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Research Article

CLUSTERING BASED RESOURCE ALLOCATION FOR OFDM BASED COGNITIVE RADIO NETWORKS

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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, energy 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 subchannels 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 existing approaches. Moreover, our proposed RA algorithm converges stably and quickly.

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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 to access 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 (C.-X. Wang *et.al*, 2014). 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 associated with 4G network in terms of multiform applications, huge numbers of subscribers, increased indoor traffic, massive power consumption and faster Internet access on the move (J. G. Andrews, *et.al*, 2014). This kind of limitations may overcome in Fifth generation (5G) mobile communication systems. 5G is envisioned to provide the platform to connect miscellaneous devices to the internet, thus, supporting the IoTs with a massive reduction in round trip latency and energy consumption. In general, mobile network architectures are classified into two types such as heterogeneous networks (HetNets), cloud radio access networks (C. Ran, *et.al*, 2015). The cognitive radio provides the normal solution to waste of spectrum resources and improve the spectrum utilization efficiency due to the scarcity of resources. 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 (D. Lopez-Perez, *et.al*, 2011). A 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 (E. Axell *et.al*, 2012, G. Wang *et.al*, 2015). 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 (G. Ding *et.al*, 2014S. Haykin *et.al*, 2005). It includes both SUs and PUs performance-guaranteed services under consideration of all practical limitations. The Fusion centre can manage the transmission of the SUs and exchange signalling information with the access nodes in the primary network. With help of reliable spectrum sensing, the SUs can access vacant spectrum for data transmission. However, as the number of subscribers increases, it is a big challenge to serve more and more SUs with limited vacant spectrum in the CR system (S. Lien *et.al*, 2014, B. Wang *et.al*,

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2011). 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 (R. Zhang *et.al*, 2010).

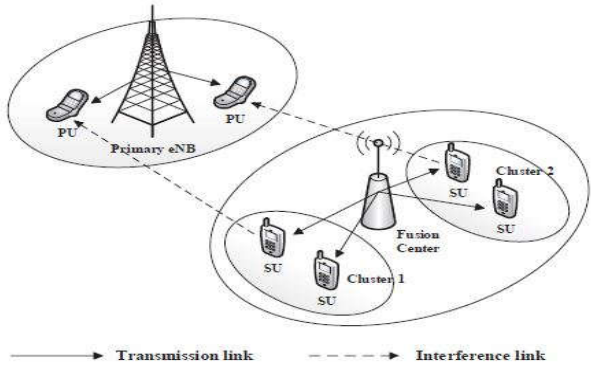

Fig 1 Illustration of System Model

Actually, it is due to improper estimation of the radio environment where cognitive procedure not properly performed. As a result, wrong spectrum sensing degrades the performance of both the CR network and users significantly (Karaputugala Madushan Thilina, *et.al*, 2013). 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 deployment.

The objective of this paper is to address the interference issues associated with SU's using two-stage procedure in the OFDM based CR network. That is, clustering and radio resource allocation are the two techniques to be implemented in the proposed scheme. A clustering technique is used to tackle the interference among the SUs by coordinating their transmissions. Then, the SU's with 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 linear complexity.

The rest of the paper is organized as follows. In Section II illustrate the system model, interference model and the formulation of the proposed scheme in the optimization task are illustrated in section II. 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.

System Model

There are many clustering-based interference management techniques are available in the market for proper data transmission in the cellular systems. However, these principles cannot be 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 designed for the critical coverage requirement. But, CR system need not require seamless coverage for the SUs who request data transmission. Therefore, it is necessary to design a proper clustering method to enhance the performance of the SUs in CR system. As a result, an efficient clustering and RA algorithm is a promising approach to improve the performance of the CR networks, which is the motivation of this work.

Network Model

Consider a multiuser OFDM-based CR network shown in Fig.1 which 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 help 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 sub channels is denoted by $N=\{1,2,.....,n\}$. The signal-to-interference-plus-noise (SINR) of the k^{th} SU on the nth OFDM sub channel with unit power as $h(k,n)$

$$h(k,n)=\frac{g(k,n)}{\Gamma\left(\frac{N_0 B}{N}+\sum_{l=1}^{L} I_l^{PS}(k,n)\right)} \quad \text{--- (1)}$$

where $I_l^{PS}(k,n)$ is the interference of the k^{th}SU on the nth OFDM sub channel by the l^{th} PU with $N0$ is noise power of each sub channel, $g(k,n)$ is the power gain of the kth SU on the n^{th} OFDM sub channel 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 k^{th} SU on the nth subchannel. Denote R_k as the sum rate of the k^{th}SU,

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

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

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 sub channels are 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.

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

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 beyond given threshold $I_{PU_m}^{th}$. That is,

$$I_{PU_m}^{th} = I^{th}.\left|C_m\right| \quad \text{--- (5)}$$

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

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

Where, $R_{\min}$ is the minimal rate constraint of the SUs in each cluster. $\rho(k,n)$ represents whether the nth subchannel is occupied by the k^{th} 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 SUs. C2 is the power constraints. C3 is the interference constraint for each cluster, which enforces that the total received interference at $PU_{Max} \leq I_{PU_m}^{th}$. C4 is the exclusion constraint, indicating the n^{th}subchannelcan only be occupied by at most one SU in the cluster Cm.

Efficient Clustering Algorithm

An efficient clustering algorithm is introduced to reduce mutual interference among SUs in different cluster groups. The fusion centre gathers information about average channel gains and performs the clustering procedure for all the SUs. Then, cluster configurations can be obtained for group of candidates in the each cluster group. After this, the clustering result has sent through common channels to 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 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 $G(V,E,W)$ based on the topology of the CR network. The vertex set is represented by $V = \{v_1, v_2, ..., v_k\}$ 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, 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 against 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 $\left(v_i, v_j\right)$. Therefore, it is givens as

$$C1:\sum_{m=1}^{N_c} C_m = V$$
$$C2: C_m \cap C_n = \phi, m, n \in 1,2,....., N_c \qquad \text{--- (7)}$$

Where N_c is the number of clusters. The weighted interference graph is obtained by setting the a set of initial values of CCs $c_1, c_2, ..., c_{N_C}$ will be selected accordingly. Then, the rest SUs are attached to their 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

$$c_j = \frac{1}{\left|C_j\right|} \sum k \in C_j \, P_k \, , j = 1,2,...., N_c \qquad \text{--- (8)}$$

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 to obtain improved accuracy and system capacity.

Subchannel Allocation Scheme

Once the clustering results have been shown, the reference user and the interference threshold of each cluster can be obtained by using equations (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.

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

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.

Fast Optimal Power Allocation

In this subsection, the optimization problem is associated with power allocation methods 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 the use of complex processing involved in Newton iteration process. 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

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

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

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

Newton step at P, denoted by ΔPnt, is given by

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

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

RESULTS 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 SU 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 as 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 follows Rayleigh model.

The proposed clustering algorithm result has been shown in the Fig.2. 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 required for the Newton step. Fig. 3 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. It shows that the number of Newton iterations is not large with given N, which indicates that the proposed method is more computationally efficient.

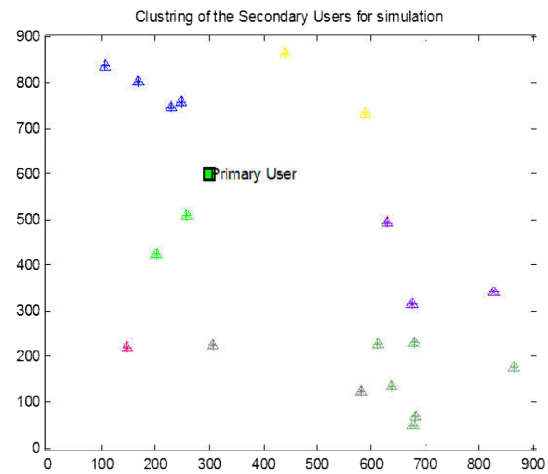

Fig 2 Formation of clustering groupsK = 20;N = 32;L =1.

In the CSth-based clustering algorithm, clustering head is first elected with given cluster size threshold and then cluster formation is followed systematically based on the interference degree. From Fig.4, it is inferred that the mutual interference between any two SUs and also the tradeoff between spectrum sharing among different clusters can be performed efficiently. Besides, the sum rate of the each clusters 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 shows the average sum rate of SUs as a function of interference threshold I_{th} 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.

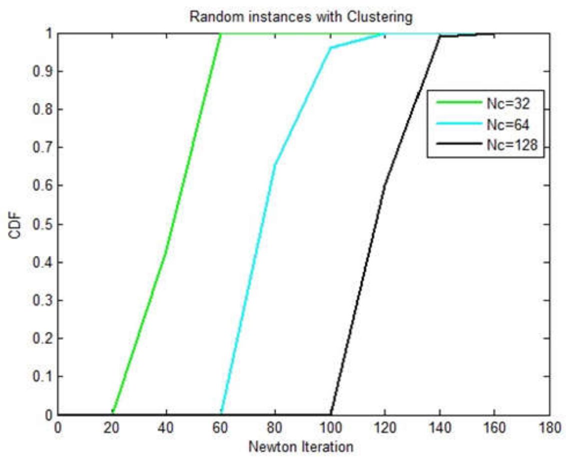

Fig 3 CDF of Newton Iterations with clustering

Fig. 6 and Fig. 7 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 (Lokman Sboui, *et.al*, 2016) and the classic K-means algorithm with Nc = 5(Ryan K *et.al*, 2013). Fig. 6 shows the average sum rate of the SUs increases as the number of subchannels increases due to channel diversity in wireless environment as shown in Fig. 6. From the Fig.7, it is concluded that 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.

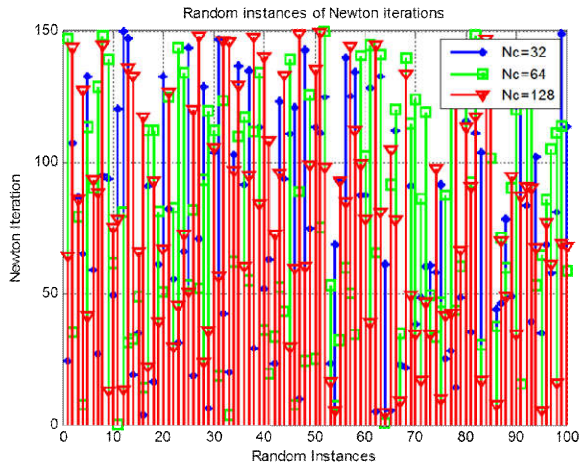

Fig 4 Random instances of Newton iterations N = 32 and PT = 1W.

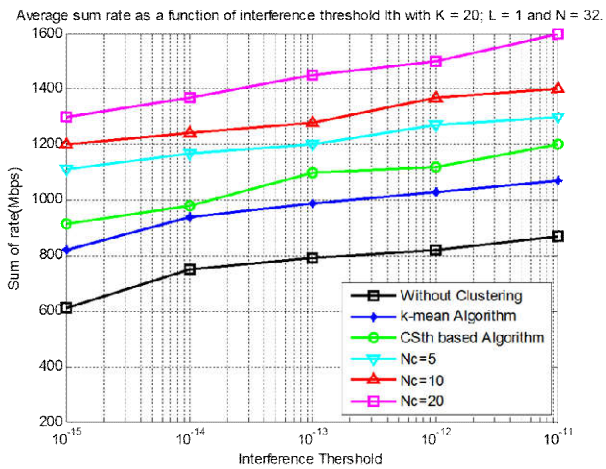

Fig 5 Average sum rate as a function of interference threshold Ith. N =32, L = 1 and K = 20.

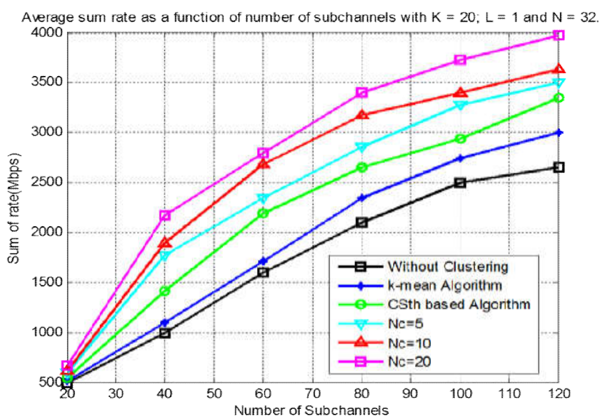

Fig 6 Average sum rate as a function of number of subchannels with K = 20,L = 1 & PT = 1W.

However, as seen in Fig. 7, 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 makes the sum rate of SUs eventually decrease. Besides, it can be also seen from both Fig. 6 and Fig. 7 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.

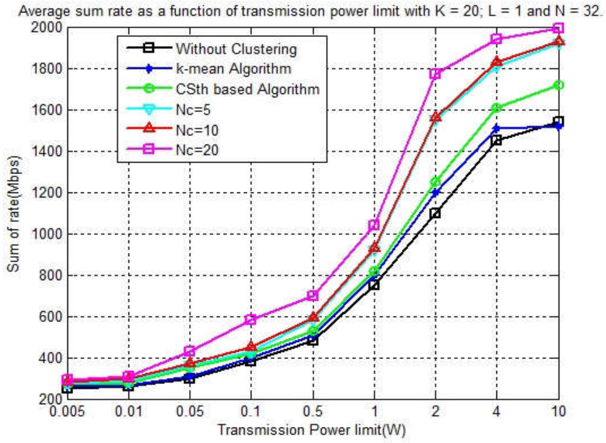

Fig 7 Average sum rate as a function of transmission power limit with K = 20; L = 1 & N = 32.

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 level. The different cluster groups can share the same subchannels to improve the spectrum utilization efficiency due to minimum interference. Then, the subchannel assignment method is proposed to provide optimization between sum rate and energy efficiency. Furthermore, resource allocation algorithm is implemented in each group to maximize the sum rate of the SUs in each cluster considering interference threshold limit. We showed that the proposed scheme improves the sum rate of all SUs in each group significantly, while maintaining the co tier interference below the threshold value compared to existing approaches.

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