A Fairness-Driven Resource Allocation Scheme Based on a Weighted Interference Graph in HetNets

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***Abstract*—One of the most important 5G features is their support for heterogeneous networks (HetNets). Complementing the classic macrocell base stations (MBS), femtocell base stations (FBS) are beneficial in terms of extensive coverage, including indoor, and enhancement of capacity. Unfortunately, FBSs performance in 5G HetNets is affected by complex cross-tier and co-tier interferences, causing reduced quality of service (QoS) and unfairness among users. This paper proposes an innovative resource allocation (RA) algorithm for interference mitigation (IM) based on graph coloring techniques to improve QoS and inter-user fairness. The proposed algorithm, named Weighted Edge-Weighted Vertex Interference Mitigation (WEWVIM), employs a weight to the directed edge corresponding to the interference strength from nearby base stations (BSs) and a weight to every vertex, indicating the color with the smallest interference or higher transmission rate. A region of interest (ROI) is formed to find the interfering BSs. Simulation results show that WEWVIM outperforms existing schemes in terms of fairness and QoS, including throughput, packet loss ratio (PLR), delay, and jitter.**

***Index Terms*—HetNets, Graph Coloring, Interference Mitigation, 5G, QoS, Resource Allocation**

I. Introduction

According to Cisco VNI Forecast Highlights Tool [1], global business mobile data traffic will grow six-fold from 2017 to 2022 at an annual growth rate of 42%. Business mobile users will continue to expect immediate and high-performance connectivity anywhere, anytime, and on any device to support rich media services [2]. To enable immersive experiences for these users, networks need to provide high end-to-end bandwidth, low latency communications, and dynamic performance control. Indeed, 5G wireless communications envision magnitudes of increase in wireless data rates, bandwidth, coverage, and connectivity, with a massive reduction in round trip latency and energy consumption [3], [4].

Efforts were put in proposing adaptive solutions to deliver rich media content at high quality levels, but they are not always efficient [5], [6]. Traffic engineering or network selection methods in sparse network environments were also designed achieving some limited success [7], [8]. A better way to achieve this is through the deployment of dense Heterogeneous Networks (HetNets). However, dense cell deployment in HetNets causes extreme inter-cell (cross-tier) interference and intra-cell (co-tier) interference (see Fig. 1), which degrade the network performance along with the user experience [9]. Therefore, the dynamic interference problem of resource allocation (RA) between femtocell base stations (FBSs) and macrocell base stations (MBSs), on the one hand, and among FBSs on the other hand, need to be thoroughly investigated. The problem of interference mitigation (IM) in the under-laid HetNets has been studied recently. The approaches mainly differ in terms of techniques, advantages, and issues. For Instance, Celik *et al.* [10] proposed a scheme combining IM with RA in HetNets. These latter are considered as device-2-device (D2D) enabled, organized in three layers: macrocells, small cells, and D2D pairs. The problem was solved using Mixed Integer Non-Linear Programming (MINLP) by considering the quality of service (QoS) requirements and power constraints. Compared to the conventional DL/UL coupled scheme, the proposed scheme significantly reduces the co-tier and cross-tier interferences. Yet, it suffers high processing overhead. A fractional frequency reuse (FFR) method labelled FFR-3SL was implemented by Khan *et al.* [11], which divides the resources into 3-sectors and 3-layers. Using FFR-3SL, the sub-bands are distributed among femtocells and macrocells and the system could handle the co-tier and cross-tier interference, providing higher throughput and better capacity. However, because of its hierarchical structure, the allocation scheme endures a high computational complexity.

IM was introduced as an optimization parameter by Kaneko *et al.* [12] in which a distributed RA approach was proposed for MBS and FBS DL based on OFDMA. This work aimed to maximize the throughput of femtocells users' (FUEs) while alleviating macrocell users' (MUEs) interference. To this end, FBSs predict the sub-channels that are possibly used by the nearby macrocells based on the locally overhead channel state information (CSI), unlike traditional methods, which use CSI provided by MBSs to mitigate interference caused by FBSs on macrocell users. The findings showed that the approach effectively mitigates FBS interference for neighboring MUEs and offers a trade-off between MBS and FBS throughput. The value of the reduction in overhead signals was demonstrated and applied to other forms of systems such as cognitive radio. Still, co-tier interference among secondary users was not considered. Xu *et al.* [13] proposed an allocation method that considers both cross-tier interference and MBS transmit power constraints to assign resources and improve the

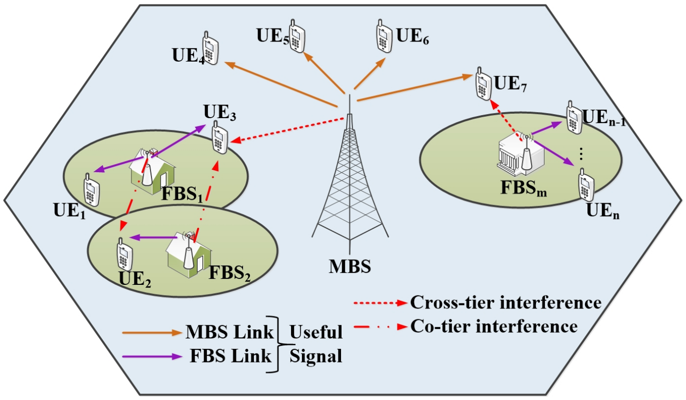

Fig. 1. Interference scenarios in a HetNet.

network's overall performance. A semi-infinite programming problem was used to solve the allocation issue, which was then relaxed into geometric programming. The results show that the algorithm could guarantee the efficiency of MUEs and FUEs under certain channel conditions, but the system's use of ultimate fairness would assign the same bandwidth among users; thus, services could not be accessed by some users with bad channel characteristics. Lv *et al.* [14] proposed a scheduling method by applying a carrier aggregation approach to eliminate cross-tier interference. The scheme starts with categorizing users into MUEs and FUEs, i.e., user association. This is followed by a cooperative transmission strategy that is femtocell user-centric to increase the data rate of FUEs. For cross-tier interference alleviation, an improved simulated annealing algorithm and maximum distance (MMD) algorithm were used based on FUEs and FBSs' location, respectively. Nonetheless, the fairness of the system was not considered, implying that users outside the radius and with a low SINR profile would not be served.

Efficient graph-based schemes were proposed in [15], [16], which apply the maximal independent set (MIS) concept in graph theory to help divide HetNets into almost interference-free groups. In [15], a distance threshold was used for indicating whether an edge is directed to the vertex or not. In [16], the scheme is divided into rounds. In each round, vertices compete for colors, and the winning vertices will use the resources in the next round. In [17], the authors proposed a solution based on graph theory, which was solved using simulated annealing. However, no explanation of how an interference graph (IG) is formed was provided. An Adaptive Interface Selection (AIS) scheme was proposed in [18] to improve the quality of experience (QoE) of end-users who are interested in high-definition (HD) content. In [19], a Hybrid Unicast-Multicast Utility-Based Network Selection Algorithm (HUMANS) was presented, which offers the option of selecting multicast transmissions in the network selection process during video delivery. The authors of this paper had previously proposed a heuristic scheme in [20], i.e., Quality Efficient Femtocell Offloading Scheme (QEFOS) for mitigating the cross-tier interference in HetNets by traffic offloading. This work moves a step further and reduces cross-co-tier interferences using a graph coloring method.

In this paper, by considering the max-min fairness for throughput, we propose an improved graph coloring method based on the simple graph coloring method suggested initially in [21] to assign physical resource blocks (PRBs) to the user equipments (UEs) for ensuring high QoS and fairness among UEs. The purpose of graph coloring PRB allocation is to mitigate the interferences experienced by UEs and which are caused by the various base stations (BSs) (MBSs or FBSs) (see Fig. 1). The constructed IG is modified into a weighted interference graph to execute graph coloring. Every directed edge's weight stands for the magnitude of the interference. Every vertex's weight stands for the color or PRB with the smallest interference or highest transmission rate. To reduce the complexity for solving the NP-hard GCP [22], we propose a novel region of interest (ROI) to determine whether an edge in the interference graph can connect two vertices. To the best of the authors' knowledge, no work has addressed the interference mitigation problem in HetNets while considering the weights of both the vertices and edges while solving it using a sub-optimal approach.

The rest of this paper is organized as follows. Section II presents the system model. Section III describes the relevant algorithm. Section IV describes the utility function. Section V presents simulation setup and results. Finally, Section VI concludes the paper.

II. System Model

As depicted in Fig. 1, consider the downlink of a HetNet consisting of fixed BSs and randomly placed UEs. The area shown in Fig. 1 is covered by a two-tier BSs: MBS (M_m) and FBS (M_f). The coverage area of these BSs may overlap, implying that each UE can be within the range of at least one BS. The set of all BSs is denoted as *BS* = $\{MBS_1, ..., MBS_{M_m}, FBS_1, ..., FBS_{M_f}\}$, with the set of the BSs indices *M* = {0,1, . . ., m-1}, where m = $M_m + M_f$. Let *S*= $\{0, 1, \cdots, K-1\}$ be the set of available sub-channels, where K is the number of total sub-channels, that each BS $i \in M$ can use. These sub-channels will be further divided and allocated to the UEs associated to each BS *i*. We assume that each BS $i \in M$ uses a constant per sub-channel transmit power P_{ij}^k on sub-channel *k*, and the total transmit power of BS i is $\hat{P}_i = \sum_{k \in S} P_{ij}^k$. Let N be the set of UEs (N = $\{0, 1, \cdots, n-1\}$, where n is total number of UEs) located inside the region G and $\psi_j \in \Psi$ be the requested downlink rate (bits per second) of UE j, where Ψ is the discrete set of service classes. In this paper, we are interested in the video service as it requires high bandwidth. We define $\tilde{\mu}$ as the total path loss (i.e., follows a log-distance path loss model) between BS i and UE j in decibels (dB).

A. Data Rate Calculation and QoS Assessment

Each UE $j \in N$ is connected to the nearest BS $i \in$ M. We denote $x_j^i \in \{0, 1\}$ as the binary decision variable used for the user association (UA) and $y_{ij}^k \in \{0, 1\}$ as the decision variable for the sub-channel allocation. x_j^i = 1 if UE j is associated with BS i while y_{ij}^k = 1 if sub-channel k is allocated to the downlink from BS i to UE j. Note that UE j can be associate with only one BS i at any time instance.

$$\sum_{i \in M} x_j^i \leq 1, \qquad \forall j \in N \tag{1}$$

To formulate our proposed algorithm, we create two non-square matrices: the association matrix (AM) and the resource allocation matrix (RM) which are based on the binary decision variables x_j^i and y_{ij}^k with sizes equal to $m \times n$ and $m \times K$ as follows:

$$AM_{mXn} = \begin{pmatrix} x_1^1 & x_2^1 & x_3^1 & \cdots & x_n^1 \\ x_1^2 & x_2^2 & x_3^2 & \cdots & x_n^2 \\ \vdots & \vdots & \ddots & \vdots & \\ x_1^m & x_2^m & x_3^m & \cdots & x_n^m \end{pmatrix} \tag{2}$$

$$RM_{KXm} = \begin{pmatrix} y_{1j}^1 & y_{2j}^1 & y_{3j}^1 & \cdots & y_{mj}^1 \\ y_{1j}^2 & y_{2j}^2 & y_{3j}^2 & \cdots & y_{mj}^2 \\ \vdots & \vdots & \ddots & \vdots & \\ y_{1j}^K & y_{2j}^K & y_{3j}^K & \cdots & y_{mj}^K \end{pmatrix}, \forall j \in N \tag{3}$$

Each column of AM should satisfy Eq.(1) and the value of each row of AM is $\sum_{j \in N} x_j^i \leq n, \forall i \in M$. **Note:** Matrix RM should be read along with AM. For example, x_1^2 =1 means that the first UE is connected to the second BS. To check which sub-channels are allocated to first UE, the second column of RM should be inspected.

The instantaneous signal-to-interference-plus-noise-ratio (SINR) γ received at UE j from BS i on sub-channel k is:

$$\gamma_{ij}^k = \frac{h_{ij} P_{ij}^k}{\sum_{\tilde{i} \in M \setminus \{i\}} h_{\tilde{i}j} P_{\tilde{i}\tilde{j}}^k + W N_0} \tag{4}$$

where h_{ij} is the positive channel power gain between UE j and BS i, W is the bandwidth of the sub-channel and N_0 is the thermal noise spectral power.

For the downlink transmission rate calculation, we use the Shannon capacity. Given AM and RM, the downlink rate R_j achieved by UE j connected to BS i is given by:

$$R_j = \sum_{i \in M} x_j^i \sum_{k \in K} y_{ij}^k W log_2 \left(1 + \frac{h_{ij} P_{ij}^k}{\sum_{\tilde{i} \in M \setminus \{i\}} h_{\tilde{i}j} P_{\tilde{i}\tilde{j}}^k + W N_0}\right) \tag{5}$$

A BS must serve its associated UEs with a minimum QoS requirement i.e.,

$$R_j \geq \psi_j, \forall j \in N \tag{6}$$

Let $\hat{N}$ be the set of UEs ($\hat{N} = \{0, 1, \cdots, \hat{n}\}$), where $\hat{n}$ is the number of UEs who did not receive the requested QoS and let $\tilde{N}$ be the set of UEs who received the requested QoS, therefore $\tilde{N} \cup \hat{N} = N$ and $\tilde{N} \cap \hat{N} = \Phi$.

Not all the BSs transmitting on the same sub-channel k need to be causing interference to a concerned UE $\tilde{j}$. Hence, it is essential to find a set of conflicting BSs that operate on the same sub-channel and causing interference above a certain threshold. To find these BSs, we propose a novel metric called region of interest (ROI).

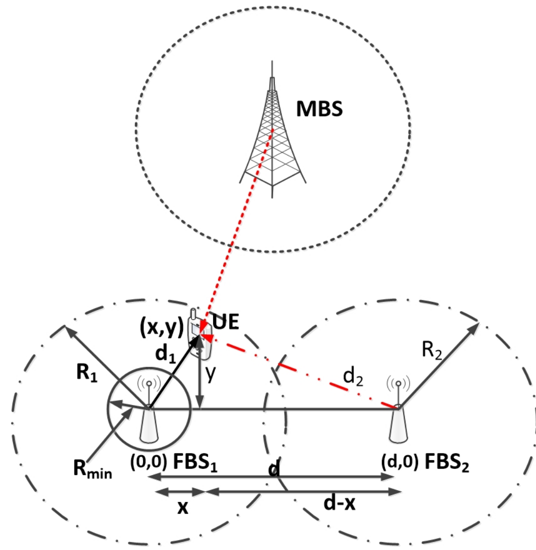

Fig. 2. Interference scenarios

B. Region of Interest (ROI)

Our current problem is determining whether an edge in the graph can connect two vertices and estimate the interference influence. Note that the impact of the interference depends on the ratio of interference power to signal power, so the ROI metric is proposed to evaluate the influence of interference. The ROI of region m which is served by BS i and suffers interference from BS $\tilde{i}$ represents the average SINR, and can be calculated as:

$$ROI(i, \tilde{i}, A_m) = \iint_{A_m} (\gamma_{i,\tilde{j}}^k(x, y) dx dy) / (C(A_m)) \tag{7}$$

where $\gamma_{i,\tilde{j}}^k$ is defined in Eq.(4); $C(A_m)$ is the area of of region m. Let A_i be the coverage region of BS_i. When ROI (i,$\tilde{i}$,A_i) $\leq \gamma_{th}$ orthogonal sub-bands should be assigned to BS_i and $BS_{\tilde{i}}$ to avoid interference.

The determination of the threshold enables the flexibility of the trade-off between complexity and performance of the solution. A low threshold will result in a relatively complicated IG but a good IM performance while a high threshold will result in a simple IG but a less ideal performance in terms of IM. Therefore, the value of the threshold can be determined according to specific requirements on the solution's complexity and performance.

For the two scenarios, i.e., interference between FBS-FBS (co-tier interference) and interference between MBS-FBS (cross-tier interference), the interference threshold based on ROI is given in the following section.

1) Interference Between FBSs: As shown in Fig.2, there are two FBSs and one MBS. The concerned UE $\tilde{j}$ is having an association with its respective BS, i.e., FBS_1. If the interference from FBS_2 is above a certain threshold, it will belong to the set BS^k, which contains all BSs operating on sub-channel k and causing interference above a certain threshold. Two FBSs are deployed, FBS_1 is placed at the origin while FBS_2 is placed at the position (d,0) and both having R_1 and

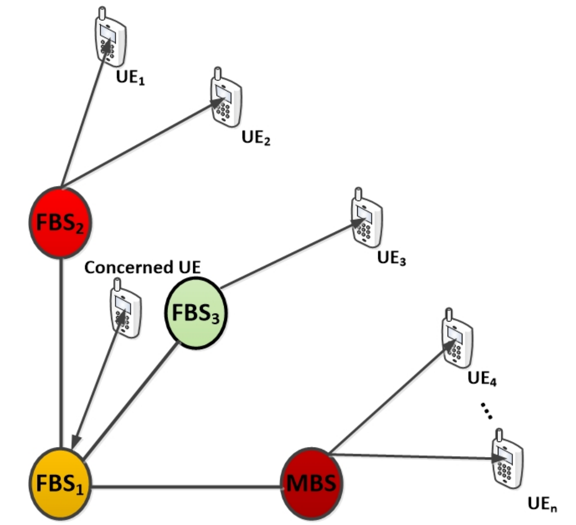

Fig. 3. **Interference Graph:** UE $\tilde{j}$ is connected with FBS_1 and using ROI, the edge is directed towards FBS_1 from other BSs, and color in each vertex corresponds to PRB with the least interference or highest transmission rate.

R_2 as radius. The position of FBS_1 was selected to simplify computations. UE is not getting the requested QoS as it is located at (x,y). It is at a distance d_1 from FBS_1 and d_2 from FBS_2. R_{min} is the minimum distance between UE $\tilde{j}$ and FBS_1.

The power received by the UE $\tilde{j}$ from FBS_1 and FBS_2 can be expressed as:

$$P^k_{\tilde{j}1} = P_1 * (d_1)^{-\tilde{\mu}} = P_1 * (x^2 + y^2)^{-\tilde{\mu}/2} \tag{8}$$

$$P^k_{\tilde{j}2} = P_2 * (d_2)^{-\tilde{\mu}} = P_2 * ((d-x)^2 + y^2)^{-\tilde{\mu}/2} \tag{9}$$

For ease of calculation, let $\tilde{\mu} = 2$ and neglect N_o. Then, the SINR (γ) received by the UE $\tilde{j}$ from the FBS_1 is:

$$\gamma^k_{\tilde{j}1}(AM, RM) = \frac{P^k_{\tilde{j}1}}{P^k_{\tilde{j}2}} = \frac{P_1 * ((d-x)^2 + y^2)}{P_2 * (x^2 + y^2)} \tag{10}$$

As the UE $\tilde{j}$ is in the coverage area of FBS_1, the ROI is calculated as follows:

$$\begin{aligned} ROI(1, 2, A_m) &= \int_{R_{min}}^{R_1} \int_0^{2\pi} \gamma^k_{\tilde{j}1}(AM, RM) r dr d\theta / S(A_m) \\ &= \frac{P_1}{P_2}(1 + \frac{2d^2}{R_1^2 - R_{min}^2} ln \frac{R_1}{R_{min}}) \end{aligned} \tag{11}$$

In this paper, we have considered a constant power per sub-channel, therefore P_1 and P_2 are constant; As a result, ROI is mainly affected by the distance between the BSs. Hence, condition for $FBS_2 \in BS^k$ is $ROI(1, 2, A_m) < c_{th}$. For a UE $\tilde{j}$ using ROI, we have formed a set BS^k. All the elements of BS^k will participate in graph coloring problem as shown in Fig.3. Similarly, it is possible to form an expression of ROI for interference between MBS and FBS.

III. Graph Coloring

A genetic algorithm approach is adopted here to allocate PRB to UEs, i.e., to solve the GCP. In order to execute graph coloring, the constructed IG is modified into the weighted edge weighted vertex interference graph as shown in Fig.3, where the weight of every directed edge obtained by ROI is calculated as:

$$\rho_{i,\tilde{i}}(x, y) = 10 * log_{10}[10^{Pr_{\tilde{j}}(x,y)/10}] \tag{12}$$

where Pr = Pt - PL = Pt - (40 + 30*log_{10}(d) + L). Pr stands for received power, Pt corresponds to transmitted power and PL is the path loss; d represents the distance between the BSs while L is the penetration loss.

The steps of the graph coloring PRB allocation algorithm, i.e, **W**eighted **E**dge-**W**eighted **V**ertex **I**nterference **M**itigation (WEWVIM) are described below:

1) *Initialization:* In this step, the interference management server (IMS) sets AM and RM defined above according to the user association and resource allocation (UA-RA).
2) *Form Set $\hat{N}$ and BS^k:* IMS keeps track of those UEs who do not get the requested QoS, i.e., Eq.(6) and form a set $\hat{N}$ which includes all such UEs. These UEs are further used to find the set of conflicting BSs, i.e., BS^k, using ROI metric described above. Set $\hat{N}$ and BS^k helps in forming the IG, in which each node or vertex represents the element from set BS^k, i.e., BSs and one edge between two BSs is established when the $\gamma < c_{th}$.
3) *Assigning weights to the edge:* Weights are assigned to each edge as defined in Eq.(12). The edge with the highest weight will be colored first because it represents the most interfering BS.
4) *Finding colors with the smallest interference:* To mitigate the interference on UE $\tilde{j}$, the PRBs on which the smallest interference exists should be assigned to BS $i, \tilde{i} \in BS^k$. Therefore, it is necessary to find the colors (PRBs) with the smallest interference. We search for these colors by seeking the colors on which UE $\tilde{j}$ can achieve the highest transmission rate.
5) *Update matrix RM:* Update the RM matrix according to the colors or PRBs allocated to nodes by solving the IG.
6) *Update the Set $\hat{N}$:* Remove all those UEs from $\hat{N}$ who have met the QoS constraint and include them in the set $\tilde{N}$.
7) *Check Whether all UEs have met QoS constraint:* This algorithm runs till $\tilde{N} - \hat{N} = N$ or $|\hat{N}| = \Phi$.

IV. Utility Function

To achieve fairness, we aim to maximize the minimum proportional rate i.e., max-min of the achieved data rate:

$$\max_{P^k_{ij}, E_i} \min_j R_j \tag{13}$$

where E_i is the set of users connected to and being served by BS i. The interference constraint, resource allocation constraint and power constraint are expressed as follows:

$$y^k_{i,\tilde{j}} + y^k_{\tilde{i},j} \le 1, \forall (i, \tilde{i}) \in BS^k, \forall k \in K, \tilde{j} \in \hat{N}, j \in \tilde{N} \tag{14}$$

TABLE I
DEFAULT SIMULATION PARAMETERS

Parameter	Value
Area of Region (G)	500m x 500m
UE traffic demand (ψ_j)	2 Mbps
# of BSs ($\lvert M\rvert = \lvert M_m \cup M_f\rvert$)	9 = 1 + 8
Total transmit power of BSs	$\{46, 26\}$ dbm

$$y^k_{i,\tilde{j}} + y^k_{\tilde{i},j} \leq 2, \forall (i, \tilde{i}) \in BS - BS^k, \forall k \in K, \tilde{j}, j \in \tilde{N} \quad (15)$$

$$\sum_{i \in BS} \sum_{k \in K} x^i_j y^k_{ij} \leq |K| \quad (16)$$

$$\sum_{k=1}^{K} \sum_{j \in E_i} P^k_{i,j} \leq P_{max}, i \in BS. \quad (17)$$

$$P^k_{i,j} \geq 0, \forall j, k \quad (18)$$

The utility function defined in Eq.(13) is to socially ensure that all UEs experienced same throughput, i.e., uplifting the deprived UEs because of hefty cross-co-tier interference. Constraints in Eq.(14) and Eq.(15) are used to determine whether any pair of BSs (i, $\tilde{i}$) can reuse the same sub-channel k or not. Furthermore, the constraint in Eq.(16) ensures that the number of sub-channels allocated to UEs by BS i does not exceed the total number of available sub-channels. Constraint Eq.(17) is on the total transmit power of each BS while the constraint in Eq.(18) ensures the non-negative powers.

V. PERFORMANCE EVALUATION

We have performed a comprehensive study in the NS-3 network simulator to evaluate our proposed algorithm. For all our experiments, we considered one MBS ($|M_m|$ = 1) and eight FBSs ($|M_f|$ = 8) that are deployed at fixed locations: 4 FBSs are deployed at two-floor residential buildings and four at commercial buildings of six floors. Both residential and commercial buildings have external walls made of concrete with windows. We have randomly deployed UEs ($|N|$=100) following a homogeneous Poisson Point Process (PPP) for the different experiments and considered a discrete user demand (i.e., requested data rate). To simulate channel fading, we used a log distance path loss model as in [13]. Other simulation parameters are given in TABLE I. We assessed the QoS matrices perceived by users and Jain's fairness index in a HetNets environment, and results are presented in Fig. 4 and 5. Beside WEWVIM, we simulated two other schemes: **C**lassical **I**nterference (CI) and **W**eighted **E**dge **I**nterference **M**itigation (WEIM). In CI, all UEs are connected to nearby BSs (MBSs or FBSs) with no IM. WEIM, on the other hand, corresponds to the IM based on a graph coloring problem in which only weights for edges are considered.

Fig. 4(a) shows that WEWVIM incurs an average throughput of 2.89 Mbps which is 39.79% and 86.50% higher than WEIM's (1.74 Mbps) and CI's (0.39 Mbps), respectively. Fig. 4(b) shows that WEWVIM incurs the least packet loss ratio (18.76%) compared to WEIM (44.56%) and CI (85.96%).

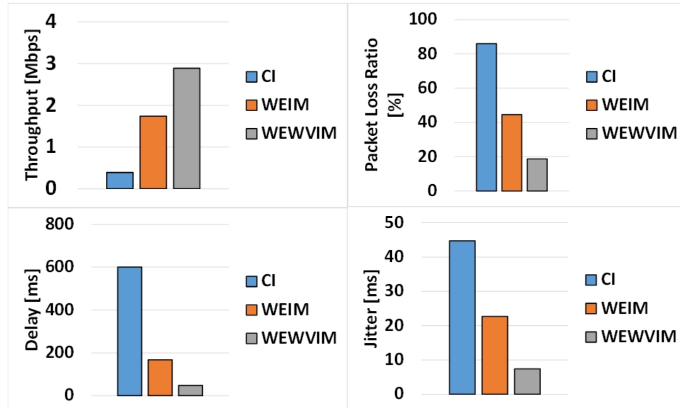

Fig. 4. QoS Metrics for 100 users under three different schemes.

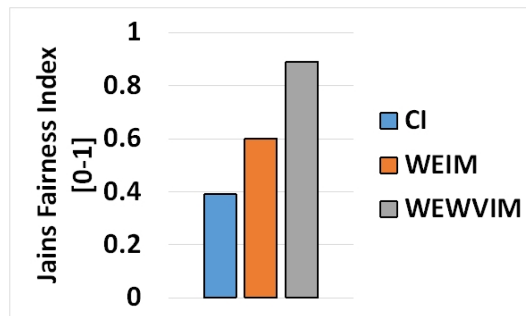

Fig. 5. Jain's Fairness Index for 100 users under three different schemes.

Fig. 4(c) illustrates that WEWVIM experiences the shortest delay (48.15 ms) which is 71.2% and 91.91% lower than WEIM (167.78 ms) and CI (600 ms). Finally, Fig. 4(d) shows that WEWVIM produces the lowest jitter (7.14 ms) compared to WEIM (22.72 ms) and CI (44.76 ms). Fig.5 depicts the fairness of throughput among UEs in HetNets. We observe that under WEWVIM, around 89% UEs have similar throughput as Jain's Fairness Index (JFI) is approximately 0.89, whereas it is around 0.6 and 0.39 under WEIM and CI, respectively. Hence, it can be concluded that our proposed scheme ensures high fairness with enhanced QoS among users compared to the other two schemes by mitigating the interference and proper resource allocation among HetNet UEs.

VI. CONCLUSION

In this paper, the downlink HetNets were investigated using a fairness criterion known as max-min fairness for ensuing high quality of service (QoS) and fairness among user equipments (UEs). The aim is to achieve equal resource management while minimizing cross-co-tier interference. To this end, we proposed a Weighted Edge Weighted Vertex Interference Mitigation (WEWVIM) algorithm under which a novel region of interest metric is proposed. It identifies interfering base stations and creates an interference graph by assigning weights to vertices and edges. The constructed graph is solved using a sub-optimal approach.

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