S_b^i and their respective S_m^b.
5	Using G_{SB}^i and G_{PM}^i, estimate distance between S_b^i and their respective P_m^i.
6	// Phase 2: estimation of signal power
7	Estimate wanted signal power at receiving PU MS using the following equation: $P_{P_m^i} = P_i^k - L_d$, where L_d Is the path loss in dB.
8	Estimate interfering signal power at receiving SU MS using the following equation: $P_{\ S_m^b} = P_i^k - L_d$
9	// Phase 3: allocate channels to SU MS receivers.
10	Repeat
11	Pick up a PU BS *i* from P_b
12	Repeat
13	Pick up *a* SUBS *b* from S_b^i
14	Repeat
15	Pick up a SUMS m from S_m^b of b^{th} S_b^i
16	Select a channel k for which, the corresponding PUMS is located farthest from current SUBS and channel k is not allocated to any SU
17	Estimate the transmission power required for S_b^i on channel *k* using the following: $\widehat{P_{\ S_m^b}} = L_d - P_{\ S_m^b} + \gamma_s$
18	If the power estimated in step 17 satisfies following $\widehat{P_{S_m^b}} < P^{max}$ and $R_{b,m,i} \geq R_{b,m,i}^{min}\quad b \in S_b^i, k \in L_i$ Go to step 19. Else go to step 15.
19	Estimate the SINR at the co-channel PUMS receiver using Eq. (13)
20	If SINR at PUMS ∈ channel *k* ≥ 19 dB and SINR at SUMS ∈ channel *k* ≥ 19 dB then
21	$L_{(r)}[i,b,m] = \hat{k}$
22	End if
23	$S_m^b = S_m^b \backslash \{m\}$
	Until $S_m^b = \emptyset$
24	$S_b^i = S_b^i \backslash \{b\}$
25	Until $S_b^i = \emptyset$
26	$P_b = P_b \backslash \{i\}$
27	Until $P_b = \emptyset$

5. Simulation results

The number of channels and PUs assumed here are fixed, which is equal to 57 [18], each PU is operating on one of the 57 channels available and occupying any of the four-time slots in the channel. The Same is true for SUs since the total number of channels considered is 57, more than 57 SUs cannot be served, as it is assumed that when a channel is allocated to the SU, all four slots are allocated to it. Extensive simulations were carried out to test the proposed algorithm in terms of CIR of the PUMS, average data rate, average number and percentage of SU served.

5.1. Average carrier to interference ratio (CIR) of PUMS

To observe variation in CIR of the PUMS with respect to increase in the number of SUs per cell, the number of SUs per cell is varied from 5 users per cell and in each iteration five users were added per cell, till CIR at the PU receiver comes as low as 19 dB, specified in ETSI standards [19]. The obtained results are compared with the results obtained by GCDPA algorithm [16]. Figure 3 shows the variation in the said parameters. As stated earlier, as long as the interference to the PU is less than the harmful interference, SUs can be assigned to the frequency channels. Therefore, as the number of SUs per cell is increased, more SUs are able to receive the transmission from their base station, which results in more interference to the primary mobile receivers. From the graph shown in Fig. 3, it is clear, initially, the CIR at PUMS is approximately around 27.8 dB for the proposed algorithm and 12.6 for GCDPA PU and SU when there were 5 SUs per cell. The CIR consistently degrades as the numbers of SUs were increased from 5 to 40. It is clear that for 40 SUs per cell PU is hit by harmful interference. The CIR of the proposed algorithm is very high as compared to the other algorithm.

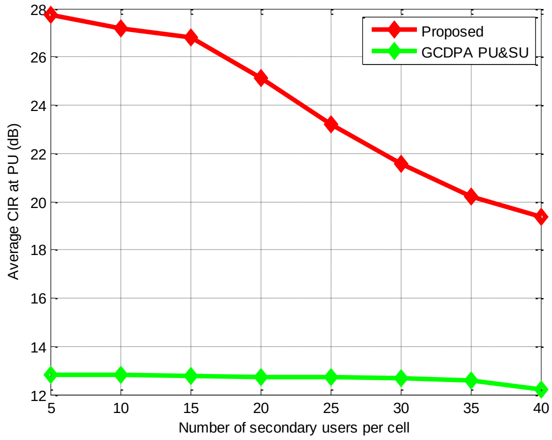

Fig. 3. Average CIR vs. number of SUs.

5.2. Average data rate of the secondary network

Figure 4 shows the variation in the average throughput (data rate) with the change in the number of SUs per cell. It is observed that as high as 0.47 Mbps of data rate enhancement can be achieved, when there are 30 SUs per cell, as compared to 5 SU per cell when the base station transmits 7 dB of power, causing the CIR at primary mobile receivers to be at its lowest tolerable value, i.e., 19 dB. It is observed that the maximal value of the average data rate is found to be at 30 users per cell. This is due to the fact that more channel allocation to SU results in more interference to PU as well as SU.

5.3. Average number of served SUs

The number of SUs per cell is varied from 5 to 40, with a step size of 5 SU per cell and the average number and percentile of the total served SUs for which, the channel is allocated for the reception was observed. As shown in Figs. 5 and 6 when the number of SUs per cell is increased, the average number of the served SU increases and the percentage of served SUs decreases. The reason for this is as the number of SU increases, their density (number of SUs per unit area) increases and this increases the probability that the SUMS could lie near the edge of the service area. When this happens, the CIR of SUMS will degrade, as the interfering signal from the PU Base Station (PUBS) will dominate with respect to the wanted signal coming from the SU Base Station (SUBS). Therefore, though the total count of the served SUs increases as the number of SUs per cell is increased, the percentage of served SU decreases.

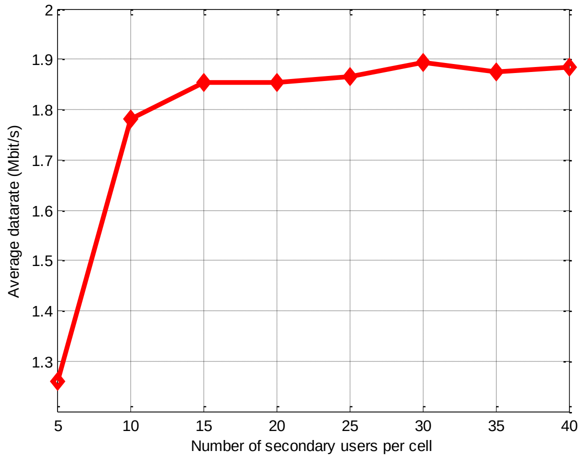

Fig. 4. Data rate vs. number of SUs.

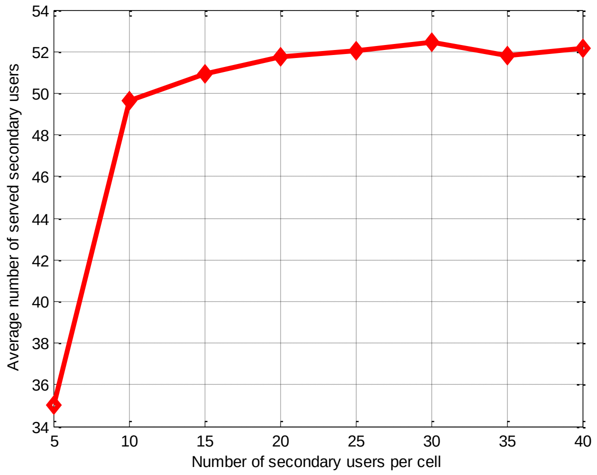

Fig. 5. Served SUs vs. SUs per cell.

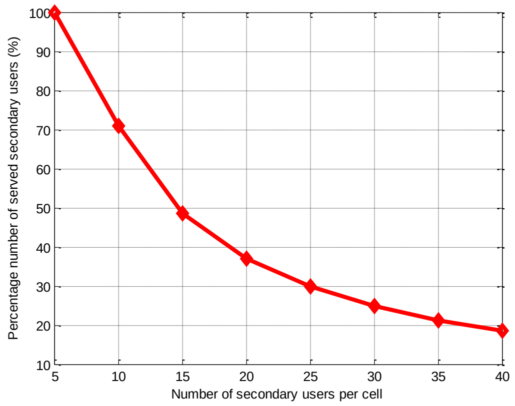

Fig. 6. Percentage served SUs vs. number of SUs per cell.

5.4. Effect of transmission power of SUBS on CIR of PUMS and served SU

The effect of an increase in transmission power of SUBS on CIR of PUMS is shown in Fig. 7. When the SUBS transmission power was increased from -6 dB to 2 dB, in the steps of 2 dB, the interference caused to the primary nodes will also increase. This causes the CIR level at the PU MS to degrade as shown in Fig. 7. As the number of SUMS per cell is increased from 10 to 40 the CIR at PUMS degrades for that particular transmission power level. When the transmission power of SUBS is increased, CIR will be violated for a greater number of PUMSs. This leads to a reduction in the number of opportunities for SU's. The served SUs are decreased as a result of this change in opportunity as shown in Fig. 8. The same behaviour is reflected in Fig. 9. As the number of SUs per cell has increased, the average number of served MS's increases, apparently the relative figure decreases, i.e., the percent served SUMS decrease owing to the reason stated in the above section.

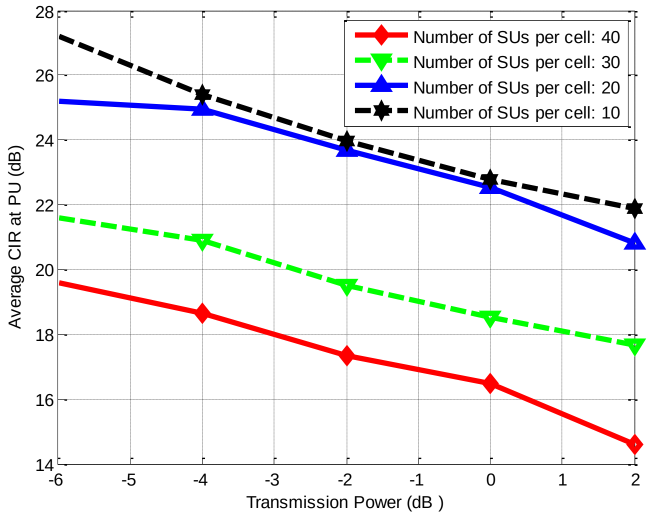

Fig. 7. CIR at PU MS vs. SUBS transmission power

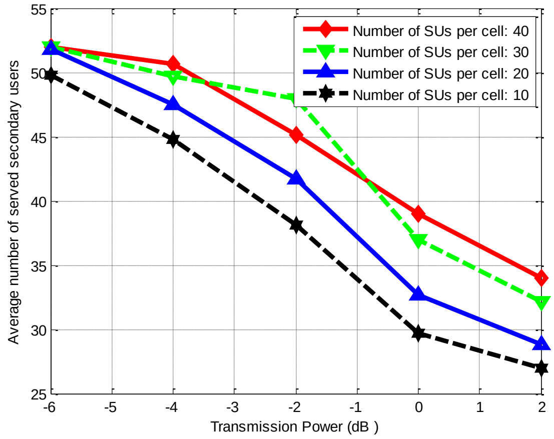

Fig. 8. Transmission power of SUBS vs number of SU served.

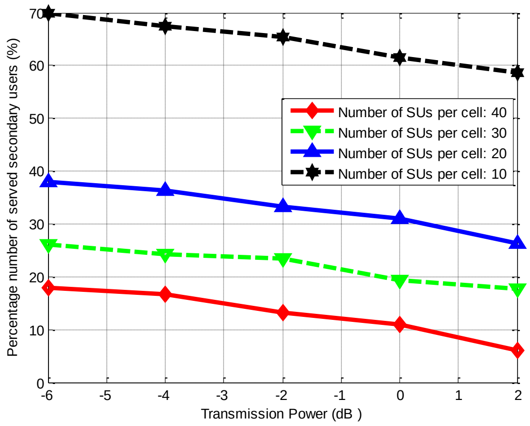

Fig. 9. Transmission power of SUBS vs. % of served SUs.

5.5. Effect of transmission power of SUBS on throughput

Figure 10 shows a comparison between average throughput obtained with and without the power control that is considering and relaxing constraint C4 given by Eq. (6) respectively when the transmission power of SUBS is varied from 31 dBm to 41 dBm. It is seen that average throughput achieved with the power allocation algorithm is less as compared to without power allocation due to the fact that the ideal CR operation demands an interference to PU under a tolerable limit. It can be seen in Fig. 11 that when the allowable transmission power of the SUBS is increased, energy efficiency measured with and without the power allocation algorithm is decreased. However, the energy efficiency with power allocation is much enhanced compared to that without power allocation. For instance, at SUBS power 33 dBm, energy efficiency is 1.2 Kbps/W wherein for without power allocation it is 0.6 Kbps/W only. The energy efficiency enhancement even for high SUBS power of 40 dBm is observed to be 27%. It is evident from the graph shown in Fig. 11 that enhancement in energy efficiency is achieved by the proposed power allocation algorithm.

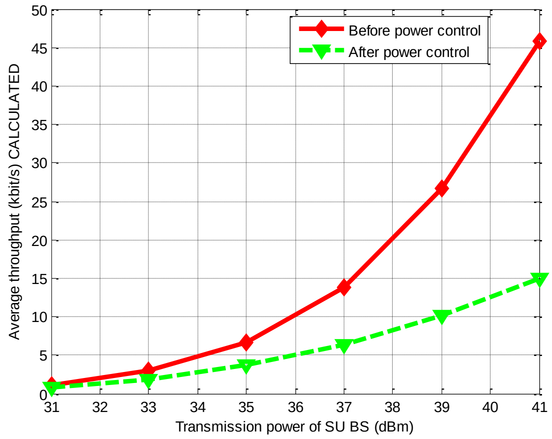

Fig. 10. Transmit power of SUBS vs. average throughput.

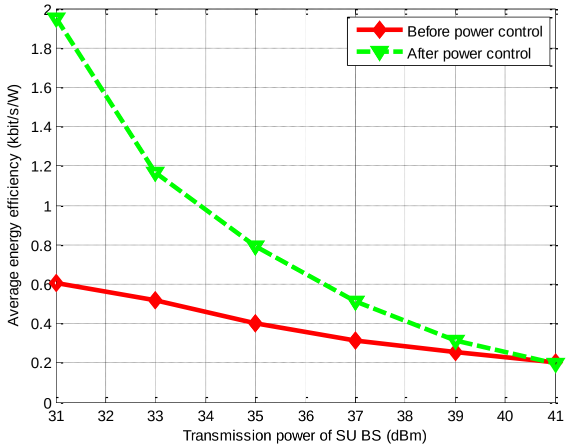

Fig. 11. Transmission power of SUBS vs. average energy efficiency.

6. Conclusions

In this paper, the problem of a spectrum and power allocation for cellular-based cognitive radio network using the principle of Geolocation aware spectrum access is investigated. Formulation of the problem to test the feasibility of deploying the secondary system within TETRA based cellular primary system to maximize the served SUs while keeping the interference to PU under a predefined threshold was carried out. A novel model is called Primary Mobility Contour for the avoidance of harmful interference to PU, which considers the velocity of PU and time taken by the secondary base station for transmission along with Geolocation information is proposed. Using this model sensing free spectrum and power allocation algorithm has been developed to obtain the maximized number of SU served and improved energy efficiency. From the simulation results, it is confirmed that the proposed scheme indeed maximizes the number of SUs served, throughput and energy efficiency and holds the promise of green communication.

Nomenclatures

c_y^k	A binary variable that is set to 1 if channel k is assigned to terminal y for reception, for $y \in S_m^b, \forall b \in S_b^i$ and 0 otherwise
$g_{x,y}^k$	The channel power gain from base station x to mobile station y
G_{PB}	A set of latitude/longitude (GPS) information corresponding to PUBS
G_{PM}^i	A set of latitude/longitude (GPS) information of PUMS corresponding to MSs administered by PUBS ∀i
G_{SB}^b	A set of latitude/longitude (GPS) location information of SUBS deployed at the cell site of PUBS i, ∀i
G_{SM}^b	A set of latitude/longitude (GPS) location information of SUMS, cell site of SUBS b, ∀b
$I_{x,y}^k$	The interference produced at mobile terminal $y \in P_m^i \cup S_m^b$, due to base station. $x \in P_b \cup S_b^i$. $I_{x,y}^k = P_x^k \cdot g_{x,y}^k$
L_i	A set of channels used by the P_b i, for its downlink transmission
No	The channel noise power, assumed to be same at all locations on all channels
P_b	A set of PUBS denoted by i
P_m^i	A set of PUMS that belong to the cell administrated by P_bi, denoted by j
P_i^k	The transmission power of PUBS i on the downlink channel k
P_b^k	The transmission power of SUBS b on downlink channel k
$R_{b,m}^{min}$	The minimum rate requirement of the SU m, in the bth secondary cell, under ith primary cell $\forall i \in P_b, \forall b \in S_b^i, \forall m \in S_m^b$
S_b^i	A set of SUBS deployed in the cell site of PUBS i, denoted by b
S_m^b	A set of SUMS that belong to the cell administrated by SUBS b denoted by m
Vp	Velocity of PUMS terminal

Greek Symbols

α	Path loss exponent.
γ_P	Minimum SINR required at PUMS to guarantee a certain BER
γ_s	Minimum SINR required at SUMS to guarantee a certain BER
τs	Time in ms, the SUBS $x \in S_b^i$ ∀i, is going to transmit on channel $k \in L_i$

Abbreviations

CR	Cognitive Radio
CRN	Cognitive Radio Networks
FLA	Full Location Aware
PLA	Partial Location Aware
PMC	Primary Mobility Contour
PUBS	Primary User Baseband Station
PUMS	Primary User Mobile Station
SUBS	Secondary User Base Station
SUMS	Secondary User Mobile Station
TETRA	Terrestrial Trunked Radio

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