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Abstract- **In very crowded areas, a large number of LTE users contained in a single cell will try to access services at the same time causing high load on the Base Station (BS). Some users may be blocked from getting their requested services due to this high load. Using a two-hop relay architecture can help in increasing the system capacity, increasing coverage area, decreasing energy consumption, and reducing the BS load. Clustering techniques can be used to configure the nodes in such two-layer topology. This paper proposes a new algorithm for relay selection based on the Basic Sequential Algorithmic Scheme (BSAS) along with power control protocol. The simulation results show that the proposed algorithm has improved system capacity and energy consumption compared to other existing clustering/relaying schemes.**

***Key words*—LTE, clustering, BSAS, frequency reuse.**

I. INTRODUCTION

LTE has been increasingly deployed worldwide to keep pace with the increasing demand of high data rates from a large number of users. As LTE is being widely applied, crowded events such as concerts, conferences, and matches could get congested with massive numbers of LTE users. This congestion in a limited area will cause the Base Station (BS) to be overloaded and thus it will not be able to serve all users successfully. Femto cells [1] and micro cells [2] have been introduced to reduce the burden of the macro cell. However, such solutions require high cost due to the additional infrastructure [3].

This paper aims at providing a way to create small cells called *clusters* inside an LTE macro cell without the need of additional infrastructure. These clusters will be created based on promoting a specific user as a *Cluster-Head* (CH) to act as a temporary (ad-hoc) relay station. This CH will relay all other users' data that are in the same cluster to the BS. These cluster members are called *slaves*.

In this manner, decisions about the specific allocation of users into different clusters is required, and therefore clustering techniques can be applied to create such topology. The allocation of users must also consider appropriate power control and resource allocation in order to mitigate interference and achieve better performance through efficient use of the available spectrum [4]. Thus, clustering techniques should be adjusted to meet these requirements.

Clustering is a broad methodology known as the "division of data into groups of similar objects. Each group, called a cluster, consists of objects that are similar between themselves and dissimilar to objects of other groups" [5]. BSAS (Basic Sequential Algorithmic Scheme) is a sequential clustering approach that is simple, yet efficient. It performs a single pass or very few passes on the data set which make it computationally inexpensive for real time applications.

Following the BSAS clustering approach, nodes are clustered into small groups of slaves and a single CH. Only CHs are directly connected to the base station and act as access points. Each slave node is connected to a CH node and can use it as a relay to send and receive information to the BS. The group of a CH node and its associated slaves is considered a cluster. Proper allocation of CH and slave nodes must be determined to meet the constraint of low power clusters. Transmitting and receiving in such low power clusters will enable reusing the frequency in other clusters without causing significant interference and hence capacity is increased.

II. RELATED WORK

Clustering Techniques are mostly used in data mining and image processing. They are also widely applied in wireless communications. K-means is one of the most popular clustering algorithms. It has been applied in many studies in communications, such as Wireless Sensor Networks (WSN), ad-hoc networks, and LTE networks. A very wide range of studies addressed the use of K-means in WSNs [6-11]. Clustering in WSNs solves problems of lifetime and scalability of the network by preserving energy of sensor nodes. K-means clustering in LTE is used to increase capacity of the network [12]. In this study a two-hop relay system is adopted to generate low power usage clusters. Communications inside the clusters is done through another frequency band (white-space).

Hierarchical Agglomerative Clustering (HAC) has also been applied in wireless networks. Studies [9, 13-15] all applied HAC in WSN clustering. Moreover, a hybrid technique that combines both HAC and K-means advantages can be found in [20]. In this approach HAC is used first to define the total number of clusters. This number is then used as k to run the K-means algorithm.

Some other studies in LTE and cellular networks [3, 16-18] use selection strategies to enable the relaying system rather than clustering. In this manner each node chooses its best relay (i.e. CH) from a predefined pool of candidate relays. The selection can be based on different criteria. Some are based on choosing the relay with least distance while others are based on the minimum path-loss. Using path-loss is better than distance because it gives better estimation of the link quality. These techniques are less complex and more applicable to distributed systems.

When using clustering or relay selection approaches in high density LTE environments, the complexity increases as the number of active users increases. However, it is crucial to work on a time-efficient solution as the topology of the system is very dynamic and changes rapidly. In this paper, a simple relay selection algorithm based on the BSAS clustering scheme is implemented. The algorithm will be modified to accommodate resource allocation and power control specifications.

The rest of the paper is organized as follows. Section 3 explains the system model. The proposed algorithm is defined in Section 4. Simulation setup and results are given in Section 5. Finally, the paper is concluded in Section 6.

III. System Model

The system is composed of an LTE cell and a total of 6 interfering cells. Soft Frequency Reuse (SFR) [19] is assumed where the center region of the cell uses all the available RBs (i.e. 100 RBs), and the edge region of the cell uses $1/3^{rd}$ of the RBs (i.e. 33 RBs). The BS is assumed to be at the center of each cell. A number of n randomly distributed users (or nodes) are assumed to be requesting services at a specific sub-frame duration. The topology of the cell consists of two layers. The first layer has nodes that are directly connected to the BS. The second layer nodes use one of the first layer nodes as a relay to access the BS. This kind of association forms *clusters*. Each cluster has only one *cluster-head* (CH) which is a first layer user and a number of *slaves* that connect to this CH. Each user has a specific SINR requirement (a) depending on the type of service needed and the number of associated slaves. CHs will have an aggregated SINR requirement of all its slaves' SINR requirements. Each connected user will be allocated a single Resource Block (RB) in a single sub-frame. First, the BS will use all the available Resource Blocks. Then, it will start the reuse process. This kind of relay topology is only assumed at the center cell while the other 6 interfering cells are assumed to have conventional LTE with no relays. Figure 1 illustrates the frequency planning of the system. In this case, clustering is applied only on cell number 1 while cells 2-6 will use a conventional LTE system.

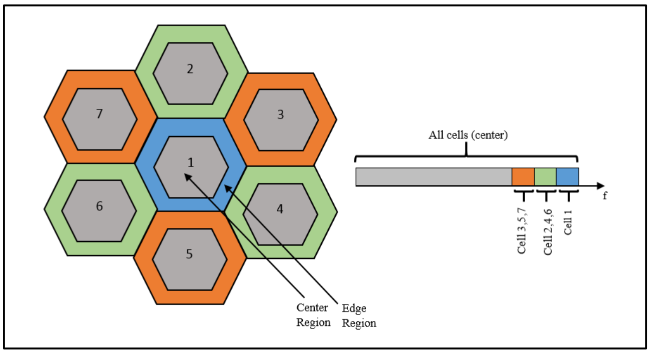

Figure 1. Applied frequency planning in proposed scheme

In order to reuse RBs, it is important to minimize interference so that an acceptable SINR is achieved to ensure QoS. Therefore, power control is applied on all users that access the same RB to adjust their transmission powers so that less interference is caused while at the same time meeting SINR requirements for the requested services. If this is not achieved, then one or more users must change their association. This is evaluated by using a system of linear equations as follows:

From the SINR equation for a node i,

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

where $P_{tx,i}$ is the transmission power of user i, L_{ij} is the path loss between user i and its receiver j, N is the noise, and n is the total number of co-channel users. Assuming a_i as the SINR required threshold, in order to achieve the value of a_i for all users accessing the same RB, a number of equations must be solved:

$$\begin{aligned}
\frac{P_{tx,1}}{a_1 L_{11}} - \frac{P_{tx,2}}{L_{21}} - \frac{P_{tx,3}}{L_{31}} - \cdots - \frac{P_{tx,n}}{L_{n1}} &= N \\
-\frac{P_{tx,1}}{L_{12}} + \frac{P_{tx,2}}{a_2 L_{22}} - \frac{P_{tx,3}}{L_{32}} - \cdots - \frac{P_{tx,n}}{L_{n2}} &= N \\
-\frac{P_{tx,1}}{L_{13}} - \frac{P_{tx,2}}{L_{23}} + \frac{P_{tx,3}}{a_3 L_{33}} - \cdots - \frac{P_{tx,n}}{L_{n3}} &= N \\
&\vdots \\
-\frac{P_{tx,1}}{L_{1n}} - \frac{P_{tx,2}}{L_{2n}} - \frac{P_{tx,3}}{L_{3n}} - \cdots + \frac{P_{tx,n}}{a_n L_{nn}} &= N
\end{aligned} \qquad (2)$$

This linear equation system can be formed as:

(3)

$$\begin{bmatrix} \frac{1}{a_1 L_{11}} & -\frac{1}{L_{21}} & \cdots & -\frac{1}{L_{n1}} \\ -\frac{1}{L_{12}} & +\frac{1}{a_2 L_{22}} & \cdots & -\frac{1}{L_{n2}} \\ \vdots & \vdots & \vdots & \vdots \\ -\frac{1}{L_{1n}} & -\frac{1}{L_{2n}} & \cdots & +\frac{1}{a_n L_{nn}} \end{bmatrix} \begin{bmatrix} P_{tx,1} \\ P_{tx,2} \\ \vdots \\ P_{tx,n} \end{bmatrix} = N \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}$$

Assuming that the matrices are **A**, **P**, and **B** respectively, this can be written as:

$$\boldsymbol{A}.\boldsymbol{P} = \boldsymbol{B} \Leftrightarrow \boldsymbol{P} = \boldsymbol{A}^{-1}\boldsymbol{B} \quad (4)$$

If a solution is not found, then the system with the current number of users accessing the same RB is not achievable and a reduction of this number is needed. A solution is considered acceptable if:

1) The resulting power values in P are greater than or equal to the minimum transmission power of a UE.
2) The resulting power values in P are less than or equal to the maximum transmission power of a UE.

L_{ij} is the path-loss between *i* and *j*. It is calculated based on the log-distance path loss model:

$$L_{ij} = r_{ij}^{e} 10^{\frac{\xi_{ij}}{10}} \quad (5)$$

where *r* is the distance between two nodes *i* and *j* (sender and reciver). *e* is the path-loss exponent, and ξ is the shadowing value between *i* and *j*.

I_i is the interference power caused to node *i*. It is assumed to be the summation of powers of all other signals that use the same RB as node *i*.

$$I_i = \sum_{\substack{k=1 \\ k \neq i}}^{n} \frac{P_{tx,k}}{L_{kj}} \quad (6)$$

This equation is used to compute interference caused to node *i* sending to node *j*, where P_{tx} and *L* are the transmitted power and path-loss of a node *k* using the same RB as node *i*.

Assuming a SINR threshold for a single connection as $SINR_{th}$, a for a CH *j* will be computed as:

$$a_j = cluster\_size_j \times SINR_{th} \quad (7)$$

where *cluster_size* of j is the total number of slaves plus one (for the CH connection).

IV. Proposed Algorithm

The proposed relay selection algorithm is based on the BSAS clustering scheme. In general, this scheme requires two predefined parameters, namely, *q* the maximum allowed number of clusters, and Θ, the dissimilarity threshold. For every new presented data point *x*, the distances between *x* and the already formed clusters *C* are computed to find the minimum distance *d* between *x* and a cluster. If the minimum distance is found to be larger than Θ and the total number of clusters is less than *q*, then *x* is assigned as a new cluster. Otherwise, *x* will join the nearest cluster [20].

The proposed BSAS based algorithm will use path loss as the proximity between a node and formed clusters rather than distance. The basic idea is that each node is assigned either to an existing cluster or to a newly created cluster, depending on its path-loss from the already formed ones. Each node u_i that forms a new cluster will be connected to the BS while a newly joined node will have a relay connection through an already connected node (CH). The decision will be based first on finding the minimum path loss value *S* for node *i*:

$$S_i = arg \min_{all\ ch \in C} \{L_{u_i,ch}\} \quad (8)$$

The value of S_i will be compared against Θ. If it is greater, then the node u_i will be allocated in a new cluster as a CH while the number of clusters doesn't exceed the maximum q. Resource allocation will be attempted in this case for a connection between u_i and the BS. In the other case if the value of S_i is less than or equal to Θ, then the node will try joining a cluster that attain $L_{u_i,ch} =< \Theta$ starting from the clusters that have lower path loss first. For each CH ch_j a node u_i is trying to connect to, several conditions are checked before the allocation is confirmed:

1) The SINR requirement of ch_j is changed to accommodate the added load of the slave (eq. 7). The mathematical system containing ch_j and all its co-channel users will be computed based on the new SINR requirement (eq. 4). If the resulting power vector is acceptable, then continue with following check and store the new power values in *TempUsers.*

2) Based on the location of the node, start trying RBs that are assigned for the node's region. Least reused RBs are attempted first until a connection is confirmed. For every RB r_k, find all co-channel users of r_k both inside and outside the cell. Then construct the mathematical system containing all users of r_k including the node u_i itself (eq. 4). If the resulting power values are acceptable, then the condition is met.

Under the meeting of these conditions having a feasible power vector in both cases, the connection will be confirmed and the new power values will be used for all co-channel users of both ch_j and u_i. This allocation process is shown in detail in the *Resource_Allocation* function. When the *Resource_Allocation* process fails to allocate u_i to ch_j, the next CH with higher path loss will be tested and so on until it succeeds. If, however, it reaches a CH with $L_{u_i,ch} > \Theta$ without success, then the user will be considered blocked. The clustering process is shown in Algorithm 1. It is assumed that users are ordered by their path loss to the BS in the *U* matrix (least first); this gives priority to closer users to the BS to be allocated as CHs. Θ is the maximum accepted path loss between a CH and a slave. Table 1 summarizes the used notations.

Table 1 Summary of notations

Parameter/function	**Description**
M	Total number of resource blocks
$U=\{u_1,u_2,u_3,\ldots,u_{\mathbb{N}}\}$	Set of all requesting users of size ℕ. Each element of U has all user information, including *ID*, *x* and *y* coordinates, *Tx_power*, allocated *RB*, allocated *receiver*, *a*, and *cluster_size*.
$BU=\{b_1,b_2,b_3,\ldots,b_{\lvert BU\rvert}\} \subseteq U$	Set of unallocated users of size |BU|
$AU=\{a_1,a_2,a_3,\ldots,a_{\lvert AU\rvert}\} \subseteq U$	Set of allocated users of size |AU|
$R=\{r_1,r_2,r_3,\ldots,r_M\}$	Set of RBs of size M. Each element of R has the RB *ID*, and a *counter* that determines the number of times the RB is reused.
$C=\{ch_1,ch_2,\ldots,ch_M\} \subseteq U$	Set of cluster heads of size M.
L(a,b)	Finds the path loss between two users a, and b, based on (eq.5)
𝕌	Set of users in all other 6 cells
InnerRegionDistance	The distance of inner region
max_Ptx_UE	Maximum transmission power of a UE
min_Ptx_UE	Minimum transmission power of a UE
Θ	Dissimilarity threshold for determining cluster membership.
Q	Maximum allowed number of clusters
FindCoUsers(U, 𝕌, r);	Finds all users in *U* and *𝕌* that use resource block *r*.
Sort_RBs(R)	Sort RBs in R based on least reuse.
Compute_powers(CoUsers)	Uses the mathematical system (eq. 4) to allocate powers for all users in matrix *CoUsers* that are using the same RB.
Check_CH_requirements(ch);	Check (eq 4) with the new SINR requirement (*a*) of ch.

Algorithm 1 BSAS Based implementation

```
1.  Input: U={u1,u2,…uN};
        R={r1,r2,r3,..,rM}
2.  Initialization: C={ }, AU= { };
        BU←U;
        q=M;        //the maximum no. of clusters (equal to total RBs)
        Θ=value;
// Assign first node u1 as a cluster-head
3.  IsConnected←Resource_Allocation (u1,BS);
4.  IF IsConnected=true,
5.       C←C+u1;
6.       AU←AU+u1;
7.       BU← U- C;
8.  End
9.  For every ui from i=2 to |N|,
10.    C← sort (C,ui);      //ch1 will have the min path loss to ui,eq(7)
11.    IF L(ui, ch1) > Θ AND (|C|< q),
12.        IsConnected←Resource_Allocation(u1,BS);
13.        IF IsConnected=True;
14.            C←C+ui;
15.            AU←AU+ui;
16.            BU← U- C;
17.        End IF
18.    Else
19.        For j←1 to |C|
20.            IF L(chj,ui)> Θ,
21.                Exit for loop(8);
22.            Else
23.                IsConnected←Resource_Allocation(bi , chj)
24.                IF IsConnected=True,
25.                    AU←AU+bi;
26.                    BU← BU – bi;
27.                    Exit for loop(19);
28.                End IF
29.            End IF-Else
30.        End For(19)
31.    End IF-Else
32. End For(9)
33. Return AU, BU;
```

Function
Resource_Allocation (a, b);

```
1.  Input:  a;      //the node trying to be allocated (transmitter)
        b;      //The receiving node (CH/BS)
        InnerRegiondistance;
        R;
        min_Ptx_UE, max_Ptx_UE, U, 𝕌;
2.  Output: isConnected, U, R;
3.  RBCenter={r1,r2,….,r100};
4.  RBedge={r68,r69,….,r100};
5.  IF A is inside center region,
6.      R← RBCenter
7.  Else
8.      R← RBedge
9.  END
10. IF b is a cluster head,
11.     (TempUsers,Accept)←Check_CH_requirements(b);
12. Else
13.     Accept←true;
14. End
15. IF Accept=true,
16.     SortedRBs←Sort_RBs(R);
17.     For each ri in SortedRBs
18.         IF reuse conditions are met for A and ri,
19.             CoUsers←findCoUsers(U, 𝕌, ri);
20.             P←Compute_powers(CoUsers);
21.             IF P< max_Ptx_UE, and P> min_Ptx_UE,
22.                 IsConnected←True;
23.                 Update U;
24.                 Update R;
25.             End
26.         End
```

```
        End
Else
        IsConnected←false;
End
Return IsConnected, U, R;
```

V. Simulation Setup and Results

The simulation environment is composed of a single cell with applied relays, and 6 conventional LTE cells at the first tier. A total of 100 RBs are used at a single sub-frame, and the scheduling requirement will be fixed to 1 RB per user. The simulation is tested for a single sub-frame duration so the actual capacity is 10 times greater than the acquired number. The simulation will be tested for the implemented scheme along with four different situations: LTE standard case where no relays are applied, relaying using a selection scheme where each node selects its best candidate CH based on minimum path loss, K-means-based clustering, and HAC-based clustering. The implementation of these other schemes are as described in [21].

Table 2 Parameters used in simulation

Parameter	Value
q	100
Dissimilarity threshold (Θ)	9e4
Cell radius	100 m
Cell area	31,400 m^2
Effective Bandwidth	18 MHz
Required Throughput	15 Kbps
No. of Resource Blocks	100 at cell center 33 at cell edge
Number of users/sub-frame	150,200,250,300
Number of users/frame	1500,2000,2500,3000
Number of iterations	100
Path-loss exponent	4
Shadowing	3 dB
Position of BS (x,y)	(0,0)
Noise	-121 dBm
$SINR_{th}$/connection	7.2 dB
Inner region distance	56 m
No. of Interfering cells	6
No. of users/interfering cell	56 inner region 44 edge region

The required throughput for a single connection is assumed to be 15 Kbps based on having VoLTE service [22]. CHs will have an aggregated throughput for their slaves' connections; for instance, a CH with two slaves will have a throughput requirement equal to 45 Kbps (holding throughput of both slaves plus its own). Based on this, the SINR threshold a will also be aggregated for a CH as in eq. 7. Moreover, the case of uplink communication is assumed in the simulation. The dissimilarity threshold value is set based on testing the scheme for a range of different values. The best result was obtained by having Θ=9e4.

SFR is used having a total of 100 RBs available at cell

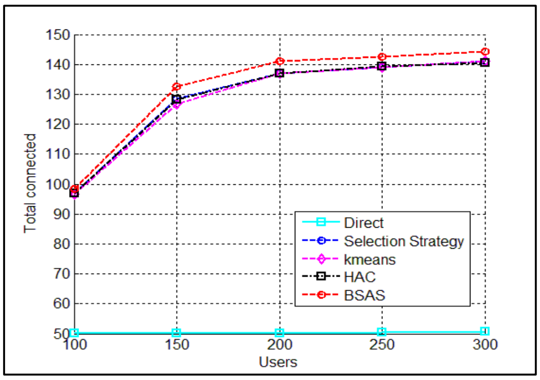

Figure 2. Total connected users vs. no of requesting users

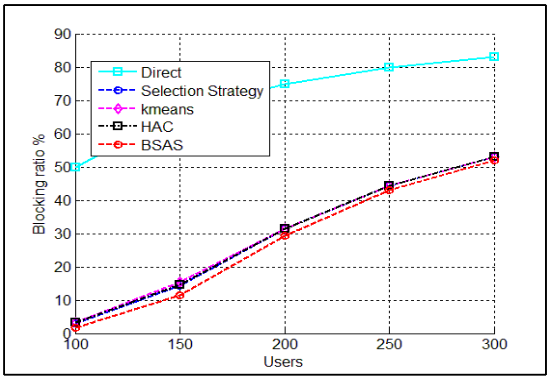

Figure 3. Blocking ratio vs no of users

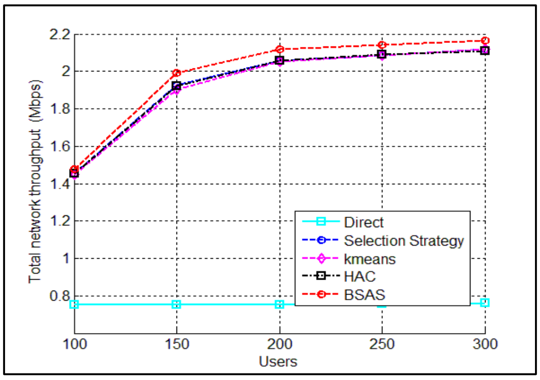

Figure 4. Total throughput vs no of users

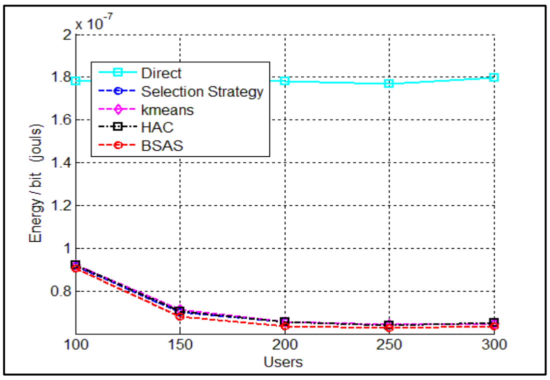

Figure 5. Energy/bit vs no of users

center and 33 RBs available at cell edge. The cell center region has a distance of 56m. Inter-cell interference will consider users at the cell center from all the surrounding cells. Cell center users in each surrounding cell are assumed to be 56.

Users are uniformly distributed in the cell. Different densities of users are assumed ranging between 100 and 300 at a specific sub-frame duration. Users are assumed to have limited mobility due to density. Moreover, the BS is assumed to be the central operator with the ability to store users' information. Simulation parameters are summarized in Table 2.

Figure 2 shows the resulting successful connections for different user densities. As the number of users increases, the total number of connections increases. The proposed algorithm (BSAS in figures) shows a maximum of 145 users compared to 100 in conventional LTE (Direct in graph) and 140 users in all other schemes. This means a 45% enhancement in capacity from conventional LTE and 3.6% enhancement from all other schemes. In terms of blocking ratio as shown in Figure 3, it decreased about 30% from conventional LTE and about 2% from all other schemes. K-means, HAC, and Selection Scheme all show approximate number of connected users here in the case of multi-cell scenario.

In terms of total network throughput (Figure 4), it is shown that the proposed scheme can reach up to 2.2 Mbps compared to 0.8 Mbps in conventional LTE. This translates to 175% enhancement in network throughput from conventional LTE. Also, total network throughput is enhanced from other schemes by 4.8%. Conventional LTE has a fixed total throughput that could not exceed 0.8 Mbps while in relay schemes the total throughput increases with the increase of users or density in the cell.

Figure 5 shows the required energy/bit of the proposed scheme for different user densities compared to all other schemes. The proposed scheme is found to be less in terms of required energy. This adds to its performance as it requires less energy for more acquired throughput. Also, it can be observed that as more users are connected, less energy/bit is consumed. This happens because the CHs will aggregate the transmission of multiple slaves at once.

From all Figures 2-5, it can be noticed that Selection Scheme, K-means, and HAC all have the same performance in the case of multi-cell scenario. The use of clustering schemes such as HAC and K-means show no benefit over the use of selection strategy scheme. This happens because in multi-cell scenarios more limitations exist for the created clusters as inter-cell interference is present resulting in different associations than those already formed by the clusters. All these schemes work by first allocating the CHs then allocating the slaves, whereas the proposed scheme has a different approach where each node could be either assigned as a CH or a slave based on its path loss to existing CHs. Therefore, it shows enhanced results over all other schemes.

VI. Conclusion and Future Work

BSAS clustering technique was adopted in order to investigate relaying through other users in an LTE cell. The nodes are configured into groups; each has one CH and a number of slaves in a two-layer topology. Frequency allocation and power control schemes have been implemented in order to avoid excessive interference. Results show that the proposed scheme improves the capacity of the cell compared to conventional LTE by 45%. The proposed scheme also improves capacity compared to the other existing relaying/clustering schemes by 3.6%. Also, enhancements in blocking ratio, energy consumption, and network throughput are acquired by using the proposed scheme. Future work includes analysis and estimation for the dissimilarity parameter (Θ) based on different user densities and distribution parameters, and the investigation of different frequency planning approaches.

VII. Acknowledgement

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