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User-Centric Based Clustering Scheme and Resource Allocation for Inter-Cell Interference Mitigation in 5G Heterogeneous Networks

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ABSTRACT :*The fifth-generation (5G) mobile communication network is believed to outperform its predecessors in terms of improved: spectral efficiency, throughput, energy efficiency, quality of experience, etc. However, if these gains are to be realized, an inter-cell interference management scheme must be designed to tackle the effect of inter-cell interference which is prevalent in systems using frequency re-use one deployment. In this work, we first design a user-centric based clustering scheme that will help identify the base stations that are providing strong inter-cell interference links to this user, afterward, resource allocation scheme is devised by the user's base station and all the other base stations involved in the clustering to mitigate the inter-cell interference as well as improve the aggregate spectral efficiency of the system. Results obtained show that the aggregate spectral efficiency of the system is improved and the inter-cell interference mitigated when the devised clustering scheme and coordinated beamforming vectors are utilized in the system.*

KEYWORDS ***Clustering, Inter-cell Interference, Resource allocation, User-Centric, 5G***.

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I. INTRODUCTION

The fifth-generation mobile communication network (5G) technologies are believed to address issues such as inadequate capacity, low data rate, decreased latency, poor quality of service/experience, etc. As the deployment of 5G is gradually taking shape all over the world, achieving spectral efficiency and dealing with interference have become one of the greatest challenges encountered. The evolution of 5G demands a significant increase in spectral efficiency compared to the fourth-generation mobile communication network (4G). It is known that the spectral efficiency of a cellular network can be improved by increasing the cell density through cell splitting, however, its achievable gain as stated above would be significantly limited by severe inter-cell interference. 5G architecture is densely heterogeneous: meaning that each macro-cell has small cells underlaid within it. If all the cells use the same frequency resource, there will be a lot of co-tier/inter-cell interference. In a classical/conventional system, interference management is achieved by a dense frequency reuse pattern with the base station having a single-cell processing policy (SCP), meaning that user equipment (UEs) in a cell are served by base stations located at the center of the cell only. Furthermore, base stations are not supposed to take care of the links to and from the neighboring cells which contain inter-cell interference. Inter-cell interference is normally handled by careful frequency planning and allocation. This frequency allocation scheme to each cell and UEs are usually computed and evaluated during the radio planning process and only long-term readjustment is performed during the operation of the network. However, because the need for high-rate wireless communication is ever-growing and due to the scarcity of spectrum in the sub-6 GHz band, Universal frequency reuse has been proposed for LTE-Advanced networks, 5G networks, and future networks. In this context, UEs, whose base stations use a single-cell processing policy will experience strong inter-cell interference from neighboring cells. Particularly, cell-edge UEs or UEs at the cell range expansion area of small cells will receive signals with low signal-to-interference-and-noise-ratio (SINR) and poor quality as a result of signal attenuation from their serving base stations and inter-cell interference from neighboring cells. However, to overcome inter-cell interference, classical mobile communication networks have employed different kinds of techniques: such as dividing the spectrum into different bands so that each cell uses a different radio frequency different from the neighboring cells. We have noticed that such orthogonal deployments improve performance, however, it leads to low spectral efficiency of the system. Inter-cell interference coordination (ICIC) schemes were proposed and introduced in the 4G long term evolution (LTE) systems to deal with inter-cell interference problems and were defined in Release 8. Also, enhanced ICIC (eICIC) schemes defined in Release 10 were also proposed and introduced in the 4G LTE Advanced system to deal with inter-cell interference problems as well. These schemes help to coordinate interference but sacrifice the spectrum. Spectral efficiency is one of the major metrics used to evaluate the performance of present and future-generation mobile communication networks. Hence, it is important to develop schemes that can curb both inter-cell interference and as well improve the system-wide spectral efficiency.

We aim to provide such a solution to the above interference problem by developing a user-centric based dynamic clustering scheme, which can determine the optimum number of base stations (BSs) that are interfering with a particular user at a particular time. When this is determined, the interfered user sends a report containing channel state information (CSI) belonging to all interfering BSs to its serving base station, requesting it to cooperate with these interfering BSs to coordinate their resource allocations (RA) in terms of spatial directions to mitigate the inter-cell interference.

A. PRIOR WORKS

5G heterogeneous networks consist of both the macro base station and the small cell base stations operating together in a single band. This research is aware of a multi-band heterogeneous network with inter-site carrier aggregation, where macro base station and small cell base stations use different bands, in this setting, interference mitigation schemes are not needed, however, it brings about a new challenge, which is, the development of a new type of user equipment (UE) which can have dual access to two different bands. We are rather interested in a 5G heterogeneous network operating in a single-band arrangement. Single band network suggests that the same band (C-band) is used by both the macro base station and the small cells base stations. This idea is not recent since it has been standardized in 3GPP release 10. However, it is important due to the scarcity of spectrum, and because the evolution of new-generation mobile communication such as 5G and beyond 5G (B5G) demands a significant increase in spectral efficiency (SE) compared to the one obtained in the current 4G systems hence the need for the maximization of the single band spectrum. However, this arrangement requires interference management schemes to address the resultant inter-cell interference that will occur. Interference is a limiting factor to the performance of most mobile communication networks including 5G networks [1]. Interference management is one of the most challenging issues facing mobile network operators and if not gotten right can lead to low signal-to-interference-and-noise-ratio (SINR) for UEs and consequently low data rate for the system [2, 3]. Many works have been proposed on how to manage interference from 2G networks up to 5G networks. Classical interference management schemes utilize a single-cell processing policy (SCP) with careful frequency planning to avoid interference, however, this method is statically done and involves a lot of frequency planning before execution. Its limitation is that it sacrifices the spectrum to control interference. Multi-cell processing (MCP) has emerged as an efficient way to suppress interference as well as enhance the SE of the system [4 – 6]. In the MCP, base stations (BSs) cooperate on different levels to manage interference and at the same time improve the individual BSs that form the cluster.

Clusteringis a key technique in MCP because it can help to group specific BSs together to cancel interference and enhance the quality of experience for UEs at the cell edges. User-Centric clustering [7] has been shown to outperform network-centric clustering schemes because it fully considers the channel variations of each UE present in the network while forming clusters. After the clustering scheme has been effected, a proper resource allocation (RA) scheme is needed for the mitigation of the significant intercell interference affecting UEs in each cell. This work adopts coordinated beamforming (CB) [8] which is a type of MCP described in the third-generation partnership project (3GPP) LTE-Advanced. In CB, each BS serves its UE with data while the control information is exchanged between the cooperating BSs that form the cluster, then RA decisions can be made collectively. Previous works on coordinated beamforming don’t consider clustering, or they either use the Wyner model [9, 10] where inter-cell interference is considered to only come from the immediate adjacent cells. In [11], user-centric-based clustering was proposed for inter-cell nulling, however, the proposal is for single-tier small-cell networks. RA has attracted a lot of attention from several authors in the past, however, it is mainly for single-tier networks such as seen in the seminal work by Dahrouj *et al* [8] and references therein. Recently, authors have investigated RA in multi-tier networks such as in [12], their RA optimization problem was similar to ours, in the sense that it was geared towards achieving spectral efficiency, however, the methodology used to actualize it differs. This work differs from the aforementioned reviewed works because they do not properly address the significant inter-cell interference problem encountered in 5G Heterogeneous Networks, and hence cannot be used effectively in it. We leverage this work on our previous work [13] but with notable differences which include: one, we reduced the number of constraints in the optimization problem for this work in order to increase the search space for obtaining the coordinated beamforming vectors, with the weighted spectral efficiency being the utility function. Two, this work utilizes simulation settings that are based on 5G-ACIA for 5G systems, while the leveraged work utilized simulation settings approved by 3GPP for 4G advanced systems.

Notation: $(\cdot)^T$ is the transpose operation, $(\cdot)^H$ is the transpose-conjugate operation, $|\cdot|$ is the magnitude of a complex variable, $\|\cdot\|_2$ denotes the Euclidean norm of a vector. $\mathbb{E}\{\cdot\}$ is the statistical expectation over a random variable. $\mathbb{C}$ denotes the set of complex numbers. $\mathbb{C}^N$ denotes the set of complex N vectors. We use upper-case boldface letters for matrices and lower-case boldface for column vectors and either upper-case or lower-case letters without boldface for scalars.

II. METHODOLOGY

A. SYSTEM MODEL

Let's consider the downlink of a 5G heterogeneous network, which consists of K_p picocells and K_m macro cells making it a total of K_t cells in the system. We assume that all cells in the 5G heterogeneous network use the same carrier frequency, note that this is not usually the case in orthogonal frequency-division multiplexing (OFDM) systems. The rth BS is denoted BS_r which can be any of the base stations (Pico BS or Macro BS) and is assumed to have N antennas with which it communicates with at least one active user equipment per cell which is assumed to have a single antenna. The set of user equipments (UEs) served by BS_r is denoted by $\mathcal{S}_r \subset \{1, \dots, K_r\}$, where K_r denotes the total number of user equipment in the 5G network, also the kth UE is denoted UE k. While the selected n-tuple base stations that interfere with UE k are denoted by $\mathcal{A}_n^k$. The major system parameters are shown in Table 1.

Table 1. System Parameters	
$\boldsymbol{K_p}$	The total number of PBS in the 5G system.
$\boldsymbol{K_m}$	The total number of MBS in the 5G system
$\boldsymbol{K_t}$	The total number of BSs in the 5G system, ($n \le \boldsymbol{K_t}$)
$\boldsymbol{BS_r}$	The rth BS.
$\boldsymbol{\mathcal{S}_r}$	The set of UEs served by $\boldsymbol{BS_r}$
$\boldsymbol{N}$	The total number of transmit antennas at PBS or MBS
K	The total number of active served UEs in each cell
$\sqrt{\boldsymbol{f_{r,k}}}$	The large-scale pathloss from $\boldsymbol{BS_r}$ to UE k.
$\boldsymbol{h}_{r,k}^{s}$	The small scale (fading) channel vector from $\boldsymbol{BS_r}$ to UE k.
$\boldsymbol{x_r}$	The data signal vector transmitted at $\boldsymbol{BS_r}$ and intended for it served UEs**.**
$\boldsymbol{\mathcal{A}_n^k}$	The selected n-tuple BSs that interfere with UE k.
$\boldsymbol{\mho_n}$	The collection of all possible n-tuple BS subsets.
$\boldsymbol{\mathcal{A}_n}$	Particular n-tuple BS subsets.
$\boldsymbol{K_r}$	The total number of UEs in the 5G system
$\boldsymbol{\sigma^2}$	The noise Power.
$\boldsymbol{q_r}$	The power limit at $\boldsymbol{BS_r}$

The complex-baseband received signal at UE k is $y_k \in \mathbb{C}$ and expressed as

$$y_k = \sum_{r=1}^{K_t} \sqrt{f_{r,k}} \left(\boldsymbol{h}_{r,k}^{s}\right)^{H} \boldsymbol{x}_r + z_k. \tag{1}$$

Where $\sqrt{f_{r,k}}$ is the large-scale pathloss from BS_r to UE k. Also $\mathbf{h}_{r,k}^s \in \mathbb{C}^N$ is the small-scale frequency-flat fading channel vector from BS_r to UE k, while $\mathbf{x}_r \in \mathbb{C}^N$ is the data signal vector transmitted at BS_r and intended for it served user equipments. Furthermore, $z_k \in \mathbb{C}$ is the noise from the surroundings and is modeled as circularly symmetric complex Gaussian, distributed as $z_k \sim \mathbb{C}\mathcal{N}(0, \sigma^2)$, where σ^2 is the noise power. Assuming BS_l is the serving BS of UE k, the received signal at UE k in Eq. (1) can be expressed as

$$y_k = \mathbf{h}_{l,k}^H \mathbf{u}_k s_k + \mathbf{h}_{l,k}^H \sum_{\substack{p\in\mathcal{S}_l,\\ p\neq k}} \mathbf{u}_p s_p + \sum_{\substack{r\in\mathcal{A}_n^k,\\ r\neq l}} \mathbf{h}_{r,k}^H \sum_{\substack{m\in\mathcal{S}_r,\\ m\neq k}} \mathbf{u}_m s_m + z_k. \tag{2}$$

Where $\mathbf{h}_{r,k} \triangleq \sqrt{f_{r,k}}\mathbf{h}_{r,k}^s$, also, the transmitted data signal vector is a linear function of the symbols, i.e., $\mathbf{x}_r = \sum_{p\in\mathcal{S}_r} \mathbf{u}_p s_p$, where $\mathbf{u}_p$ denotes the transmit beamforming vector for each symbol s_p. The first addend of Eq. (2) is the desired signal transmitted to UE k while the second and third addends represent the intra-cell interference within the same base stations and the inter-cell interference from different BSs respectively. For the fifth-generation heterogeneous network that uses frequency reuse one deployment, the important problems that need to be resolved are:

- **Problem 1**: How does one identify the dominant inter-cell interference from base stations in the 5G heterogeneous network to UE k.To be specific, which base stations should be selected among the possible n-tuple base stations that interfere with UE k the most? Any base station whose interference power towards UE k is less than or equal to the noise power is regarded as negligible interference, hence is not to be included for coordination.

- **Problem 2**: How does one jointly design the coordinated beamforming vectors, that will spatially separate the transmitted signal vector from the interfering base stations to avoid interference towards UE k? Note that these interfering base stations are not fixed but selected for UE k by solving **problem 1**.

B. USER CENTRIC CLUSTERING SCHEME

In this section, the solution t problem 1 was provided by finding an optimal base station subset that will give the aggregate largest interference to UE k at a given time slot. An abridged expression of Eq. (2) is now written to show only the summation of the inter-cell interference signals,

$$I_{sig} = \sum_{\substack{r\in\mathcal{A}_n^k,\\ r\neq l}} \mathbf{h}_{r,k}^H \mathbf{x}_r . \tag{3}$$

The inter-cell interference power corresponding to Eq. (3) is now expressed as

$$I = \sum_{\substack{r\in\mathcal{A}_n^k,\\ r\neq l}} \left|\mathbf{h}_{r,k}^H \mathbf{x}_r\right|^2. \tag{4}$$

Let $\{I_n^k\}_{k\in\mathcal{S}_r}$ denote the set of all aggregate inter-cell interference power calculated from n-tuple base stations interfering UE k with $n \leq K_t$. It is worth noting note that for a system that comprises of K_t base stations there are altogether 2^{K_t} possible subsets. Let $\mho_n$ denote the collection of all possible n-tuple base stations subsets in the 5G heterogeneous network. The optimal base station subset that will maximize the interference suffered by UE k can be expressed as

$$\mathcal{A}_n^{k^*} = \underset{\mathcal{A}_n \in \mho_n}{\text{argmax}}\, I_n^k \quad \forall k. \tag{5}$$

To find the optimal number of base stations, in the optimal base station subsets, that will cause the highest interference to UE k, it can be determined through the following expressions:

$$l_n = \max_{\mathcal{A}_n \in \mho_n} I_n^k. \tag{6}$$

Where l_n denotes the maximum value of the inter-cell interference directed to UE k by n-tuple base stations. Furthermore, the serving base station to UE k, can choose the optimal number of interfering base stations that it will coordinate with, based on l_n. This can be expressed as

$$n_{opt} = \underset{n=1,\dots,K_t,}{\text{argmax}}\, l_n. \tag{7}$$

However, it involves finding $\mathcal{A}_n^{k^*}$ using Eq. (5), and l_n using Eq. (6) for each n, before selecting the optimal interfering base stations using Eq. (7).

For the avoidance of doubt, the optimal interfering base station set for UE k is now denoted as $\mathcal{A}_{n_{opt}}^{k^*}$, while the optimal number of interfering base stations that are needed to coordinate interference with the serving base station of UE k is n_{opt}. Consequently, the received signal by UE k after identifying its dominant inter-cell interferers is expressed as

$$y_k = \boldsymbol{h}_{l,k}^H \boldsymbol{x}_l + \sum_{\substack{r=1, \\ r \in \mathcal{A}_{n_{opt}}^{k^*}}}^{n_{opt}} \boldsymbol{h}_{j,k}^H \boldsymbol{x}_r + z_k. \qquad (8)$$

Therefore, the achievable spectral efficiency (SE) as a function of the signal-to-interference-and-noise-ratio (SINR) for UE k in beamforming terms, with $s_k$normalized to unit power, is expressed as

$$SE_k = \log_2(1 + SINR_k). \qquad (9)$$

Where $SINR_k = \frac{\left|\boldsymbol{h}_{l,k}^H \boldsymbol{u}_k\right|^2}{\sigma^2 + \sum_{p \in \mathcal{S}_l}\left|\boldsymbol{h}_{l,k}^H \boldsymbol{u}_p\right|^2 + \sum_{r=1}^{n_{opt}} \sum_{m \in \mathcal{S}_r}\left|\boldsymbol{h}_{r,k}^H \boldsymbol{u}_m\right|^2}$. (10)

Observe that from the foregoing we have established that for a particular chosen base station subset, the received signal$y_k$in Eq. (8) suffers from the highest meaningful inter-cell interference that exists in the system and is specific to UE k. The corresponding achievable spectral efficiency SE_kwill diminish if these interference sources are not curbed. However, if the n_{opt} base stations are to jointly serve UE k then there will be no inter-cell interference. The next section shows how this can be expressed mathematically based on the foregoing context.

C. JOINT TRANSMISSION

Note that if a joint transmission technique is to be applied to the interfered UE k by the set$\mathcal{A}_{n_{opt}}^{k^*}$, then there won't be any issue with inter-cell interference, because the n_{opt} base stations in $\mathcal{A}_{n_{opt}}^{k^*}$will be transmitting the desired signals synchronously to UE k. Consequently, increasing the data rate and by extension the spectral efficiency of the system. In that case, Eq. (8) can now be rewritten as:

$$y_k = \boldsymbol{h}_{l,k}^H \boldsymbol{x}_l + \sum_{l=1}^{n_{opt}} \boldsymbol{h}_{l,k}^H \boldsymbol{x}_l + z_k. \qquad (11)$$

Meaning that there is no interference link in the cluster any longer, all interfering base stations now transmit desired signal to UE k. The advantage of this technique is that it will make the system achieve maximal spectral efficiency. On the contrary, it might be difficult to realize in practice because it will require full phase coherence among signals received from different base stations, which is not possible because of the difference in their propagation delays. Furthermore, in a Heterogeneous network scenario, it will require a backhaul link that is delay-free and has unlimited capacity. This limitation brings about more research in coordinated beamforming schemes where authors are worried only about how to control inter-cell interference emanating from the n_{opt} base stations in $\mathcal{A}_{n_{opt}}^{k^*}$.

To make sure that the inter-cell interference sources in Eq. (10) are effectively curbed, the next section presents how resource allocation is done to resolve problem 2.

D. RESOURCE ALLOCATION

In this section, resource allocation decisions were made by the serving base station of UE k together with the selected BS subset that causes interference to UE k. The focus is to achieve the fundamental trade-off between maximizing the spectral efficiency of the 5G heterogeneous network and achieving a minimum performance level for all UEs in the system. This decision is motivated by the poor individual performance of user equipment located at the cell edges or cellrange expansion (CRE) [14] area of picocells in a macro-pico heterogeneous scenario.

E. PROBLEM FORMULATION

The target is to select $\{\mathbf{u}_k\}$ $k = 1, \ldots, K_r$, that will maximize the weighted sum spectral efficiency of the 5G heterogeneous network, while fulfilling power constraints, and quality of service (QoS) constraint for all user equipments. Note that the spectral efficiency is a function of the $SINR_k$. And the optimal interfering base station set $\mathcal{A}_{n_{opt}}^{k^*}$that affects the spectral efficiencyhas been used to determine $SINR_k$as expressed in Eq. (9). The optimization problem is, therefore, formulated as

$$\underset{\{\boldsymbol{u}_k\}_{k=1}^{K_r}}{\text{maximize}} \sum_{k=1}^{K_r} w_k SE_k,$$

$$\begin{aligned}
&\text{subject to } \mathcal{C}_1: SINR_k \geq \gamma_k k = 1, \dots, K_{r,} \\
&\mathcal{C}_2: \textstyle\sum_{k\in \mathcal{S}_s} \|\boldsymbol{u}_k\|_2^2 \leq q_s \quad s = 1, \dots, K_{p,} \qquad (12) \\
&\qquad \mathcal{C}_3: \textstyle\sum_{k\in \mathcal{S}_m} \|\boldsymbol{u}_k\|_2^2 \leq q_m \quad m = 1, \dots, K_m .
\end{aligned}$$

Where the utility function describes the weighted sum spectral efficiency of the system, with w$_k$ denoting a positive weight allocated to the individual user equipment, chosen to represent the varying levels of the individual channel gain. The constraints ($\mathcal{C}_1$~$\mathcal{C}_3$) denote the desired quality of service constraint upper bounded by a threshold denoted as γ_k for UE k; Pico base station power constraint and Macro base station power constraint respectively.

Maximizing the weighted sum spectral efficiency of a 5G heterogeneous network under some given constraints as expressed in constraints ($\mathcal{C}_1$~$\mathcal{C}_3$) is usually regarded as a non-convex, non-polynomial hard optimization problem because there are no known efficient algorithms that can solve them in polynomial time. However, this type of problem can be solved by branch and bound (B&B) algorithms as presented in [15], which can provide global optimal solutions.

To identify the actual cause of the non-convexity of the optimization problem of Eq. (12), let us analyze each function that makes up the optimization problem. The utility function in Eq. (12) is a concave function that can be maximized, nevertheless, it depends on the SINRs of the user equipments in the system (see Eq. (10)). The power constraints function in $\mathcal{C}_2$~$\mathcal{C}_3$ are all convex functions. The SINR constraint function in $\mathcal{C}_1$ is a non-convex function of the beamforming vectors $\{\boldsymbol{u}_k\}_{k=1}^{K_r}$, because it is not classified as a semi-definite constraint or second-order cone constraint. To get more insight into the reason behind the non-convexity of Eq. (12), the optimization problem can be rewritten as follows:

$$\underset{\{\boldsymbol{u}_k\}_{k=1}^{K_r}}{\text{maximize}} \sum_{k=1}^{K_r} w_k SE_k,$$

$$\begin{aligned}
&\text{subject to} \quad \mathcal{C}_1: \left|\boldsymbol{h}_{l,k}^H \boldsymbol{u}_k\right|^2 \geq \gamma_k (\Gamma_k) k = 1, \dots, K_{r,} \\
&\mathcal{C}_2: \textstyle\sum_{k\in \mathcal{S}_s} \|\boldsymbol{u}_k\|_2^2 \leq q_s \quad s = 1, \dots, K_{p,} \qquad (13) \\
&\qquad \mathcal{C}_3: \textstyle\sum_{k\in \mathcal{S}_m} \|\boldsymbol{u}_k\|_2^2 \leq q_m \quad m = 1, \dots, K_m .
\end{aligned}$$

Where: $\Gamma_k = \sigma^2 + \sum_{p\in \mathcal{S}_l} \left|\boldsymbol{h}_{l,k}^H \boldsymbol{u}_p\right|^2 + \sum_{r=1}^{n_{opt}} \sum_{m\in \mathcal{S}_r} \left|\boldsymbol{h}_{r,k}^H \boldsymbol{u}_m\right|^2.$

In other words, it is the SINR constraint that stopsEq. (13) from being a convex problem. These constraints are non-convex because of the multiplication between γ_k (the SINR threshold at UE k) and Γ_k (inter-cell interference and the multi-UE interference caused to UE k). To resolve the non-convexity, it is either the SINR threshold at each user equipment is fixed to a constant value or the Γ_k is fixed to a constant value, making them to be known constants. For example, we can assume γ_k= 1 for all user equipments or Γ_k= 0.5 for all user equipments. In this work, we decide to fix all the SINR thresholds to the same constant. This will resolve the issue of non-convexity of the optimization problem and also achieve a minimum performance for all user equipments in the system. This disciplined convex-optimization problem can, now, be solved using CVX, a software package for specifying and solving convex programs under the MATLAB environment.

III. SIMULATION RESULTS

We evaluate the performance of the proposed method of this work by comparing it with the proposed method of another of our work[13] and other existing resource allocation methods based on the aggregate spectral efficiency, average SNR, and number of transmitted antennas.

A. SIMULATION SETTINGS

The deployment scenario considered is titled Urban-Macro for 5G New Radio. The carrier frequency adopted is around 4GHz (c-Band) assuming a 100MHz bandwidth. Let's consider a simple simulation setting with a minimum of five randomly distributed Pico base stations (PBSs) deployed at hotspot locations in the coverage area of the macro base station (MBS). The minimum distance among Pico sites is set to 40m, and it is assumed that all PBSs are not geometrically separated, hence interference among PBS is possible and therefore considered. The minimum distance from the Macro base station site to the Pico base station site is 75m. It is assumed that the UEs in the 5G heterogeneous network are uniformly distributed and are located at the cell range expansion (CRE) such that each UE will receive significant inter-cell interference. Note, more focus is on UEs at the CRE area because they suffer both signal attenuation from their serving BS as well as inter-cell interference from neighboring cells. The UEs served by PBS are uniformly distributed between 35m and 55m from the PBS. Similarly, the UEs served by MBS are uniformly distributed between 210m and 260m from the MBS. Also, the distance between the macrocell UEs and the PBS is between 40m and 44m, while the distance between the picocell UEs and the MBS is between 220m and 270m. Other system parameters are also based on 5G-ACIA [16]. The total BS transmit powers for MBS and PBS are 46dBm and 30dBm respectively, the UE transmit power is 23dBm . The channel vector between BS_r and UE k is modeled as $\boldsymbol{h}_{r,k} \triangleq \sqrt{f_{r,k}}\boldsymbol{h}^{s}_{r,k}$. Where $\sqrt{f_{r,k}}$ is the large-scale pathloss from BS_r to UE k, also $\boldsymbol{h}^{s}_{r,k} \in \mathbb{C}^N$ is the small scale flat fading channel vector BS_r to UE k. The large scale pathloss in linear scale is given as

$$f_{r,k} = \frac{\psi}{d^{n}_{r,k}}\,. \tag{14}$$

Where ψ is a constant which accounts for system losses; n is the path-loss exponent, typically n >3, while $d_{r,k}$is the distance between $BS_r$and UE k. The large-scale path loss model in dB for the macro and pico cells are respectively $PL(dB) = 128.1 + 37.6\ \log\left(\frac{d_{r,k}}{10^3}\right)$ and $PL(dB) = 140.7 + 36.7\ \log\left(\frac{d_{r,k}}{10^3}\right)$. This simulation setting will be used except otherwise indicated.

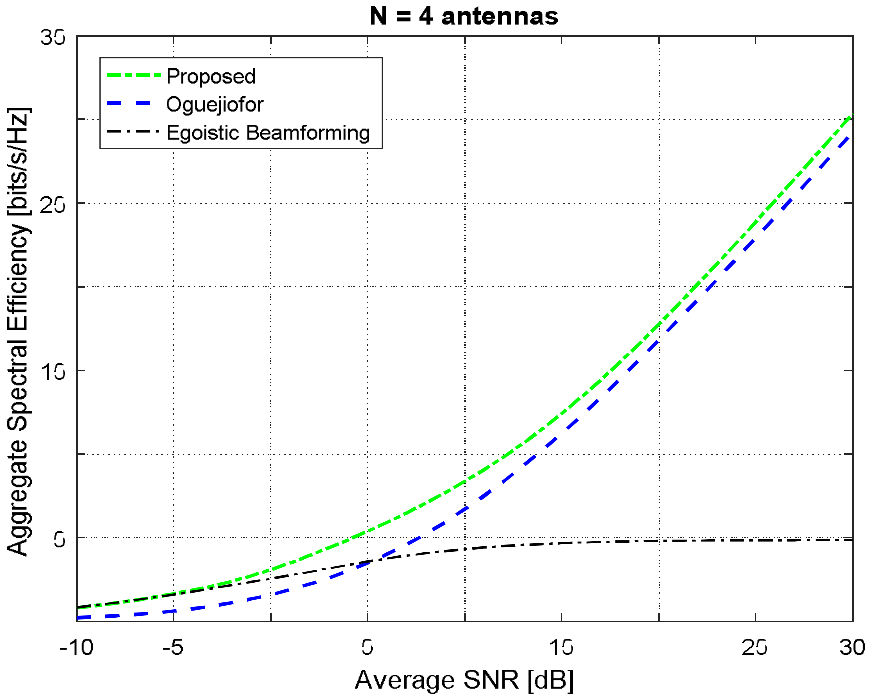

Fig. 1 Aggregate Spectral Efficiency as a function of SNR for different beamformers

In Fig. 1, the aggregate system spectral efficiency was plotted against the average SNR for different resource allocation methods. Note some of the methods above didn't consider clustering. In Fig 1, the proposed method outperforms methods used by Oguejiofor *et al* in [13] and the Egoistic beamforming method. The Egoistic beamforming method is a method whose design doesn't consider both clustering and interference from other cells. The method is more interested in designing beamformers for UEs in each cell without considering interference from other cells. This method as can be seen cannot compete with the proposed method when applied to a 5G heterogeneous network where inter-cell interference is a factor because universal frequency is being utilized.

The theoretical minimum achievable spectral efficiency for a 5G system is assumed to be 30 bits/s/Hz based on 3GPP simulations. If one is using 30 bits/s/Hz as a baseline, then it will take the following parameters (Kr=4, N=4, SNR = 30dB) for the proposed method to actualize it. The egoistic beamforming method cannot achieve that based on the same parameters, while it will take Oguejiofor's method a higher SNR to achieve.

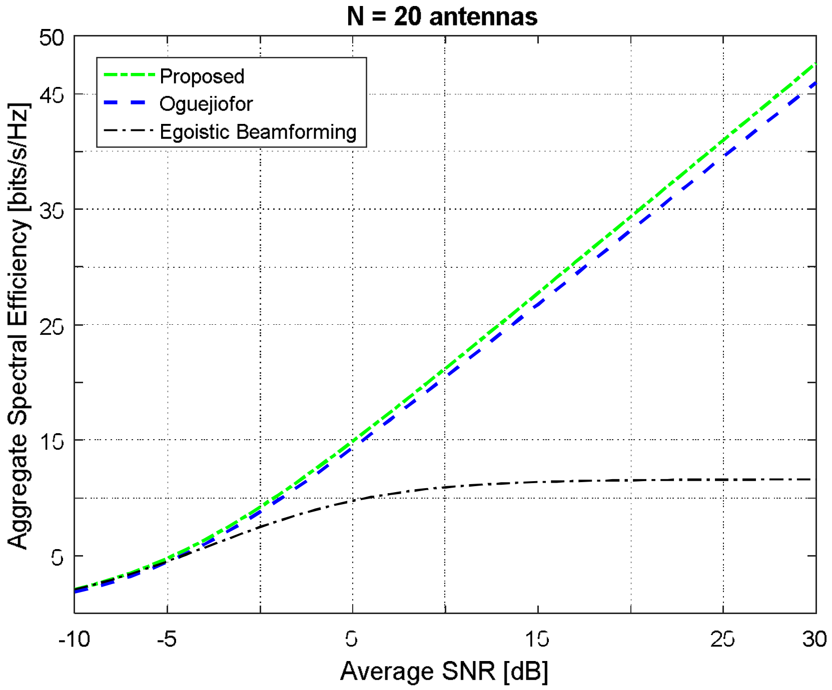

Fig. 2 Aggregate Spectral efficiencies achievable at different *SNR* for *N*=20, *Kr*=4

In Fig. 2, The proposed method at SNR = 30dB was able to achieve a spectral efficiency of 48bits/s/Hz, while Oguejiofor'smethod also surpassed the 30bits/s/Hz at SNR = 30dB. At SNR = 30dB comparing Fig. 1 and Fig. 2 respectively, one can see clearly that the proposed method achieved an improved spectral efficiency of 18bits/s/Hz. This is due to the increase in the number of transmit antennas in each BS in each cell and also, the optimal coordinated beamformers designed by the proposed method which helps the transmit antenna to focus the desired signal energy to the desired UE.

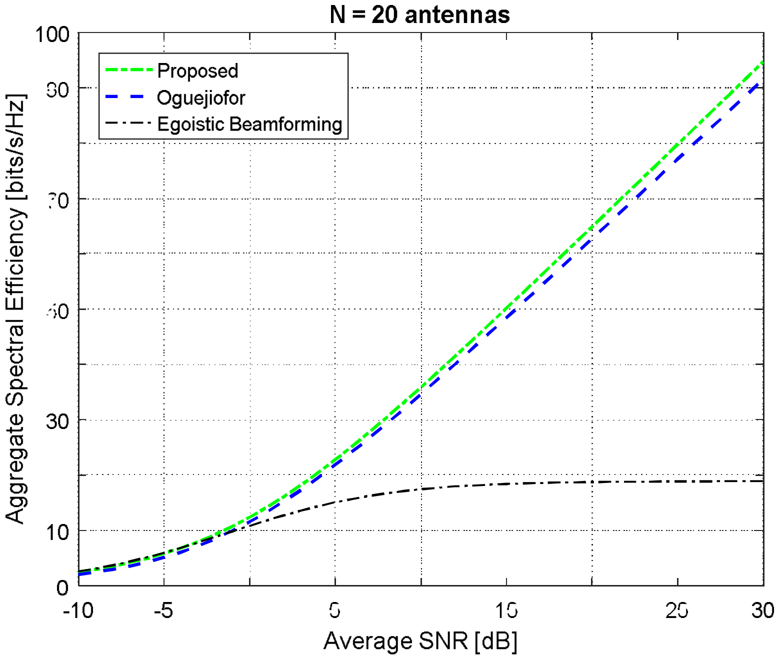

Fig. 3 Aggregate Spectral efficiencies achievable at different *SNR* for *N*=20, *Kr*=9

In Fig. 3, the aggregate spectral efficiency achievable for the proposed method is 95 bits/s/Hz at *SNR* = 30dB. When compared to the aggregate spectral efficiency achievable for the proposed method in Fig. 2, which has the following parameters (*N* =20, *Kr* =4), one can see that at SNR = 30 dB, the achievable aggregate spectral efficiency is at 48 bit/s/Hz. Therefore, the aggregate spectral efficiency in Fig. 3 has improved by 47bits/s/Hz to that achievable in Fig. 2 at *SNR* = 30dB. What this means is that as the number of UEs increases in the system, together with the transmit antenna at each base station, the aggregate spectral efficiency of that system must increase when coordinated beamforming methods like the one proposed in this work is utilized at the base stations for precoding of signals before downlink transmission.

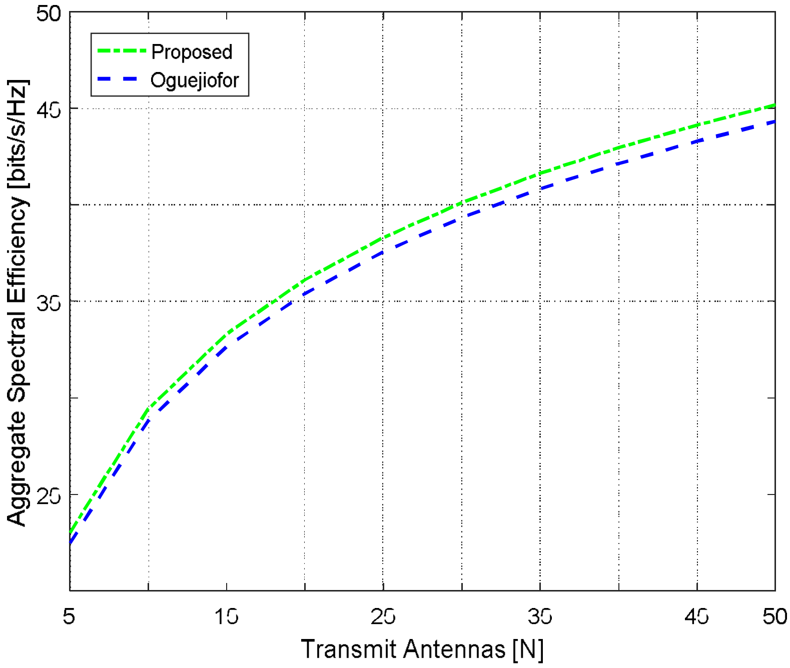

Fig. 4: Aggregate spectral efficiency at different transmit antenna for *SNR* = 10dB

In Fig. 4, the plot of the aggregate spectral efficiencies of the system as a function of the number of transmit antennas in base stations shows that at SNR = 10dB, for 20 transmit antennas, the spectral efficiency achievable by the proposed method is approximately 37 bits/s/Hz, while that of Oguejiofor's method is approximately 36 bits/s/Hz. This is quite similar to the figure obtained in Fig. 3 under SNR = 10dB. However, it was observed that to achieve a minimum spectral efficiency of 30 bit/s/Hz which is the minimum requirement for a 5G system by 3GPP, for a low SNR =10dB, the number of transmit antennas needed at the base stations must be greater than 10.

V. CONCLUSION

In this work, the proposed method helps to curb the inter-cell interference problem that occurs in a 5G heterogeneous network deployed under a universal frequency reuse scheme. The proposed method was able to improve the system's spectral efficiency using clustering and optimally coordinated beamforming vectors designed to curb inter-cell interference and focus the desired signal energy to the desired UE. This work has also established a relationship on how the following parameter: number of antennas in BSs, signal-to-noise ratio (SNR), and number of UEs in each cell impact the spectral efficiency and inter-cell interference management in 5G heterogeneous networks. We recommend that further works should investigate situations when UEs are very large and equal to or greater than the number of transmit antennas in all the cooperating cells.

VI. ACKNOWLEDGEMENT

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