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Multi-Hop Multi-Environment Relay Assisted CRNs

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Abstract: ***A relayed transmission model of multi hop cognitive radio system is introduced. Objective of this paper is to minimize the outage probability while satisfying the total power constraint and interference threshold for primary user(PU) and also the signal-to-interference and noise ratio. Network life of cognitive radio network is also considered using the concept of battery life to improve the overall capacity of the cognitive radio(CR).Overall Capacity of secondary user(SU) is calculated from the subcarrier allocation between source and destination of secondary user. Convex optimization and Linear Programming based approaches are carried out in this scheme. In addition, classical schemes are compared with proposed scheme. Extensive simulations have been performed for both energy aware and non-energy aware scheme to obtain a better overall capacity, reduced interference.***

Keywords: cognitive radio network, relay, SINR, outage probability, linear programming

1. Introduction

J. Mitola discussed broadly about CR in [1]&[2].CR-based article was firstly published in an article in 1999[3].

S. Haykin proposed an architectural view of CR in [4] with considering the software radio concept.

CR is suggested to be the future of secondary communication while also being useful for the spectrum band utility[5].Federal Communications Commission(FCC) reported that the spectrum bands remain unutilized for most of the time interval[6].A mutual trade off can be done between interference and overall capacity using OFDM[7]. OFDM subcarrier helps a lot in CRNs[8],[9]&[10]. CRN To communicate without any default, cooperative relay models have been came into existence and termed as co-operative relays for CRN[11].Optimal power allocation is a concern for CRN. Relay aided OFDM based CRNs are introduced later. Different types of power allocation strategies are come into play for different relay networks[12]. Different relay aided CRNs need different subcarrier allocation methods[13].

The single hop CRNs comes first in terms of simple CRN models.[22]&[23].Gradually dual hop CRNs came into that genre[14].Rayleigh distributions are mostly considered for its performance and evaluations [15].Resource allotment based on QoS(Quality of Service) is also taken care with the Outage Probability(OP) realization[16].The network life-time concept was considered for multihop CRN in [20].

Two traditional approaches are most widely applied over a long time. Those are-i) Uniform power loading scheme and ii) Water-filling Scheme. Bansal et. al. discussed optimal and suboptimal schemes for above two approaches in [17]&[18].

The linear programming is not proposed in previous cases of CRNs. It is performed in [19] for several time slots.

The whole paper is directed as follows. Section II only describes the basic CRN model. Objective function formulation and optimal allocation of resource are being covered in section III. And in section IV, optimal solutions are being discussed. Simulation results are analyzed are explained in Section V. And finally, section VI concludes this paper.

2. System Model

A multi-hop relayed cognitive radio transmission network is considered on the basis of OFDM subcarriers. All channels are assumed to be Rayleigh distributed for making simpler calculations. Hence, the fading introduced is also considered as Rayleigh fading. Here primarily concern is the outage probability (OP). The outage probability of SU is limited by the interference power threshold (IPT). Another constraint is here i.e. the SINR (Signal-to- interference + noise ratio) constraint. During whole communication, the SU, relay and PUs will interfere one another. But the interference from SUs cannot cross beyond a certain threshold level.

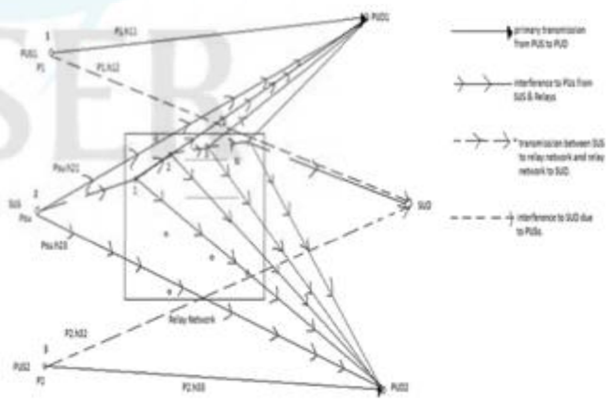

Figure 1: System Model

PUS-Primary user source, PUD-Primary user destination, SUS- Secondary user source, SUD- Secondary user destination. P1, P2 -Primary users' transmission powers(for primary user 1,2 respectively).

P_{su}-Secondary user's transmission power. h11,h33-channel gains of PUS1to PUD1 & PUS2 to PUD2 respectively. h12, h32 -channel interference co-efficients for PUS1 to SUD & PUS2 to SUD respectively.

h21,h23- channel interference co-efficients for SUS to PUD1 & SUS to PUD2 respectively. hn1,hn3-channel interference co-efficients for relay network to PUD1 and relay network to PUD2 respectively.

System model shown in fig 4.2 is based on a multi-hop multi-environment scheme. Here, two primary users are considered whereas a secondary user is co-existing with these PU(primary user)s. Some considerations are made to achieve the optimal power allocation. Those are as follows:-

1) PUS1 & PUS2 are transmitting to their own destinations i.e. PUD1 & PUD2 respectively.
2) A SUS is present within their(PUS1 & PUS2) range.
3) SUS can have two types of communications- firstly it can directly transmit data to its destination i.e. SUD and secondly it has to take the help of relays to transmit its data to SUD. First possibility is not available here because SUS is far away from SUD. So, here a relay network is taken.
4) Interference is considered in two ways-
   a) Interference to PUs from SUS & relays.
   b) Interference to SUD due to PUs.
5) There is provision that PUs can use some of the relays from the relay network.
6) The SINR (Signal-to-interference + noise ratio) values of primary users are also to be increased during the whole communication procedure.

Here, all the channels are assumed to have Rayleigh fading.

Interferences are appeared in two ways as discussed previously. Firstly, interference due to primary users upon secondary users and secondly, interference introduced to the primary user due to secondary user and relays.

SINR can be calculated as, SINR=signal-to-interference+noise ratio= $\frac{\prod signal\ power}{\sum Noise\ Power + interference}$ = $\frac{(Power\ of\ Primary\ or\ secondary\ user)*respective\ channel\ gains}{noise\ variance + interference\ introduced\ by\ primary\ or\ scondary\ user}$

Capacity or system throughput is calculated as shannon's capacity formula.

3. Optimal Power Allocation

OP in multi-hop CRNs can be shown as[15].

$$P_{out}=1-e^{-\gamma_{th}\left(\frac{1}{G_{su}P_{su}}+\sum_{n=1}^{N}\frac{1}{G_nP_n}\right)} \quad (1)$$

γ_{th}= Threshold limit considered previously.
G= gain or loss of the parameter on an average.
su stands for secondary user and n=1,2,….,N.
where N stands for total number of relays.
P_{su}= Total power allocated to secondary user.
P_n= Total power allocated to N number of relays.
For minimization problem,

$$e^{-\gamma_{th}\left(\frac{1}{G_{su}P_{su}}+\sum_{n=1}^{N}\frac{1}{G_nP_n}\right)} \quad (2)$$

Now that is minimizing.

$$\gamma_{th}\left(\frac{1}{G_{su}P_{su}}+\sum_{n=1}^{N}\frac{1}{G_nP_n}\right) \quad (3)$$

We introduced a new approach that is called as **Network lifetime** based approach**.** As known so far in Scheme I, α= E_r/E_i, where E_i is the initial energy and E_r is residual energy at the current time at any node.

Objective Function is as follows,

$$\text{Min } \gamma_{th}\left(\frac{\alpha_{su}^{y}}{G_{su}P_{su}}+\sum_{n=1}^{N}\frac{\alpha_n^{y}}{G_nP_n}\right) \quad (4)$$

Constraints are

$$1.\ P_{su}+\sum_{n=1}^{N}P_n\le P_T \quad (5)$$

$$2.\ P_{su}h_{sup}+\sum_{n=1}^{N}P_nh_{np}\le I_{th} \quad (6)$$

$$3.\ \frac{P_1h_{11}}{\sigma^2+P_{su}h_{21}+\sum_{n=1}^{N}P_nh_{n1}}+\frac{P_2h_{33}}{\sigma^2+P_{su}h_{23}+\sum_{n=1}^{N}P_nh_{n3}}\ge\gamma \quad (7)$$

Where h_{sup} & h_{np} are the channel coefficients of S.U.S. to P.U.D. and relay to P.U.D on an average basis respectively and I_{th} is the permissible interference threshold. The limit in Eq. (6) is taken on the basis SINR requirements of the PUs. γ stands for SINR of PUs on an average over the two PUs. P_T is the total power allocated to the SU and relays. σ is the variance of AWGN(Additive White Gaussian Noise) channel.

The third constraint can be modified in a linear equation after complicated and rigorous processes and thus we can have Eq. (6) as follows,

$$-(P_{su}m_1+\sum_{n=1}^{N}P_nm_2)\le\sigma^2(P-\gamma\sigma^2) \quad (8)$$

Where, $m_1=h_{11}h_{23}P_1+h_{21}h_{33}P_2-\gamma\sigma^2(h_{21}+h_{23})$;
$m_2=h_{11}h_{n3}P_1+h_{n1}h_{33}P_2-\gamma\sigma^2(h_{n1}+h_{n3})$ &
$P=P_1h_{11}+P_2h_{33}$.

Outage probability (OP) is a convex function and the linearity nature of constraints made them also convex functions.

The Lagrangian function is given as under,

$$L(P_{su}, P_n, \lambda_1, \lambda_2, \lambda_3) = \text{Min } \gamma_{th}\left(\frac{\alpha_{su}^{y}}{G_{su}P_{su}}+\sum_{n=1}^{N}\frac{\alpha_n^{y}}{G_nP_n}\right) + \lambda_1(P_{su}+\sum_{n=1}^{N}P_n - - P_T) + \lambda_2(P_{su}h_{sup}+\sum_{n=1}^{N}P_nh_{np}-I_{th}) + \lambda_3\{-(P_{su}m_1+\sum_{n=1}^{N}P_nm_2)-\sigma^2(P-\gamma\sigma^2)\} \quad (9)$$

4. Optimal Solution

The NEA & EA based approaches are taken into considerations. There will be many solutions but all of them are not feasible to the optimal conditions.

1. NEA Approach :- (y=0; α=1)

Case-1: λ_1 0, λ_2=0 , λ_3=0, λ_4=0, λ_5=0. (P_T has a lower value. λ_1 has a less value but greater than 0)

Case-1: $\lambda_1 \neq 0$, $\lambda_2=0$, $\lambda_3=0$, $\lambda_4=0$, $\lambda_5=0$. (P_T has a lower value. λ_1 has a less value but greater than 0)

$$P_{su}^* = P_T\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_{su}}{G_n}}\right)^{-1} \quad (10)$$

$$P_n^* = P_{su}\sqrt{\frac{G_{su}}{G_n}} \quad (11)$$

Case-2: $\lambda_1 \neq 0$, $\lambda_2 \neq 0$, $\lambda_3=0$, $\lambda_4=0$, $\lambda_5=0$. ($\lambda_1 >>0$)

$$P_{su}^* = \frac{I_{th}}{h_{sup}} \quad (12)$$

$$P_n^* = \left(P_T - \frac{I_{th}}{h_{sup}}\right)\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)^{-1} \quad (13)$$

Case-3: $\lambda_1=0$, $\lambda_2 \neq 0$, $\lambda_3 \neq 0$, $\lambda_4=0$, $\lambda_5=0$. (P_T has no effect.)

$$P_{su}^* = \frac{I_{th}}{h_{sup}} \quad (14)$$

$$P_n^* = I_{th}\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)h_{np} \quad (15)$$

Case-4: $\lambda_1 \neq 0$, $\lambda_2=0$, $\lambda_3=0$, $\lambda_4 \neq 0$, $\lambda_5=0$. (P_T has some effect.) ($\lambda_1 >>0$)

$$P_{su}^* = \frac{a\sigma^2(\gamma\sigma^2-P)}{m_1}. \quad (16)$$

$$P_n^* = \left(P_T - \frac{a\sigma^2(\gamma\sigma^2-P)}{m_1}\right)\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)^{-1} \quad (17)$$

Case-5: $\lambda_1=0$, $\lambda_2=0$, $\lambda_3=0$, $\lambda_4 \neq 0$, $\lambda_5 \neq 0$. (P_T has no effect.)

$$P_{su}^* = \frac{a\sigma^2(\gamma\sigma^2-P)}{m_1} \quad (18)$$

$$P_n^* = (1-a)\sigma^2(P-\gamma\sigma^2)\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)m_2 \quad (19)$$

2. EA Approach :- (γ=1; α has some value)

Case-1: λ_1 0, $\lambda_2=0$, $\lambda_3=0$, $\lambda_4=0$, $\lambda_5=0$. (P_T has a lower value. λ_1 has a less value but greater than 0)

$$P_{su}^* = P_T\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_{su}}{G_n}}\right)^{-1} \quad (20)$$

$$P_n^* = P_{su}\sqrt{\frac{G_{su}}{G_n}} \quad (21)$$

Case-2: $\lambda_1 \neq 0$, $\lambda_2 \neq 0$, $\lambda_3=0$, $\lambda_4=0$, $\lambda_5=0$. ($\lambda_1 >>0$)

$$P_{su}^* = \frac{I_{th}}{h_{sup}} \quad (22)$$

$$P_n^* = \left(P_T - \frac{I_{th}}{h_{sup}}\right)\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)^{-1} \quad (23)$$

Case-3: $\lambda_1=0$, $\lambda_2 \neq 0$, $\lambda_3 \neq 0$, $\lambda_4=0$, $\lambda_5=0$. (P_T has no effect.)

$$P_{su}^* = \frac{I_{th}}{h_{sup}} \quad (24)$$

$$P_n^* = I_{th}\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)h_{np} \quad (25)$$

Case-4: $\lambda_1 \neq 0$, $\lambda_2=0$, $\lambda_3=0$, $\lambda_4 \neq 0$, $\lambda_5=0$. (P_T has some effect.) ($\lambda_1 >>0$)

$$P_{su}^* = \frac{a\sigma^2(\gamma\sigma^2-P)}{m_1} \quad (26)$$

$$P_n^* = \left(P_T - \frac{a\sigma^2(\gamma\sigma^2-P)}{m_1}\right)\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)^{-1} \quad (27)$$

Case-5: $\lambda_1=0$, $\lambda_2=0$, $\lambda_3=0$, $\lambda_4 \neq 0$, $\lambda_5 \neq 0$. (P_T has no effect.)

$$P_{su}^* = \frac{a\sigma^2(\gamma\sigma^2-P)}{m_1} \quad (28)$$

$$P_n^* = (1-a)\sigma^2(P-\gamma\sigma^2)\left(1+\sum_{n=1}^{N}\sqrt{\frac{G_n}{G_{su}}}\right)m_2 \quad (29)$$

Linear programming is considered as in [19].

5. Simulation Results

In this part, we ultimately test performances of different characteristics of CRN on the basis of sum power and interference constraints and sum SINR constraints. Here we also compare the classical approaches with our proposed schemes.

After rigorous calculations and extensive studies it is seen that $\lambda_1=0$, $\lambda_2 \neq 0$ & $\lambda_3=0$ combination outperforms other two combinations i.e. $\lambda_1 \neq 0$, $\lambda_2= 0$ & $\lambda_3= 0$ & $\lambda_1=0$, $\lambda_2=0$ & $\lambda_3 \neq 0$ in case of water-filling algorithm.

After performing several steps of calculations, the combination- λ_1 0, $\lambda_2=0$, $\lambda_3=0$, $\lambda_4=0$, $\lambda_5=0$ gives better solution than other combinations in convex optimization based algorithms.

Below table gives the parameter values needed in simulation process.

Values of the channel fading gains or co-efficients (h_{sup} & h_{np}) are obtained from performing extensive simulations on Rayleigh channel gain model using MATLAB.

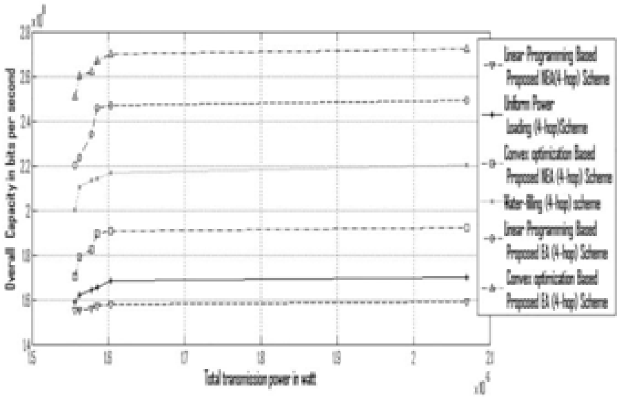

Figure 2: Overall Capacity versus Total Transmission power of CRs

Fig. 2 depicts the change in overall capacity of CRs by increasing the total transmission power of CRs. This figure also distinguishes between different schemes under different prospects. Here, all the results are performed over 4-Relay based CRNs. Results clearly show that proposed Linear EA scheme outperforms classical unifrom laoding scheme by approximately 25% and also shows an increase of 5-10% over classical water-filling scheme. And water-filling proves to be better(17-20%) than the uniform loading scheme. Whereas, the proposed Convex EA scheme outperforms the uniform loading scheme by 34-36% and water-filling scheme by approximately 20%. Also it proves to be better than proposed Linear scheme by 9-11%. After a certain level(from Fig. 2, it is 1.7 10 watt interms of total transmission power of CRs.), the curve saturates and tends to be a straight line.After this level(given in previous bracket),the overall capacity of CRs does not increase although the transmission power of CRs increase. The reason behind is CRN acts as an interference limited agent inthis particular zone.

Table 1: Values of Simulation Parameters

Parameters	Values
Number of subcarrier(K)	10[21]
G_{su}	1[9]
G_n	10 [9]
γ_{th}	3[9]
P_T	0.001 watt [9]
Interference threshold, I_{th}	0.1watt [13]
Noise variance(σ^2)	1 microwatt [20]
$_{Ei}$ (initial battery energy)	0.06 to 0.09 mili Joule.[20]
Packet size	250 bytes[20]

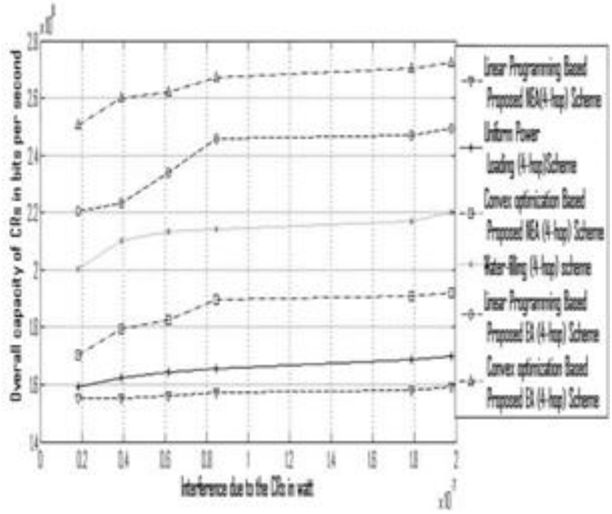

Figure 3: Overall Capacity versus Interference due to the CRs

Fig. 3 relates the overall capacity of CRs with the interference caused by CRs on different basis. All the results here are also performed over 4 -Relay CRNs. As in fig. 2,here also Convex EA proposed scheme ouperforms all the schemes i.e. conventional uniform loading scheme, water-filling scheme and proposed Linear EA scheme by 30-36%, 23-24% and approximately 11% respectively. Whereas, Linear EA scheme results an increase of 21-23% over uniform loading scheme and also 6-9% increase over water-filling scheme. Reaching upto a certain point (from Fig. 3, it is 1.2 10 watt interms of total transmission power of CRs.), the curve almost goes to saturation for some casesand tends to be a straight line gradually.

After this level(given in previous bracket),the overall capacity of CRs does not increase although the interference due to CRs increase. The reason of this saturation is that when interference due to CRs on primary user 2 is not affected by its increasing value, other related constraints like P_T, interference due to CRs on primary user 1 are found to be prominent.

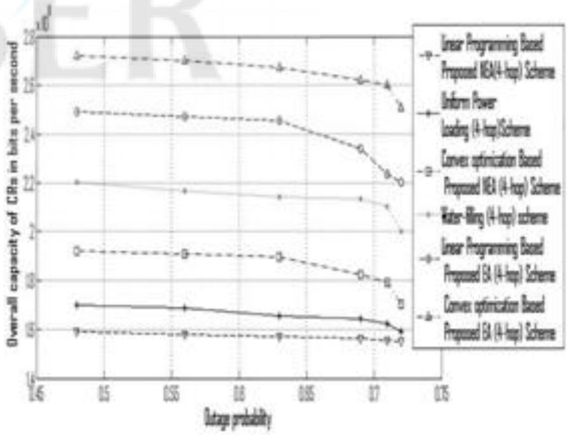

Figure 4: Overall Capacity versus Outage probability

In Fig. 4, the graph is plotted between overall capacity of CRs and outage probability. Here, all the results are performed over 4-Relay based CRNs like in pervious two graphs. In this case also, proposed Convex and Linear EA schemes outperform the uniform loading and waterfilling schemes. From observations, it is clear that the overall capacity of CRs decrease as the outage probability increases for a predetermined total power and interference limits & SINR constraints.

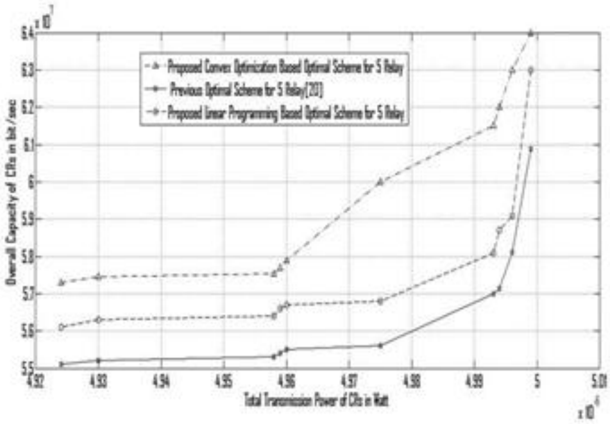

Figure 5: Overall Capacity versus Total Transmission Power of CRs(comparison with previous scheme).

Fig. 5 gives a comparative study among our proposed schemes and previously established works[20] on the basis of a plot between overall capacity of CRs and total transmission power of CRs. From observations it is obvious that our proposed scheme are giving better results than the previous. Here, an optimal point is considered for convex and linear both approaches. Actually, putting y=0.5 in EA case, an optimal scenario is obtained for both linear and convex proposed schemes. All the results generated are on the basis of 5-Relay based CRNs for this graph. The convex optimal proposed scheme gives 3-7% increase in overall capacity of CRs over the previous scheme [20]. And linear programming based optimal scheme shows 2-5% increase than the previously published work [20].

6. Conclusion

In this paper, the scheme is based on multiple PUs influence and co-existence of CRs. The comparative studies of conventional schemes and proposed schemes are made on different basis. All the results show that proposed schemes turn to be better than the conventional schemes. Proposed convex scheme proves to be better than the Linear proposed scheme by approximately 11% in terms of overall capacity. Finally, proposed convex scheme outperform the previous work [20] by 3-7% and proposed linear scheme shows an increase of 2-5% over the previous work [20].

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