Coordinated Cognitive Tethering over TV White-Spaces Considering Co-Channel interference in Dense Wireless Areas

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***Abstract*—Enormous number of people use their smart phones and tablets to share photos, upload videos or send messages and download other information. These activities creates traffic load with lack of efficient spectrum utilization especially in dense areas. This paper investigates the performance gain that can be achieved by introducing a hotspot-slave configuration of nodes in densely populated areas. The proposed algorithm aims to maximize spectrum efficacy by iteratively clustering the nodes into hotspots and slaves and allocating resources. This approach does not require any additional infrastructure. Simulation results show that the proposed algorithm can significantly enhance the overall performance of the network by five times as compared to direct connection between the nodes and the base station, hence increasing the capacity of the cell.**

***Index Terms*—TV White-Space; LTE; Clustering; SINR; Interference; relaying**

I. Introduction

Nowadays the demand for ubiquitous access to wireless data anywhere and at anytime becomes increasingly important due to the increase of wireless technology and smart devices. This seems obvious in the dense areas such as sports stadiums, concert halls and conference halls. One traditional approach in dense wireless areas has been the deployment of more base stations (BSs), but that requires cell planning and site acquisition [1] and thus increase complexity and cost. Nowadays, The popularity of smart-devices has created the require for ubiquitous access to wireless networks.

One solution is to employ advanced physical layer technologies to increase the spectral efficiency. Even though this solution is still not sufficient in todays massive demand. Study in [2] investigates how the performance of physical layer is oncoming its theoretical limits. Authors in [3] have proposed an algorithm using clustering method without using any additional LTE and TV white space (TVWS) resources dynamically with the aim of minimizing total network transmission power and number of restricted users.

However, they don't consider co-channel interference between different macro-cells in their research. In [4] presented a inclusive survey of multiple proposed clustering methods for Mobile Ad Hoc Networks (MANET), these schemes have been classified and analyzed based on their major objectives. In [5] Ryu and et al.. have proposed algorithm of clustering scheme for energy saving. This algorithm is in some way related to the proposed algorithm in this paper since it concentrates on minimizing the transmission power in each cluster to accomplish a better performance with longer battery lifetime. Moreover, every node is either considered as a master (cluster-head) or as a slave which means a node can connect to only one master node without any direct link between slaves. In [6], [7] an on demand weighted clustering algorithm (WCA) is developed.

This paper has developed new clustering algorithm for LTE networking. The proposed algorithm can improve the LTE networks capacity by using the TVWS to join new users to the network. The solution results show that the proposed a method achieve capacity gain by 84% compared to the standard LTE system. In addition the proposed algorithm doesnt need any additional infrastructure unlike conditional approaches such as deploying femto-cells and offloading traffic over WiFi which can solve lack of spectrum problem, but that needs fixed deployments. Moreover, this paper proposes utilizing unlicensed and unused locally available TV white-space (TVWS) spectrum which characterized by higher bandwidths, lower frequencies and low cost [8], [9] Spectrum sensing is one of the challenges for TVWS. A number of challenges emerge when the SNR (Signal to noise ratio) is as low as -20 dB. It becomes unreliable and impractical to utilize coherent techniques and implement signature sequence acquisition. Other major challenges of white space is its variation across space and time. More specifically, the available channels are not contiguous and may vary from one location to another. Managing interference between nodes of the same network is a difficult problem and becomes a challenging job when these TVBD belongs to heterogeneous networks of different air interface. Authors in [10] proposed using cellular-based TVWS in their algorithm. A cellular-based device is allowed to use both TVWS and another cellular band by just changing its frequency of operation when required.

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Tethering (relaying) is commonly known technique used in WiFi. It is a method of delivering data to a destination node through an intermediate node (hotspot). Our proposed algorithm uses this technique with mobile devices that lets a hotspot with cellular access to act as a relay base station and to supply broadband access to nearby users (slaves). In addition the proposed algorithm tries to provide full connectivity by coordinating users, managing interference and electing hotspots systematically. This configuration creates a two sets of non-overlapping spectra which is required to eliminate interference between BS-hotspot links and hotspot-slave links. The link between hotspot-slave operates over TV white space band. Tethering is not a new idea, Authors in [11] investigated this technique in an ad-hoc approach over unlicensed bands and it is not focusing on relaying data over inactive nodes to send it for active nodes. This method does not let more than one slave per hotspot and does not focus on spectrum reuse. Furthermore, adding another spectrum can obtain performance gain by adding a TV white space to the LTE band has been investigated in [12]. In [13] tethering over TV white-space with cellular based access method in a dense wireless areas has been studied and an algorithm has been proposed that forms hotspot-slave configuration. In [14] authors proposed iCaRA algorithm to meet user demands in densely populated areas by using hotspot-slave mode and also utilizing white-spaces (WS) band for data offload with re-using resources among clusters. In [15] a new method called the QoS is proposed for operator-controlled, QoS-Aware Tethering in a Heterogeneous Wireless Network (QTHN) using LTE and TVWS to develop QoS for Best Effort users and Constant Bit Rate (CBR). Study in[16] presented a three major challenges like mobility management, interference and offloading which are also compared between the access types of femtocells in case of dense wireless areas. Paper in [17] proposed a new dynamic clustering approach which takes into account, the likely changes in the cells. They studied the performance of the proposed protocol by modeling different network scenarios and computing the essential number of handovers as a role of user mobility, availability of network resources and data rate requirements for nodes arranged into given cluster [14]. Paper in [18] discussed how to resolve the congestion problems in a HetNet by dynamically formed new clusters through proposed Distributed dynamic load balancing (DDLB) cellular-based device that can operate on both LTE and TVWS by simply switching its frequency when necessary.

The rest of paper organized as follows Section II describes the system model. Section III presents the proposed algorithm. Simulation results are shown in Section IV. Conclusions are presented in Section V.

II. SYSTEM MODEL

This paper proposes a concept in which a mobile node (hotspot) refers to a mobile device that can connect with BS directly and then relay (tether) the downlink and uplink data rate with its own data rate by aggregating both the signal to other nodes (slaves) if any, when communicating with the base station. Also, slaves refer to mobile devices that communicate with BS through the hotspot. This configuration is depicted in Figure 1.

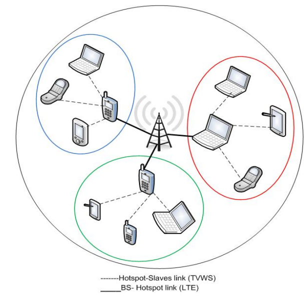

Fig. 1. Clusters configuration formed in a macro cell.

Assume a cellular network with four hexagonal macro-cells in which the radius equals 100m for each macro cell. There are U active number of users randomly and uniformly distributed within the cells and need to communicate with their own base station (BS). Each node $u \in U = \{1, 2, ..., U\}$ can act either as a hotspot or slave and this role can be changed according to the network conditions. The hotspot communicate directly to the BS in a Direct Mode and the slaves connect to the BS via hotspot (Relay Mode) as depicted in Figure 1. Let the set of hotspots denoted by H and the set of slaves is denoted by S, such that $S \cup H = UandS \cap H = \phi$. This configuration produces non-overlapping two layer transmission scheme, where the first layer is the BS-hotspot links which provides the required data to the hotspots and the second layer is the hotspot-slave links. Moreover, the first layer perform as wireless network backhaul for all the hotspots and slaves. In the first layer there are L number of licensed band (LTE) available channels that can be used by the nodes which are directly connected to the base station (BS). On the other hand, there are W white space channels that can be used in the second layer connections. The number of TVWS channels can be only one channel in some regions. We consider a similar environment as in downtown San Francisco[10], where the BS can operate on TVWS channel 26 (frequency band 542 - 548MHz). It is also assumed that each node can support both LTE and the TVWS bands with same cellular access technology. Resource allocation is based on resource block groups (RBG) of an LTE network [19]. The set of available channels can be allocated to each cluster with a constraint that it may create negligible interference on other clusters. Each user can be allocated one resource block (RB) (180 kHz). Moreover, each BS may use all available RBs as long as there is no interference to users in adjacent cells.

The proposed algorithm can be adapted to any locally available under-utilized spectrum this spectrum can be identified through sensing or accessing a database of incumbents.

III. PROPOSED ALGORITHM

This proposed algorithm depicted in Figure 2 starts with distributing users randomly (uniform) in the four macro-cells. Then K mean clustering is used to make clusters according to shortest distance. After that, the power of each user when communicating to BS directly or through hotspot. Resource Allocation is done by assigning RBs to direct users, hotspot users and slave users. This provides power and rate of all types of nodes. Then, finding the co-channel users among different clusters and checking the feasibility of their power vectors based on power control algorithm to achieve minimum SINR. For those which the solution is not feasible, their power is calculated until their solution gets feasible. Then re-clustering is done by applying K-mean until all the slave users gets the desired throughput. These steps are repeated for all users in the four macros cells to calculate the power vector for checking feasibility solution. Flowchart depicted in figure 2 shows the proposed algorithm.

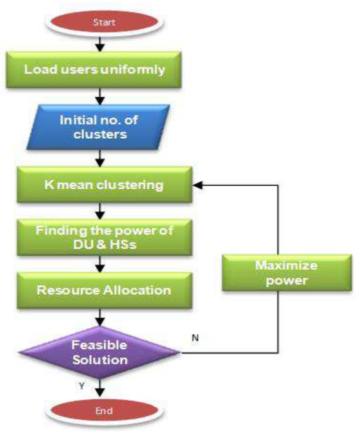

Fig. 2. Proposed Algorithm.

The algorithm steps can be summarized as follows:

A. Step 1 - Load users coordinates randomly (uniform)

After designing the four hexagonal macro cells using area formula:

$$S = 3\frac{\sqrt{3}}{2}R^2 \quad (1)$$

Where, radius R $\bar{1}$00m. We distribute the user coordinates randomly and uniformly inside these macro cells. The macro cells are placed close to each other whereas the BS is placed at the center of each macro cell. The algorithm calculates the distance between the users and their BS using a Euclidian distance equation which is given below.

$$d = ||x_i - x_c||^2 \quad (2)$$

Where d is the Euclidian distance, x_i is the coordinates of each users and is the center of a macro cell.

B. Step 2 - Clustering: K-means clustering

This step is performed centrally by the BS. The task consists of clustering the nodes into groups based on their relative distances. The aim of this step is to group the neighboring users together, hence the communication among the nodes (hotspot and slave) occurs over shorter distances. There are many clustering methods that differ in immediate purpose and complexity. In this paper we performed clustering by a K-means clustering algorithm [20]. K-means clustering algorithm is a well-known technique in data-mining for partitioning data into K clusters based on a similarity metric which is the distance between the data point and the cluster. K-means clustering in this research has been applied due to its low computational complexity. The parameter W determines the number of white space channels and each user gets one Resource Block. If the number of users per cell is N and Number of clusters is C. Then (C = N/W). The K-means clustering algorithm is given as follows [21].

Algorithm 1 steps for K-Means clustering:

Initialize:
$t \leftarrow 1$
randomly select cluster centers:
$x_c^{(1)} \in [0, P], c \in \{1, ..., C\}$
Repeat:
Cluster Assignment: Assign each node $n \in 1, ..., N$ to cluster c, by solving problem (1) given $X_c^{(t)}$
Cluster Update: Compute $X_c^{(t+1)}$ as the mean of the Location of all points assigned to cluster c
Until $X_c^{(t+1)} = X_c^{(t)}, \forall c$

C. Step-3: Finding power for direct users and hotspots

The step (2) groups the nodes into C clusters. One simple approach to select the hotspot within each cluster, is to determine the node that is closest on average, to the BS and take into account the transmission power should be nonzero. Otherwise, we cannot assign the node to that base station. Therefore, the cluster heads are elected according to K-mean clustering and power. According to that, clusters are made till all users gets the granted throughput with minimum power. As well, the direct users connected to BS are selected on the basis of power requirement and this transmission power is further dependent upon user distance from BS and co-channel interference if present. In the same way slaves users are connected to the cluster heads. Criteria that should be used to access clustering scenarios/techniques are both mean distance and achieved throughput. To calculate the power we define an individual transmission power as following:

$$P_{tx,i} = A^{-1} * B \quad (3)$$

Where $P_{tx,i}$ is the transmission power of user i , A and B matrices are given by:

$$A = \begin{bmatrix} \frac{1}{a_1 L_{11}} & -\frac{1}{L_{21}} \cdots & -\frac{1}{L_{n1}} \\ -\frac{1}{L_{12}} & \frac{1}{a_2 L_{22}} \ddots & -\frac{1}{L_{n2}} \\ \vdots & & \\ -\frac{1}{L_{1n}} & -\frac{1}{L_{2n}} \cdots & \frac{1}{a_n L_{nn}} \end{bmatrix} \quad (4)$$

Where $a = 0.05$ and L_i is the user path-loss and we calculate the path-loss according to this equation:

$$L_{ji} = r_{ji}^{e} 10^{\frac{ji\xi}{10}} \quad (5)$$

Where e is the path loss exponent and ξji is the shadowing coefficient.

$$B = \begin{bmatrix} N \\ N \\ \vdots \\ N \end{bmatrix} \quad (6)$$

$$P = \begin{bmatrix} P_{tx,1} \\ P_{tx,2} \\ \vdots \\ P_{tx,n} \end{bmatrix} \quad (7)$$

We have to ensure if matrix A is nonsingular . Else, user i will be not allocated to that BS and one component will be taken out from allocation vector and recalculate the power vector again to find a nonzero matrix and then allocate the users to BS.

D. Step-4: Resource Allocation Among the nodes

This step comes after clustering step and finding the power for all direct nodes and hotspots. This step for allocating resource blocks and channel resources to all slaves and hotspots.

1) Resource Allocation among Slaves: : Every hotspot in cluster assigns resource blocks RBs to its slaves, such that each channel is allocated to a single user in a distributed manner based on local channel information [22]. In this approach we allocate separate RBs to each user in each cluster (one user always uses a specific RB on every timeslot). The main propose of this algorithm is to minimize the transmission power of all slaves over all the available channel. Resource allocation in this step is similar to the optimal resource allocation optimization performed in OFDMA systems [23].

2) Resource Allocation among Hotspots:: Resource allocation among hotspots is performed by the BS. The resource allocation in this step is similar to the slaves resource allocation, with a little difference in the rate requirements. The rate requirement R of each hotspot equals to the rate requirement of its own plus the total rate requirement of its slaves. Then we have:

$$R = R_{hc} + \sum_{i \in S_c} R_i \quad (8)$$

Where $R_h c$ is the rate of hotspot h in cluster c, R_i is the rate of users (slaves) and S_c Slaves in cluster c.

In each cell this algorithm allocate separate RBs to each user, same RBs may be reused in cells to increase system capacity. In this step the proposed algorithm calculates the achieved SINR per link according to the following equation:

$$SINR_i = \frac{\frac{P_{tx,i}}{L_{ij}}}{\sum_{k=1,k\neq i}^{n} \frac{P_{tx,k}}{L_{kj}} + N} \quad (9)$$

Where $P_{tx,i}$ is the transmit power of the ith user. L_i is the user i path-loss, j is a hotspot ID, $L_{j,i}$ the path loss between each hotspot j and each user i. N is the total noise ratio, K is the number of users currently being served by that BS. N is the noise power. In the equation(9)the denominator is the term which corresponds to the co-channel interference from the n users in neighboring clusters using the same channel. Calculating throughput of each user has been calculated according to equation (1) as follows:

$$Throughput_i = BW.log_2(1 + SINR_i), i = 1, 2, 3 \quad (10)$$

Where BW is the bandwidth. Throughput varies because of interference and power.

before calculating the SINR, we need to check the feasibility of the solution the proposed algorithm checks the power vector values. If power vector has positive values then solution is feasible. Otherwise it is not feasible. In addition,the SINR should be higher than or at least equals to the minimum required SINR threshold we have initially considered.

IV. SIMULATION RESULTS

A. Simulation Setup

Consider U users that are randomly and uniformly distributed in four hexagons macro cells square area. The base station BS placed at the center of each macro cell and operates on licensed LTE bands for layer-1. Assume the smallest bandwidth that can be allocated to a user is 180KHz. The only one TVWS channel is used in layer-2 between each cluster head and its slaves. In the simulations model, a is set to 0.05 and the simplified pathloss model with pathloss exponent 4 is assumed [24].

$$PL = ED^{ple} \quad (11)$$

Where: PL is path loss, ED : Euclidean distance between the nodes and ple is path loss exponent.

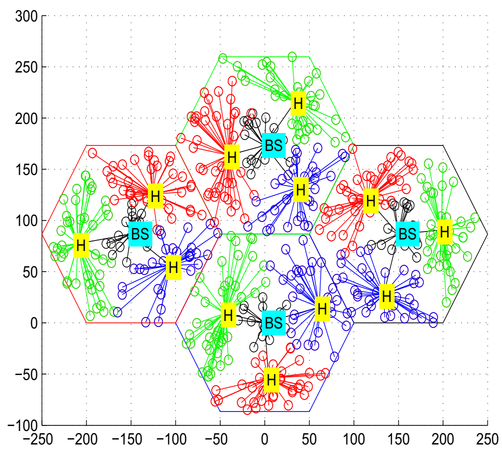

Fig. 4. Relay mode communication

TABLE I
TRANSMISSION POWER IN DM AND RM VS. NUMBER OF USERS

Users no.	Users/cell	DM1	DM2	RM
500	125	13.7%	9.37%	5%
600	150	13.8%	10%	5.6%
700	175	13.18%	10.6%	5.7%

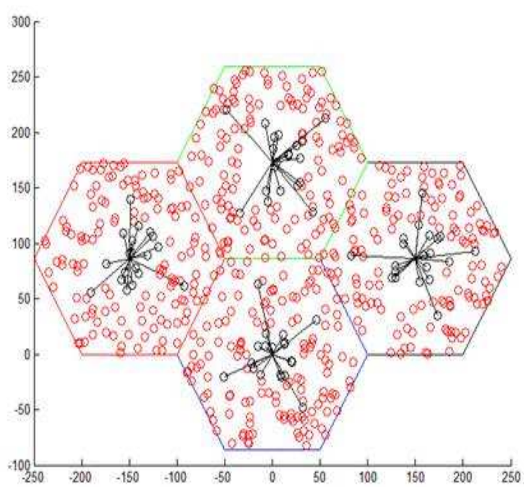

Fig. 3. Direct mode communication

B. Results and Discussion

The performance of the proposed algorithm and the traditional Direct Mode (DM) where the user communicate directly to the BS over the licensed bands have been compared. Moreover, assume that the BS can also connect directly with the users over WS bands in addition to licensed bands. This mode of connection is referred to as DM: licensed + WS. In our case, LTE as a licensed band and TVWS as WS band. Figure 3 shows the four macro cells in the both direct modes communication , DM1: LTE and DM2: LTE + TVWS. Six hundred users distributed among four macro cells. Each cell contains 25% of users. Black points represent the direct nodes where these nodes connect to the BS and the red ones represent the blocked or outage users. Result shows that the number of blocked users is huge in Direct modes compared to the connected ones. 84% are blocked users whereas 16 % are connected users.

Figure 4 shows the same four macro cells after applying the Relay Mode. Results show that our proposed algorithm could solve lack of spectrum problem with low cost of power and complexity. This algorithm perform several iterations of re-clustering until all nodes successfully grants requested resources.

Table 1 summarizes the results of all clusters for multiple simulation runs and shows the power average for both the modes: Direct Mode (DM) and Relay Mode (RM) in 500, 600 and 700 number of users respectively. Results show that increasing the number of users, the total transmission power will be saved by employing proposed Relay Mode RM. Table 2 shows simulation parameters used in this experiment.

The purpose of proposed algorithm is to maximize network spectrum reuse and minimize the total transmission power. Figure 5 shows the comparison between different modes in different number of users in four macro cells. Users have been generated uniformly and equally in each cell. The results show that the power saving is achieved by using Relay Mode operation compared to the Direct Modes DM: LTE which employs LTE band only for a fair comparison in terms of available resources and is assumed that the BS can also communicate directly with the nodes over WSs as well as licensed bands, by employing DM: LTE + TVWS bands during increment in number of users.

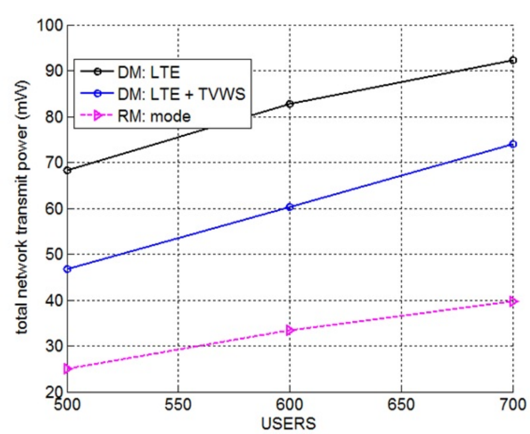

Fig. 5. Transmission power avg. vs. Number of Users

TABLE II
SIMULATION PARAMETERS

Parameter	Value
Cellular layout	4 hexagons grid
Simulation Scenario	Dense urban
Macrocell Radius (Rm)	100 m
Macro BS TX Power	46 dBm = 39.8 watt
Carrier frequency	2 GHz
LTE Bandwidth (MHz)	20 MH
UE distribution	Randomly uniformly distributed
Subcarrier Spacing	15 kHz

V. Conclusion

Nowadays with the extraordinary expansion of mobile technology, the demand for ubiquitous access to wireless data anywhere and at anytime and more spectrum with more efficient methods of utilizing this resource becomes more and more important. This demand is particularly obvious in crowded areas. This paper investigates on clustering users into small cells inside the macro cells and then resource allocation in such densely packed venues. The proposed algorithm in this paper is a promising approach to meet user demands with low cost of power and complexity with no need for additional infrastructures. This algorithm takes advantage of K- mean algorithm to utilize the close proximity of the nodes to generate clusters, in which an elected node serves as a hotspot for others. Moreover, this proposed algorithm takes benefit of the available white-spaces band to offload traffic, and exploits the clustered configuration to reuse frequency and spectrum amongst them. Simulation results show that this algorithm can significantly decrease the total number of blocked users plus the required transmission power when compared to traditional direct mode cellular communication.

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