RESOURCE ALLOCATION (RA) STRATEGY FOR OPTIMUM SPECTRUM ALLOTMENT FOR MULTIUSER OFDM BASED COGNITIVE RADIO SYSTEM

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Abstract— *In this paper, an optimal spectrum sharing strategy is proposed to enhance the sum capacity of the secondary users (SUs) in multiuser orthogonal frequency division multiplexing (OFDM)-based cognitive radio network. Even though many schemes are available for spectrum sharing, improvement is needed due to practical constraints in wireless communication. Here, the efficient clustering based resource allocation (RA) method is presented in which all the SUs are placed into different groups based on their interference degree. The different groups can use the same sub channels which improves the efficiency of the spectrum utilization. Then, resource allocation algorithm is implemented in each group to maximize the sum rate of the SUs in each cluster. The simulation results show that the sum rate of all SUs in each group is significantly improved compared to other methods. Moreover, our proposed RA algorithm converges stably and quickly.*

Keywords— *Clustering, cognitive radio, convex optimization, resource allocation, spectrum sharing.*

I. INTRODUCTION

The cognitive radio (CR) is one of the most promising technologies for the future radio spectrum utilization. In CR, a secondary user (SU) is allowed access to primary user (PU) spectrum bands on the condition that the interference caused to PUs is tolerable. Nowadays, telecommunication industry has shown huge development in mobile wireless services. They are really influence with our daily life such as personal entertainment, studying, education and other industry sectors. The high amount of data rate requirement is need from 4G mobile communication network under low and high mobility conditions. However, there are some challenges associate in 4G network in terms of multiform applications, huge numbers of subscribers, increased indoor traffic, massive power consumption and faster Internet access on the move. This kind of limitations are may overcome in Fifth generation (5G) mobile communication systems. In general, mobile network architectures are classified into two types such as heterogeneous networks (HetNets), cloud radio access networks. Even, in the forthcoming 5G networks, has a way to show the dramatic growth in the demand of radio spectrum resources. Because of the limitation of spectrum availability, the cognitive radio is provide the normal solution to waste of spectrum resources and improve the spectrum utilization efficiency. It will satisfy the traffic demands requirement in mobile networks, which can exploit scarce radio spectrum resource fully and alleviate the burden on mobile service providers. A novel radio spectrum resource management principle said that the secondary users (SUs) in the CR network can access vacant spectrum without causing interference to the primary users (PUs) in the licensed system. This process can be done under the collection of spectrum sensing information and report sensing results to the fusion center (FC) in the CR network as shown in Fig. 1. Now, the CR system has known its surrounding environment in which radio resource allocation can be done in an intelligent manner by developing efficient cognitive radio resource management scheme. It includes both SUs and PUs performance-guaranteed services under consideration of all practical limitations. The Fusion center can manage the transmission of the SUs and exchange signaling information with the access nodes in the primary network.

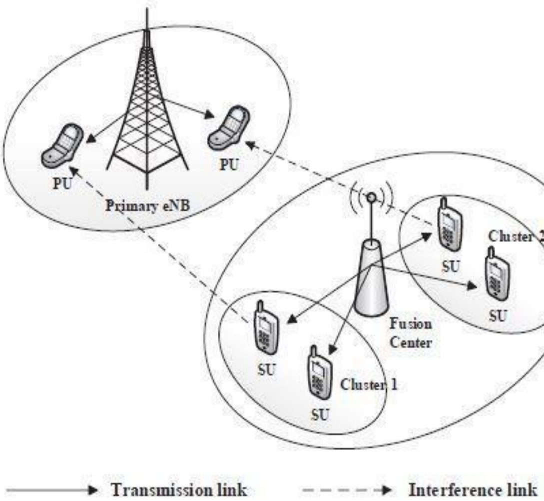


Fig. 1. Illustration of System Model.

With help of reliable spectrum sensing, the SUs can access vacant spectrum for data transmission. However, in the future, as the number of subscribers increases which in turn to serve more and more SUs with limited vacant spectrum in the CR system. If the users access the same subchannel for data transmission, then, the CR system suffers to severe mutual interference just like the conventional cellular systems. Actually, it is due to improper estimation of the radio environment where cognitive procedure not properly performed. As a result, wrong spectrum sensing, which leads to deteriorate the performance of both the CR network significantly. Therefore, interference issue is still present in the CR network. Even many advanced interference techniques are available which would not address all kind of interference problem. This will be the bottleneck of the future CR network development.

The objective of this paper is to address the interference issues associate among various SU's by two-stage procedure in the CR network. That is, clustering and radio resource allocation. A clustering technique is used to tackle the interference among the SUs by coordinating their transmissions. Then, the SU's with orthogonal frequency division multiplexing (OFDM) modulation can access the licensed spectrum opportunistically to satisfy their pre-defined transmission rate. Initially, the SUs are divided into many disjoint clusters in which all subchannels are available to each cluster to enhance spectrum utilization efficiency. Then, the subchannel and power allocation procedures are performed in each cluster to maximize the sum rate of the SUs. In the clustering stage, the SUs with heavy mutual interference are grouped into the same cluster and use different subchannels to eliminate mutual interference. After that, subchannel allocation and power distribution are performed by a cluster center (CC) selected from the SUs in each cluster. The rate requirements and a coarse proportional fairness among SU's can be satisfied by the subchannel allocation procedure, then a fast algorithm is developed to yield optimal power distribution with near linear complexity.

The organization of chapters as follows. In Section II illustrate the system model, interference model and its formulate expression involved in the optimization task. In section III, the clustering issue has been addressed by an efficient clustering algorithm in detail. Section IV describes the subchannel allocation and fast optimal power distribution algorithms. Simulation results and discussions are presented in Section V and finally conclusion is drawn in Section VI.

II. SYSTEM MODEL

There are many clustering-based interference management principle are available in the market for proper data transmission in the cellular systems. However, these principles are not directly extended to the CR scenarios. Because, the CR system is low-cost and simpler as compared to that of the conventional cellular system. So, complex signal processing technique is usually unavailable in the CR system. Usually, the cellular network is design for the critical coverage requirement. But, CR system need not require seamless coverage but sample opportunity for the SUs who request data transmission. Therefore, it is profitable by employs a proper clustering methods for the SUs to enhance the performance of the CR system. As a result, an efficient clustering and RA algorithms is promising approach to improve the performance of the CR networks, which is the motivated in this work.

A. *Network Model*

Consider a multiuser OFDM-based CR network has shown in Fig.1 with contains 'K' number of SUs and 'L' number of Pus. That is, $K = \{1, 2, ..., k\}$.The fusion center (FC) can do the channel state information (CSI) function which means sense the presence or absence of the primary signals. It helps to makes a decision properly. Whenever, the primary signals are absent, then, the CR network is allowed to utilize the channel for data transmission. Otherwise, the channel is not available for the SUs in that time instant. Regularly, each SU senses the primary signals and send their report to FU for the observation. Once, the perfect CSI is available at the transceivers of the SUs, which is sent to the subcarrier and power allocation module through FC. The multiuser OFDM-based CR network is divided the whole spectrum B into N OFDM subchannels is denoted by $N = \{1, 2, ..., n\}$.Thesignal-to-interference-plus-noise (SINR) of the the kth SU on the nth OFDM subchannel with unit power as $h(k, n)$

$$h(k,n)=\frac{g(k,n)}{\Gamma\left(\frac{N_0B}{N}+\sum_{l=1}^{L} I_l^{PS}(k,n)\right)} \quad \text{--- (1)}$$

where $I_l^{PS}(k,n)$ is the interference of the kth SU on the nth OFDM subchannel by the lth PU with $N0$ is noise power of each subchannel, $g(k,n)$ is the power gain of the kth SU on the nth OFDM subchannel with unit power. Γ is the SINR gap for an uncoded multilevel quadrature amplitude modulation (MQAM) with a specified bit-error-rate (BER).

$$r(k,n)=\frac{B}{N}\log_2\left(1+p(k,n)\times h(k,n)\right) \quad \text{--- (2)}$$

where $p(k,n)$ is the transmission power of the kth SU on the nth subchannel. Denote Rk as the sum rate of the kth SU,

$$Rk=\sum_{n=1}^{N}\rho(k,n)\times r(k,n) \quad \text{--- (3)}$$

where $\rho(k,n)$ can be either 1 or 0, informing whether the kth SU occupies the nth subchannel or not.

B. Interference Model

The CR network contains many SUs which can causes mutual interference among SUs and it can be minimize by dividing a CR network into number of disjoint clusters groups. It is denoted by set of clusters as *C*. Note that if there is no mutual interference among the SUs in the same cluster. Then, the entire set of subchannels is available to the SUs for data transmission over different subchannels simultaneously in a single cluster. That implies, cluster size is an important parameter to make a trade-off between the available spectrum and the co-tier interference among different clusters. If the cluster size is very small, the number of available subchannels for each user within a cluster is relatively large but interference among clusters may be serious. Otherwise, if the cluster size is larger, the co-tier interference between adjacent clusters could be minimized. However, the sharing of subchannels for each cluster would be smaller. So, an efficient clustering algorithm is proposed in such a way that it can reduce the mutual interference among SUs and also maintain spectrum efficiency even the SUs are grouped into different clusters for transmission. The interference induced by the SUs to the PUs can be estimated the concept of reference user. To define the heaviest interference can occur in the PU from various cluster groups, which is denoted as PU_{Max}. For analysis, assume that the co-tier interference between two clusters is negligible.

$$PU_{Max}=\arg\max_l\left(\sum_{k\in C_m}\sum_{n\in N}\left(\frac{P_T.|C_m|}{N}\left|\tilde{h}(k,n)\right|^2\right)\right) \quad \text{---(4)}$$

where $\tilde{h}(k,n)$ is the channel gain of the interference link from the SU k to the PU l on the n-th subchannel and $\frac{P_T.|C_m|}{N}$ represents the average power distribution on each subchannel in the cluster Cm. For simplicity, the guarantee interference received by each PU cannot exceed behind given threshold I_{PUm}^{th}. That is,

$$I_{PUm}^{th}=I^{th}.\,|Cm| \quad \text{--- (5)}$$

To maximize the sum rate of the SUs under predefined interference threshold to each PU. The mathematically, it is given as follows:

$$\begin{aligned}
&C1: Rk\geq R_{\min}\\
&C2: \sum_{n=1}^{N}\rho(k,n).\,p(k,n)\leq P_T\\
&C3: \sum_{k\in Cm}\sum_{n\in Nl}\tilde{h}(k,n)\leq I_{PUm}^{th}\\
&C4: \sum_{k\in Cm}\rho(k,n)=1
\end{aligned} \quad \text{--- (6)}$$

Where, $R_{\min}$ is the minimal rate constraint of the SUs in each cluster. $\rho(k,n)$ representing whether the nth subchannel is occupied by the kth SU or not (either 1 or 0), P_T is the power budget of each SU. C1 is the required sum rate of the each SU. C2 is the power constraints. C3 is the interference constraint for each cluster, which enforces that the total received interference at $PU_{Max}\leq I_{PUm}^{th}$. C4 is the exclusion constraint, indicating the nth subchannel can only be occupied by at most one SU in the cluster Cm.

III. EFFICIENT CLUSTERING ALGORITHM

An efficient clustering algorithm is introduced to reduce mutual interference among SUs in different cluster groups has been discussed in this section. The fusion center gathers information about average channel gains and performs the clustering procedure for all the SUs. Then, a cluster configuration can be obtained for group of candidate in the each cluster groups. After this, the clustering results have sent through common channels to the each SUs in the different cluster groups. Besides, a cluster center (CC) is identified among SUs within each cluster group and it performs subchannel allocation and power distribution function for the cluster members (CMs). Finally, achievable sum rate has been reported to the FC. Hence, it guarantees the best cluster configuration yielding the highest sum rate in the CR network. All possible clustering configurations could be found for a given number of SUs, by means of exhaustive search. With help of subchannel allocation and power distribution, the cluster configuration yields the highest system capacity. Therefore, the number of possible cluster configurations increase grows exponentially with increasing number of the SUs. Thus, it is difficult to obtain the optimal cluster configuration even for small number of SUs. The main objective of the proposed algorithm is to construct a weighted interference graph $G(V, E, W)$ on the basis of the topology of the CR network. The vertex set is represented by $V = \{v_1, v_2, \ldots\ldots, v_k\}$ where each vertex denotes an SU node and (i, j) ∈ E is the set of edges between two vertices. W is the weight set which contains non-negative weight $w(i, j)$ and every edge (i, j) is represents the interference degree between SU i and SU j. In fact, two SUs are severely interfering to each other if they have high channel gain $g^n(i, j)$ between each other. Therefore, after obtaining an interference graph, the SUs should be assigned to disjoint clusters based on the weighted interference graph. Hence, as mentioned above that, the number of clusters and the cluster size are important parameters to make a trade-off between the available spectrum and the co-tier interference. Our proposed clustering scheme can change the number of clusters and cluster size as the SU density differs, which outperforms some traditional clustering algorithms based on a given number of clusters. The optimal clustering problem can be formulated for a given weighted interference graph G(V,E,W) with K SUs and the edge weight $w(i, j)$ for each edge (v_i, v_j). Therefore, it is givens as

$$C1 : \sum_{m=1}^{N_c} C_m = V \qquad \text{--- (7)}$$

$$C2 : C_m \cap C_n = \phi, m, n \in 1, 2, \ldots.., N_C$$

where N_C is the number of clusters. The weighted interference graph is obtained by setting the set of initial values of CCs will be selected accordingly. The rest SUs are then attached to their $c_1, c_2, \ldots\ldots, c_{N_C}$ own clusters as CMs. An SU x belongs to cluster i when $w(x, i) > w(x, j), i \neq j$ where $w(x, i), w(x, j)$ indicate the interference degree between SU x and CC i, SU x and CC j, respectively. Regular interval, update the CCs by

$$c_j = \frac{1}{|C_j|} \sum_{k \in C_j} P_k, j = 1, 2, \ldots., N_C \qquad \text{--- (8)}$$

where P_k represents the position of SU k in the weighted interference graph. The complexity of the proposed clustering algorithm can be controlled by setting the number of maximum iterations and the average interference degree of the CR network. Furthermore, the FC can be equipped with power computing capacity, the proposed clustering scheme is practical for applications.

IV. SUBCHANNEL ALLOCATION SCHEME

Once the clustering results shown, the reference user and the interference threshold of each cluster can be obtained by using equation (4) and (5). Based on the assumption on the cotier interference, the resource allocation for each cluster is independent of the other clusters. The sum rate of all SUs are maximized within each cluster while keeping the interference to each PU below its predefined threshold. The proposed subchannel allocation method to remove the integer constraints, by considering both SNR of a subchannel and the interference introduced to PUs in the OFDM-based CR network. Therefore, each subchannel can be allocated to only one user in which they can achieve the highest possible rate among all available subchannels. The procedure is repeated until all subchannels are consumed. The set of subchannels allocated to SU k is denoted as Ωk. The highest achievable rate of subchannel n for SU k is given by

$$r^M(k, n) = \frac{B}{N} \log_2 \left(1 + p^M(k, n) \times h(k, n)\right) \qquad \text{--- (9)}$$

where $p^M(k, n)$ is the maximum power allocated to subchannel n for SU k.

$$p^M(k, n) = \min(P_T, \min_{l \in L}(\frac{I^{th}_{PUm}}{\tilde{h}(k, n)})) \qquad \text{--- (10)}$$

we can see that the constraints C2 and C3 in (7) are satisfied in (10), which means the power on subchannel n is always bounded by the power constraint P_T and the interference constraints laid by the PUs.

A. Fast Optimal Power Allocation

In this subsection, the optimization problem is associated with power allocation starigties in all CR networks. For a given subchannel assignment, the constraints C4 and C6 in (7) vanish. Such kind of problem can be solved by standard convex optimization techniques which includes barrier method. However, this method has high computational complexity due to Newton iteration step involved in the barrier method. It needs matrix inversion with a complexity of O(N3), where the number of subchannels N is always several thousand in practical systems. Thus, to develop an efficient fast barrier method by exploiting the structure of (12) to calculate Newton step. The barrier function of (12) is

$$f(P) = \sum_{k \in C_m} \sum_{n \in \Omega_k} \frac{B}{N} \log_2\left(1 + p(k,n) \times h(k,n)\right) \quad \text{--- (11)}$$

Then, by introducing a logarithmic barrier function with a parameter t, the optimal solution of (12) can be approximated by solving the following unconstrained minimization problem

$$\min \psi_t(P) = -tf(P) + \phi(P) \quad \text{--- (12)}$$

Newton step at P, denoted by ΔP_{nt}, is given by

$$\nabla^2 \psi_t(P) \Delta P_{nt} = -\nabla \psi_t(P) \quad \text{--- (13)}$$

where $\nabla^2 \psi_t(P)$ is the Hessian and $\nabla \psi_t(P)$ is the gradient of $\psi_t(P)$, respectively.

V. RESULT AND SIMULATION

The performance of the proposed clustering based resource allocation algorithm is evaluated with a series of numerical experiments. Let us consider 100 secondary users (SUs) which are randomly located in a 3×3 km area. Each SUs occupies random bandwidth which is uniformly distributed in the circle within 0.5 km from its transmitter. Initially, the simulation parameter values are set to, noise power is 10−13 W, interference threshold of all PUs are 5 × 10−13 W, the channel allowable path loss exponent is 4 and minimal rate requirement of SUs is 20 bits/symbol. The variance of logarithmic normal shadow fading is 10 dB and the amplitude of multipath fading is Rayleigh. The proposed clustering algorithm result has been shown in the Fig.5.1. In which five different clustering groups are formed and each group have 20 SUs and 1 PU in the system.

It has been concluded that proposed clustering algorithm is reasonable for investigating the computational load lies in the Newton step. Fig. 5.2 (a) and (b) shows the Cumulative Distribution Function (CDF) of the number of Newton iterations of proposed method for convergence in 100 random instances with different settings of N, respectively. As a result convey that the number of Newton iterations is not large with given N which indicating proposed method is very efficient. Fig. 5.3 shows the average sum rate of SUs as a function of Ith with different setting of Nc and other clustering algorithms including CSth- based clustering algorithm developed and classical K means algorithm with Nc = 5. There are 32 subchannels with the total transmission power limit PT = 1W. In the CSth-based clustering algorithm, clustering head is first elected with given cluster size threshold and then cluster formation followed step by step based on the interference degree. From the result given in Fig.5.3 deals with the mutual interference between any two SUs and also made the tradeoff between spectrum sharing among different clusters.

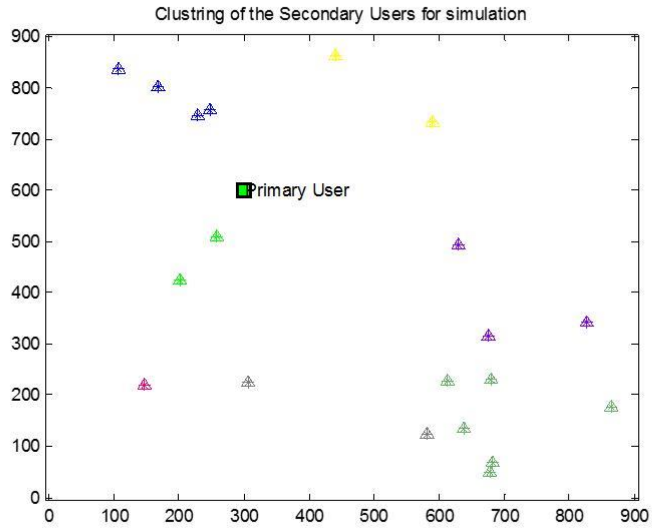
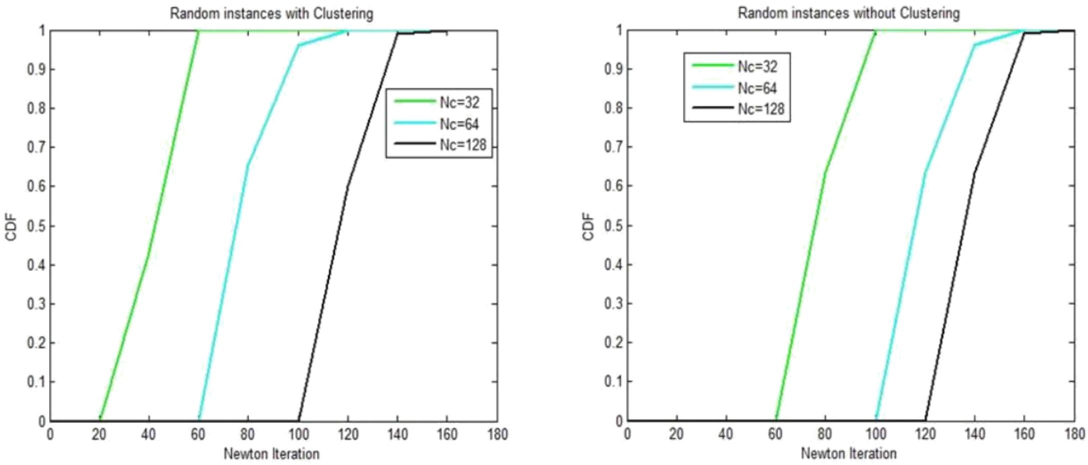


Fig.5.1 Results of the proposed clustering algorithm. K = 20; N = 32; L =1.

Besides, the sum rate of the each clusters are increases by increasing the number of clusters size, because the whole subchannels can be used within each cluster on the assumption that there is no co-tier interference among clusters and the high frequency reuse leads to high system throughput.

Fig. 5.5 and Fig. 5.6 shows the result of proposed method for average sum rate as a function of the number of subchannels and the transmission power limit obtained for different number of Nc, respectively. Here, two clustering algorithms for compared which includes CSth-based clustering algorithm and the classic K-means algorithm with Nc = 5. In Fig. 5.5, shows the average sum rate of the SUs increases as the number of subchannels increases due to channel diversity in wireless environment. In Fig. 5.6, the sum rate of the SUs increases with the increase of the transmission power limit, this is because more power can be consumed to increase the transmission rate with the growth of transmission power limit.

However, as can be seen from Fig. 5.6, the increase of sum rate slows down with the continuous growth of transmission power limit (PT > 2 W), the reason is that the interference threshold limits the maximum transmission power of the SUs, which results the sum rate of SUs eventually. Besides, it can be also seen from both Fig. 5.5 and Fig. 5.6 that the sum rate increases with the increase of the number of clusters. It is intuitive because more clusters lead to higher area spectrum efficiency, which will finally increase the transmission rate of the SUs.



(a) (b)

Fig.5.2 CDF of Newton Iterations. (a) With clustering (b) Without clustering

Table.1 Comparison of Average sum rate with a function of Interference Threshold Ith. N =32, L = 1 and K = 20.

S. No	Interference Threshold	Sum of Rate (Mbps)					
		Without Clustering	K-Mean Algorithm	CS th Based Algorithm	Nc=5	Nc=10	Nc=20
1.	10^{-15}	610	834	925	1130	1200	1350
2.	10^{-14}	788	960	980	1175	1230	1350
3.	10^{-13}	810	980	1180	1232	1370	1440
4.	10^{-12}	820	1020	1185	1250	1380	1510
5.	10^{-11}	850	1060	1210	1360	1410	1590

Table. 2 Comparison of Average sum rate with a function of Number of subchannels with K = 20, L = 1 & PT = 1W.

S. No	Number of Subchannels	Sum of Rate (Mbps)					
		Without Clustering	K-Mean Algorithm	CS th Based Algorithm	Nc=5	Nc=10	Nc=20
1.	20	500	570	620	670	685	695
2.	40	1000	1120	1450	1630	1820	2300
3.	60	1620	1725	2230	2420	2630	2870
4.	80	2125	2360	2620	2875	3250	3480
5.	100	2500	2670	2930	3260	3470	3860
6.	120	2320	3100	3420	3490	3620	3980

Table. 3 Comparison of Average sum rate with a function of Transmission Power Limit with K = 20; L = 1 & N = 32.

S. No	Transmission Power Limit	Sum of Rate (Mbps)					
		Without Clustering	K-Mean Algorithm	CS th Based Algorithm	Nc=5	Nc=10	Nc=20
1.	0.005	210	260	320	340	350	375
2.	0.01	216	263	326	345	358	382
3.	0.05	220	265	328	348	368	426
4.	0.1	372	376	382	386	438	606
5.	0.5	465	480	520	580	610	758
6.	1	770	780	870	960	980	1120
7.	2	1018	1026	1086	1560	1685	1725
8.	4	1425	1560	1600	1780	1800	1830
9.	10	1580	1595	1640	1880	1920	2000

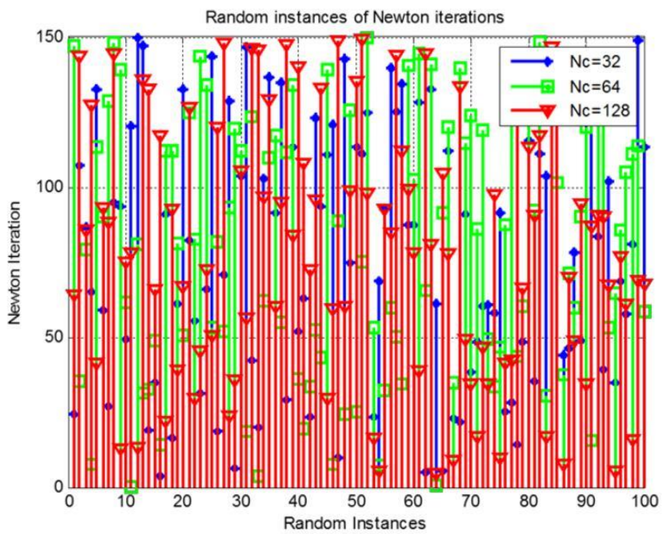


Fig.5.3 Random instances of Newton iterations. N = 32 and PT = 1W.

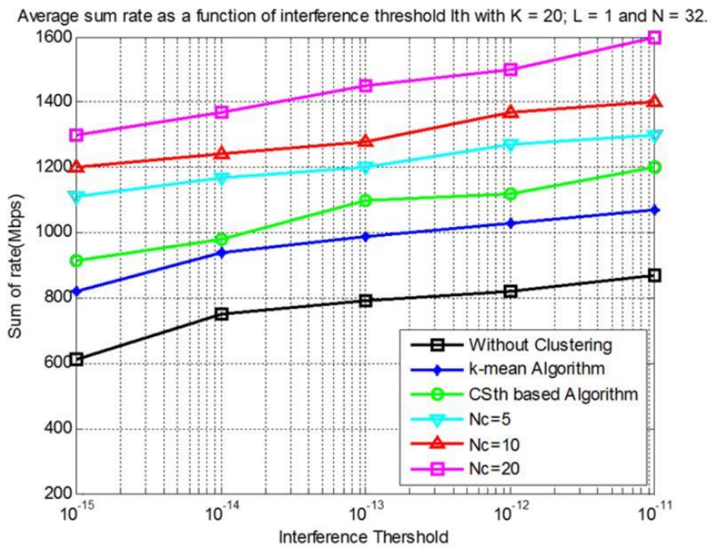


Fig.5.4 Average sum rate as a function of interference threshold Ith. N =32, L = 1 and K = 20.

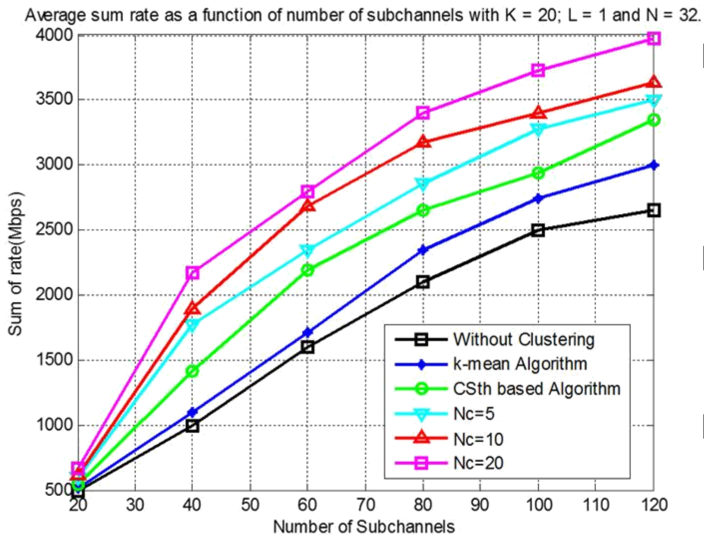


Fig.5.5. Average sum rate as a function of number of subchannels with K = 20, L = 1 & PT = 1W.

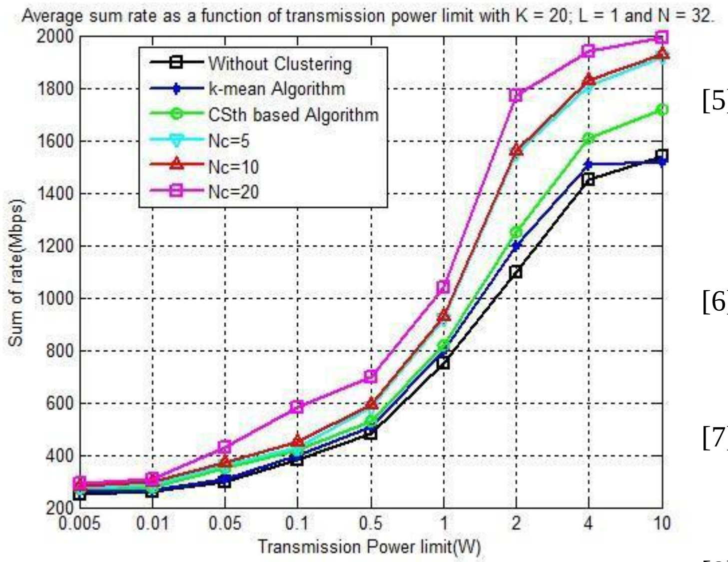


Fig.5.6 Average sum rate as a function of transmission power limit with K = 20; L = 1 & N = 32.

VI. CONCLUSION

The clustering-based resource allocation (RA) method is presented for an OFDM-based cognitive radio network. The sum rate of all SUs is maximized by reducing the interference among the PUs and SUs below their tolerable thresholds. SUs are grouped into different cluster group based on their interference. Due to minimum interference, the different groups can share the same sub channels to improve the spectrum utilization efficiency. Then, the subchannel assignment method is proposed where the cluster center in each cluster performs subchannel and power allocation for the SUs in the cluster. The proposed method has reduced the integer constraints problem in the resource allocation and computational complexity problem is also minimized in the optimal power distribution. Simulation results convey that the proposed method has higher system capacity compared to other methods.

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