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Load balancing and control with interference mitigation in 5G heterogeneous networks

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Abstract

Biased user association is a promising load balancing approach in 5G heterogeneous networks due to its effectiveness in offloading users from macro base stations (BSs) to small cell BSs. However, users that are offloaded from macro BSs to small cell BSs suffer from severe interference as they are not served by the BS that provides the strongest received power. To mitigate this interference problem, this work utilises joint transmission coordinated multipoint (JT-CoMP) to enable users that are located in the cell expansion area (CRE) to be jointly served by multiple BSs thereby increasing their signal-to-interference noise ratio (SINR) and throughput. Unlike the traditional per-tier biasing approach, this paper utilises particle swarm optimisation (PSO) to assign each small cell BS a specific biasing value with the aim of balancing and control the load among BSs while the overall throughput of the system is still maximised. Simulation results demonstrate that per-tier biasing with no JT-CoMP achieves poor performance in terms of coverage probability, average user throughput and the throughput of offloaded users since offloaded users are not served by the best downlink BS. By implementing JT-CoMP with per-tier biasing, a 5 dB JT-CoMP biasing value can improve the throughput of offloaded users and it slightly improves the average user throughput. Comparing PSO with 5 dB CoMP, results show that per-BS biasing using PSO with CoMP improves the average user throughput from 0.59 to 0.72 Mbps (22%) and the throughput of an offloaded user from 0.04 to 0.1 Mbps (+ 150%).

Keywords: Heterogeneous networks, Interference mitigation, User association, 5G, CoMP

1 Introduction

One of the main approaches towards the success of 5G is the deployment of heterogeneous networks (HetNets) that consist of high transmission power base stations (BSs) such as macro BSs and low transmission power BSs (pico and femto BSs). The main advantages of HetNet deployments are that they can increase the capacity of the network and it provide users with a better link quality since users are closer to BSs. However, with standard cellular user association approaches, most users still associate with macro BSs due to their high transmission power even if they have a shorter distance to small cells, e.g. pico or femto BSs. This traditional association approach causes a load imbalance with the macro BS being overloaded while small cell BSs are lightly loaded.

The load imbalance problem has been addressed by 3GPP in Release 10 by artificially increasing the coverage area of small cells based on the cell range expansion (CRE) concept. In CRE, a positive bias value is added to the user equipments' (UEs') received power from small cell BSs.

Most of the research efforts on biased user association have attempted to find an optimal per-tier biasing values where all small cell BSs in each tier are assigned a common bias value [1–6]. With the aid of stochastic geometry, the work in [7] attempted to find the optimal per-tier biasing values that will achieve the highest signal-to-interference ratio (SIR) in multi-tier networks. Considering user mobility in multi-tier networks, stochastic geometry is utilized in [8] to derive the downlink outage probability in biased user association where all BSs in

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each tier are assigned a common bias value. The work in [9] developed an analytical model for SINR HetNets when per-tier biasing is applied. The SINR analysis is only valid for per-tier biasing with no interference mitigation technique. In biased user association, as this work shows, it is essential to jointly consider load balancing and interference mitigation. The theoretical analysis in [9] can be further developed by considering per-BS biasing and implementing an interference mitigation technique such as coordinated multipoint joint transmission (JT-CoMP). The work in implemented per-tier biasing in decoupled downlink-uplink biased user association in multi-tier networks. The results have shown that decoupled per-tier biasing significantly outperforms coupled per-tier biasing in terms on rate coverage. In [10], the authors provided a comparative analysis of different user association strategies in HetNets including biased user association. According to [10], the overall performance of multi-tier networks cannot achieve optimum performance unless an optimal bias value is found. In [11], utilising centralised subgradient algorithm and taking backhaul constrains into account, the problem of joint load balancing and interference mitigation in massive MIMO HetNet has been addressed.

Besides per-tier biasing, some research has proposed to assign each small cell BS a unique biasing value that can balance the load among different tiers [12–14]. In [12][13], particle swarm optimisation (PSO) has been utilised to search for effective biasing values that can balance the load and maximise spectral efficiency in HetNets. Recently, PSO has been used to balance and control the load in multi-tier networks by assigning each small cell BS a certain biasing value [14]. In this work, the aim of PSO is to search for effective biasing values that can control the number of UEs that can associate with each small cell BS. Although the work on per-BS biasing in [12–14] has shown its effectiveness in achieving better load balancing and higher spectral efficiency, the authors did not apply any interference mitigation technique to tackle the interference in the expanded area.

Though biased user association has proved its effectiveness in improving capacity and balancing the load [1–6][12–14], UEs that are offloaded from macro BSs to small cell BSs are not associated with the best downlink and the amount of interference that they receive from macro BSs is high [15]. Therefore, addressing this interference becomes crucial. One of the promising approaches to tackle this interference is to apply coordinated multipoint joint transmission (JT-CoMP) where a UE can be served by multiple BSs jointly. Throughout this paper, JT-CoMP and CoMP are used interchangeably.

The work in [16–20] has demonstrated the capability of JT-CoMP in providing significant SINR gain and enhancing the overall throughput and cell-edge throughput; however, one of the drawbacks of JT-CoMP is that it reduces the available bandwidth as a CoMP UE requires its cooperative BSs to reserve identical PRB(s) to send the same data. Thus, it is crucial to balance between SINR improvement and bandwidth wastage by effectively identifying the UEs that should operate in CoMP mode. In this work, only UEs that are located in the extended area are served by JT-CoMP since they have poor SINR. Since JT-CoMP eliminates the dominant signal(s) and converts them into useful signals, it is expected that the SINR gain of these UEs will improve and compensates the loss of bandwidth. Nevertheless, extreme artificial expansion of the coverage area of small cells, i.e. a high biasing value, will increase the number of CoMP UEs resulting in severe bandwidth loss. Moreover, some of the CoMP UEs may not significantly benefit from JT-CoMP as their second strongest received power may be weak. On the other hand, a small bias value may still leave the macro BS overloaded. As a result, it is essential to carefully choose effective biasing values.

Significant research efforts on JT-CoMP exist in the literature aiming at addressing inter-cell interference. In [16], the authors proposed optimal and suboptimal user-centric clustering algorithms with the objective of enhancing cell-edge throughput. The proposed user-centric clustering algorithm was compared against the static clustering approach and the results demonstrated the superiority of the proposed algorithm in improving not only cell-edge throughput but average throughput as well. Considering a single tier-network, the work in [17] developed a user-centric clustering algorithm in order to address inter-cell interference. In the proposed algorithm, UEs measure path loss from neighbouring BSs and they select their potential set of cooperative BSs. After performing this step, a UE selects its set of cooperative BSs that can maximise normalised goodput. According to the results, this approach outperforms the static clustering approach. In [18–20], the authors allow a UE to operate in CoMP mode only if its first and second strongest received powers are comparable. In [21], a user-centric clustering algorithm is developed to maximise energy efficiency in heterogeneous networks. The existing work on JT-CoMP has shown its effectiveness in tackling inter-cell interference, improving SINR and enhancing cell-edge throughput.

The purpose of this work is to balance and control the load in HetNets and apply JT-CoMP to reduce inter-cell interference in the expanded region. PSO is utilised to search for effective per-BS biasing values that can balance and control the load among BSs from different tiers while maximising cell spectral efficiency (CSE).

The main contributions of this work are summarised as follows:

1- This work mathematically proves that the SINR of offloaded users due to biasing is always less than 0 dB. This proof indicates that it is essential to implement an interference mitigating technique in order to improve the SINR levels of offloaded users.
2- Utilising the strength of JT-CoMP in eliminating the dominant interfering signal(s) and turning them into useful signals, this work implements JT-CoMP in biased user association to allow an offloaded user to be served by the two strongest BSs in order to reduce the interference that it suffers from.

This paper is organised as follows. Section 2 describes the system model. In Section 3, the methodology of generating per-BS biasing using PSO is explained. Section 4 presents the results and discussion of this work. Finally, Section 5 concludes this work.

2 System model

2.1 System layout

This work considers a downlink HetNet that consists of a set of BSs $\mathcal{M}$ that includes macro BS, pico BSs and femto BSs. Pico and femto BSs are randomly distributed over the area served by the macro BS. $\mathcal{M} = \{1, \ldots, M\}$ represents the set of BSs in the system where the first element denotes the macro BS while the rest of the elements denote pico and femto BSs. A number of users is also randomly located in the same area. Users that are located in the expanded area are served by two cooperative BSs (CoMP mode), whereas the remaining users are served only by one BS (non-CoMP mode). Figure 1 shows the system model of this work.

2.2 User association

Traditionally, user association is based on maximum received power [9]:

$$p_{kj}^{r1} = \max p_j^t \left|g_{kj}\right|^2 \quad , j \in \mathcal{M} \tag{1}$$

where p_{kj}^{r1} is the maximum received power by user k, p_j^t is the transmit power of BS j and g_{kj} is the channel gain between user k and BS j. In this work, when biasing is implemented, user association is based on maximum biased received power [9]:

$$B_{kj}^{r1} = \max p_j^t \left|g_{kj}\right|^2 b_j \quad , j \in \mathcal{M} \tag{2}$$

where B_{kj}^{r1} is the maximum biased received power and b_j is the biasing value of BS j.

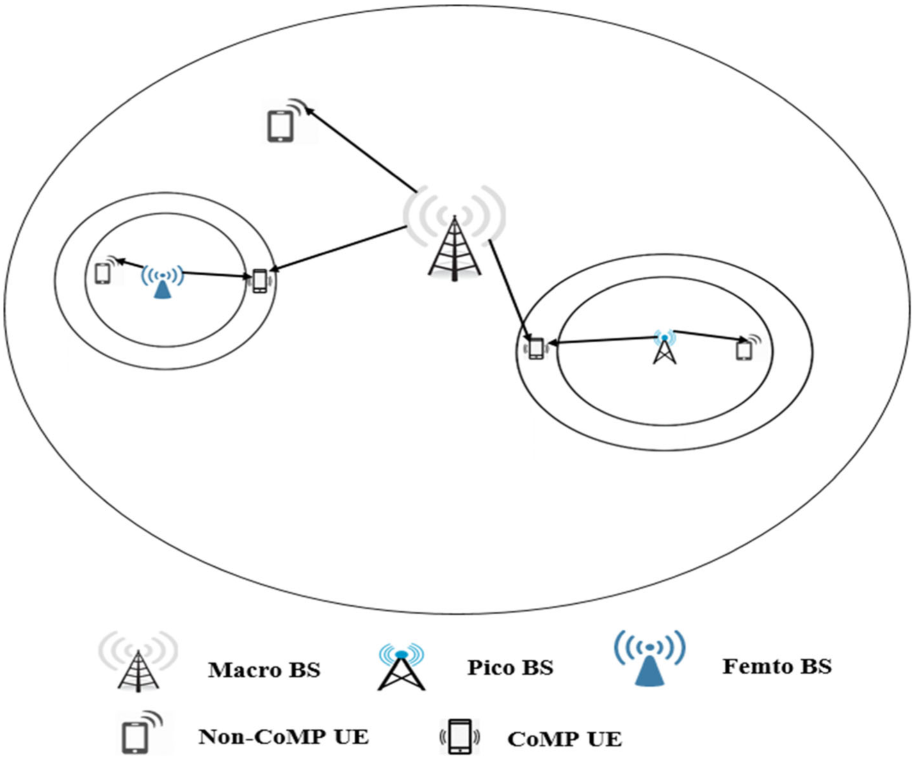

Fig. 1 System model. This figure describes the system model used in the paper. Users at the cell range expansion area are defined as cell range expansion users (CRE users). CRE users are served by multiple base stations jointly while the remaining users are served by one base station only

This biased user association has proved its effectiveness in balancing the load among different tiers; however, offloaded users that are located at the cell range expansion area (CRE users) are not served by the strongest BS. The SINR that a user k receives with no biasing is calculated as follows:

$$\mathrm{SINR}_k = \frac{x_1}{x_2 + x_3 + x_4 \ldots x_m + \sigma^2} \tag{3}$$

where x_1, x_2, x_3 are the strongest, second strongest and third strongest unbiased received power and so on and σ^2 is the noise power.

The SINR received by a user k with biasing when all small cell BSs are assigned the same biasing value is expressed as follows:

$$\mathrm{SINR}'_k = \frac{x_2}{x_1 + x_3 + x_4 \ldots x_m + \sigma^2} \tag{4}$$

This illustrates that the best serving BS has become a source of interference while the dominant interfering signal is now the serving BS.

Since $x_1 > x_2$

$$x_2 < x_1 + x_3 + x_4 \ldots x_m \tag{5}$$

$$x_2 < x_1 + x_3 + x_4 \ldots x_m + \sigma^2 \tag{6}$$

Let $a = x_2$ and $b = x_1 + x_3 + x_4 \ldots x_m + \sigma^2$, the SINR with biasing in dB is calculated as follows:

$$\mathrm{SINR}_k^{db\prime} = 10\ log_{10}(a/b) \tag{7}$$

Since the numerator (a) is less than the denominator (b), the SINR with biasing in dB ($\mathrm{SINR}_k^{db\prime}$) that a user k receives will always be less than 0 dB:

$$\mathrm{SINR}_k^{db\prime} < 0 \tag{8}$$

In case different biasing values are assigned to small cell BSs, x_2 or x_3 or x_4 and so on have the potential to become the serving BS while the remaining BSs including the best serving BS (x_1) are sources of interference. The aforementioned proof in (8) still applies in this case since $x_1 > x_2 > x_3 \ldots x_m$. The proof in (8) shows that users that are located in the CRE area will always suffer from high interference and always obtain an SINR that is less than 0 dB. Therefore, it is essential to mitigate interference at the CRE area in order to improve the SINR of the CRE UEs.

2.3 Performance metrics

The received SINR for UE_k is calculated according to the following [22]:

$$\mathrm{SINR}_k = \frac{P_{Tx}\sum_{i\in\mathcal{C}_M^k}\left|g_{ki}\right|^2}{P_{Tx}\sum_{i\in\mathcal{M}/\mathcal{C}_M^k}\left|g_{kj}\right|^2 + \sigma^2} \tag{9}$$

where P_{Tx} is the transmit power of a BS, $\mathcal{C}_M^k$ is the set of BSs in a UE_k 's cluster, g_{ki} is the channel gain between BS i and user k which consists of path loss and shadowing and σ^2 is the noise power. It is obvious from (9) that the SINR received by UE_k depends on its cluster size. The SINR of UEs that have a cluster size of two (CRE UEs) will improve since the dominant interference signal is not only cancelled but it is also converted into a useful signal.

To evaluate the SINR performance with and without biasing, the coverage probability is measured. The coverage probability is defined as the probability that a UE can achieve an SINR higher than θ which is mathematically written as follows:

$$\mathbb{P}(\mathrm{SINR} > \theta) \tag{10}$$

The transmission rate is calculated based on the modified Shannon Bound as follows [23]:

$$r = \begin{cases} 0; & \text{for SINR} < \mathrm{SINR}_{\mathrm{min}} \\ \gamma\ log_2(1 + \mathrm{SINR}); & \text{for } \mathrm{SINR}_{\mathrm{min}} < \mathrm{SINR} < \mathrm{SINR}_{\mathrm{max}} \\ r_{\mathrm{max}}; & \text{for SINR} > \mathrm{SINR}_{\mathrm{max}} \end{cases} \tag{11}$$

where r is the achievable rate in bps/Hz, γ is a constant value, $\mathrm{SINR}_{\mathrm{min}}$ is the minimum required SINR to obtain satisfactory quality of service (QoS), $\mathrm{SINR}_{\mathrm{max}}$ is the maximum SINR value that can achieve r_{max} and r_{max} is the maximum achievable rate. According to [23], $\mathrm{SINR}_{\mathrm{min}}$, $\mathrm{SINR}_{\mathrm{max}}$, γ, r_{max} have values of 1.8 dB, 21 dB, 0.65 and 4.5 bps/Hz.

The throughput that a UE_k can achieve is calculated as follows:

$$Th_k = B.r \tag{12}$$

where B is the bandwidth that is assigned to UE_k.

2.4 Bandwidth allocation

Effective resource allocation in JT-CoMP networks is required to balance the amount of bandwidth given to non-CoMP UEs and the amount of bandwidth to be allocated to CoMP UEs. A large amount of bandwidth given to CoMP UEs will enhance the throughput of these UEs; nevertheless, this improvement is achieved at the expense of non-CoMP UEs. Similarly, allocating a large amount bandwidth to non-CoMP UEs increases the throughput of non-CoMP UEs but the throughput of CoMP UEs will decrease. In this work, we follow our previous work in [18] to allocate bandwidth to non-CoMP and CoMP UEs.

Each BS considers UEs that are located in the expanded region as its CoMP UEs whether they are the

UE's strongest BS or second strongest BS. The remaining UEs that are not located in the expanded region of a BS are considered as its non-CoMP UEs. The total bandwidth is divided into non-CoMP and CoMP bandwidth as follows [18]:

$$BS_m^{non-CoMP} = \frac{B_m}{\left(\left|\mathcal{N}_K^m\right| + \left(b\left|\mathcal{Q}_K^m\right|\right)\right)}\left|\mathcal{N}_K^m\right| \tag{13}$$

$$BS_m^{CoMP} = bBS_m^{non-CoMP}\left|\mathcal{Q}_K^m\right| \tag{14}$$

where B_m is the total bandwidth of B_m, $\mathcal{N}_K^m$ and $\mathcal{Q}_K^m$ are the set of non-CoMP and CoMP UEs that are associated with BS_m, respectively. Expressions (13) and (14) are based on the idea that the assigned bandwidth of a CoMP user is b times the bandwidth of a non-CoMP user. In this work, b is set to be 0.5 which indicates that a CoMP user obtains half bandwidth compared with what a non-CoMP user obtains. This half bandwidth assignment is considered to be fair since the SINR of a CoMP user is expected to significantly improve. In addition, a CoMP user requires its two strongest BSs to reserve identical resource blocks to transmit the same data.

3 Dynamic per-BS biasing using PSO and problem formulation

3.1 Dynamic per-BS biasing using PSO

Generally, bias values can be generated either statically or dynamically. In the static case, bias values do not change over time, whereas bias values keep changing over time in the dynamic case. In addition, there are mainly two approaches to assign bias values: per-tier biasing and per-BS biasing. In per-tier biasing, a common bias value is assigned to all BSs that are from the same tier. For example, all pico BSs are assigned the same biasing value. The per-BS biasing approach assigns each BS a specific bias value.

Although per-BS biasing is a promising technique that can balance the load among BSs from different tiers, obtaining optimal per-BS bias values is an NP hard problem. An optimal, yet prohibitively complex, approach to obtain per-BS bias values is to perform exhaustive search. Taking advantage of its fast convergence speed, high solution quality and few controlling parameters, PSO is used in this paper to generate per-BS bias values with the aim of balancing and controlling the load and maximising the throughput.

PSO is an iterative search algorithm that aims to optimise a certain objective function. In PSO, a swarm of particles flies in the search space seeking better solutions where each particle in the swarm represents a candidate solution. In each iteration of the PSO process, particles will move towards the direction of the global best position (*gbest*) which is the particle that has achieved the best solution so far. In addition, each particle is attracted by its own historical best position (*Pbest*). Particles update their velocities and positions in each iteration as follows:

$$\begin{aligned} v_{id} = wv_{id} + c_1r_1\left(Pbest_{id}-x_{id}\right) \\ + c_2r_2\left(gbest_d-x_{id}\right) \end{aligned} \tag{15}$$

$$x_{id} = x_{id} + v_{id} \tag{16}$$

where w, c_1 and c_2 are inertia weight, cognitive acceleration coefficient and social acceleration coefficient, respectively. r_1 and r_2, are two uniform random variables that have values in the range of [0, 1].

Figure 2 shows a flowchart that explains how PSO can be used to generate per-BS bias values with the objective of balancing and controlling the load and enhancing throughput. Initially, PSO generates a number of particles in the search space with random positions and velocities.

Each particle consists of n dimensions where n is the number of total BSs that include macro BSs and small cell BSs. Each dimension represents a biasing value that can be assigned to a specific BS. Each dimension can have a value in the range of $[b_{\min}, b_{\max}]$ where $b_{\min}$ and $b_{\max}$ are the minimum and maximum biasing values, respectively. Figure 3 shows an example of three different particles with a dimension of seven (one macro, two picos BSs and four femto BSs).

The first dimension of each particle represents the biasing value that is assigned to the macro BS. Macro BSs are assigned a biasing value of 0 dBm since they have a wider coverage area compared with small cell BSs. Pico BSs are the second and third elements with biasing values of 3 dBm and 5 dBm for particle 1. The remaining elements are the biasing values assigned to femto BSs. As the PSO process iterates, each particle updates its velocity and position based on (6) and (7), respectively in order to obtain a better solution. Since not all particles in the swarm will be able to control the load per-BS, particles are categorised into valid and invalid particles. A valid particle is a particle that can control the load per BS by satisfying the constraint in (19). After identifying valid from invalid particles, the fitness of each particle is evaluated. An invalid particle will be penalized by setting its fitness to be zero, whereas the fitness of valid particles will be evaluated based on (9). During each iteration, the best historical valid particles are denoted as *Pbest* whereas the best valid particle that has achieved the best fitness so far is denoted as *gbest*. The PSO process continues until it reaches the maximum number of iterations. At the end of the PSO process, the global best position

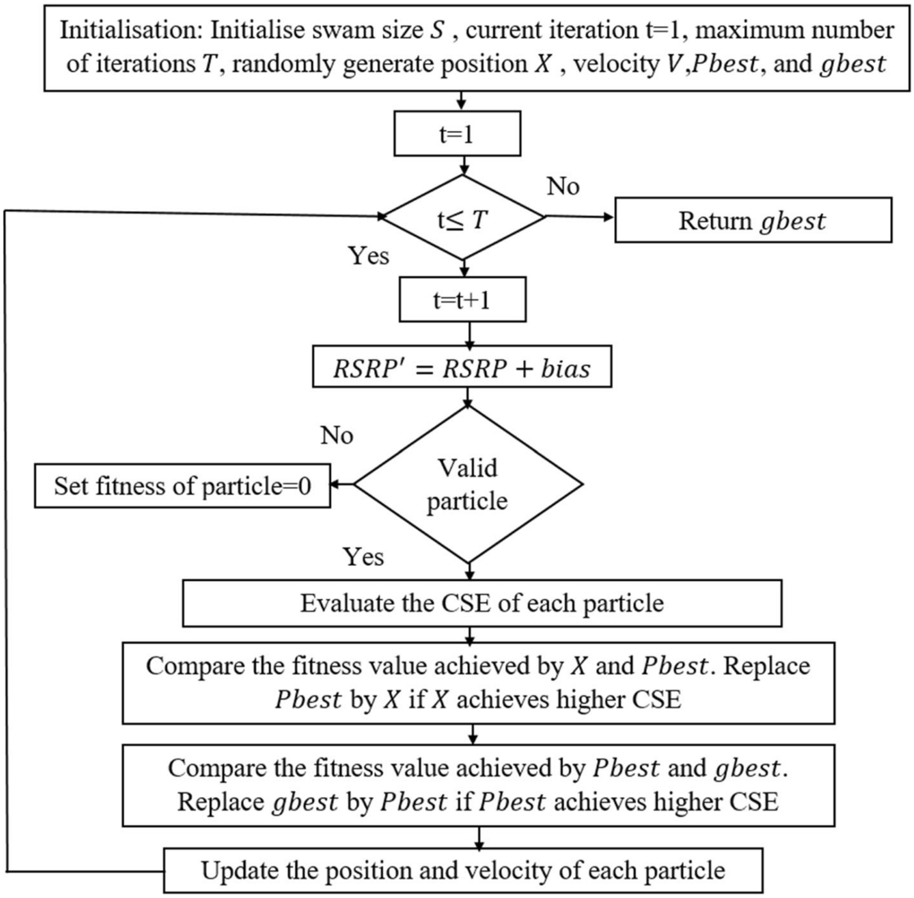

Fig. 2 The PSO process to generate dynamic biasing per-BS. This figure describes how particle swarm optimisation can be applied to generate per base station biasing. It first generates the particles, checks the validity and fitness of each particle and it records the best achievable particle is in the swarm so far. PSO keeps repeating this process until the maximum number of iterations is reached

gbest is returned which denotes the best obtained biasing values that can be assigned to each small cell BS.

3.2 Problem formulation

This work utilises PSO to search for the best per-BS biasing values that can maximise the CSE while the percentage of UEs that can associate with each small cell BS is controlled. The following provides a mathematical expression of the CSE:

$$V = \sum_{m=1}^{M} \sum_{k=1}^{K} D_{mk} Th_{mk} \quad (17)$$

Fig. 3 An example of three particles that generate per-BS biasing values. This figure provides an example of a number of particles that represents the per base station biasing values

$$\mathrm{CSE} = \frac{V/BW}{|\mathcal{M}|} \tag{18}$$

where V is the system throughput and D_{mk} is expressed as follows:

$$D_{mk} = \begin{cases} 1 & \text{, if a user } k \text{ is connected to BS } m \\ 0 & \text{, if a user } k \text{ is not connected to BS } m \end{cases}$$

The D_{mk} value is dependent on the biasing values that are generated by each particle. For UE_k, a small biasing value of BS m may cause D_{mk} to have a value of 0 since this biasing value is not high enough to attract UE_k to associate with BS m, whereas a high bias value may cause the D_{mk} value to be 1.

In this work, the aim of PSO is to maximise the following formulated objective function:

$$\begin{aligned} &\max && \mathrm{CSE} \\ &\text{Subject to} && U \leq \alpha|\mathcal{K}| \end{aligned} \tag{19}$$

where α is the spread load control parameter that will ensure that the number of CRE UEs U that are associated with BS m does not exceed or go below a specific number and $|\mathcal{K}|$ is the total number of users in the system. The benefit of the constraint in (19) is to ensure that a small cell BS is not overloaded or highly loaded. Also, it limits and controls the number of CRE UEs as allowing many UEs to operate in JT-CoMP mode will consume the available bandwidth.

4 Results and discussion

The performance of the proposed PSO algorithm against the traditional biasing scheme with and without JT-CoMP is evaluated based on a MATLAB snapshot simulation. To evaluate the performance with and without CoMP, UEs are first served by a single BS and the results are recorded as no CoMP. Then, CoMP is implemented for the same snapshot where UEs that are in the extended region are served by the two strongest BSs while the remaining UEs are served only by a single BS. A macro BS is deployed in an area of 1 km by 1 km and small cell BSs are randomly distributed over the same area. The density of UEs in this work is considered to be 500 users/km^2. The simulation parameters in this work are based on 3GPP recommendations to evaluate the performance of wireless networks [24]. Two common scheduling algorithms are round robin and proportional fairness. In round robin algorithm, all users are assigned the same bandwidth. It is true that round robin scheduling algorithm does not provide the highest cell throughput but is the best scheduling algorithm in terms of fairness. The proportional fairness algorithm attempts to balance between fairness and system throughput [25]. Proportional fairness assigns resources to a user based on its channel quality and the average amount of resources that it had been assigned in the past. The limitation of round robin algorithm is that users with poor SINR levels (cell-edge users) waste the available bandwidth; however, when CoMP is implemented, the SINR levels of cell-edge users are significantly improved which indicates that the round robin scheduling algorithm is a robust scheduling algorithm candidate for CoMP networks. It is expected that the performance of other scheduling algorithms such as proportional fairness will be more similar to the performance of the round robin algorithm when CoMP is implemented, since the SINR level variation between cell-centre users and cell-edge users is minimised.

In this work, full buffer traffic is considered. The reason for choosing full buffer traffic is to evaluate the overall performance under the worst-case interference scenario. Since CoMP is an interference mitigation technique, it is desirable to evaluate its performance under the worst-case interference scenario. Additionally, full buffer traffic is widely used by 3GPP [24] for interference analysis. Table 1 summarises the simulation parameters of this work.

The PSO parameters including swarm size, controlling parameters and maximum number of iterations are presented in Table 2. Inertia weight (w), cognitive acceleration constant (c_1) and social acceleration constant (c_2) are the three main parameters of PSO. Several works [26][27] on PSO have recommended their values to be 0.9–0.4, 2 and 2 respectively.

Figure 4 shows the coverage probability with and without JT-CoMP for biasing values ranging from 0 to 15 dB. As Fig. 4 illustrates, with no CoMP, the percentage of UEs that achieve an SINR higher than 0 dB is 64% with no biasing. By implementing biasing with no CoMP, the percentage of UEs that obtain higher than 0 dB is 60%, 50% and 39% when the biasing values are 5 dB, 10 dB and 15 dB, respectively. It is clear that biasing with no CoMP decreases the coverage probability. It

Table 1 Simulation parameters

Parameter	Value
Bandwidth	20 MHz
Tx Power (macro, pico, femto)	(46 dBm, 30 dBm, 20 dBm)
Macro pathloss [24]	$128.1 + 37.6\log_{10}(R)$, R in km
Pico pathloss [24]	$140.7 + 36.7\log_{10}(R)$, R in km
Femto pathloss [24]	$127 + 30\log_{10}(R)$, R in km
Shadowing std. dev.	8 dB (macro), 10 dB (pico), 10 dB (femto)
Noise power level	− 174 dBm/Hz
Scheduler	Round robin
Traffic model	Full buffer

Table 2 PSO parameters

Parameter	Setting
Swarm size	40
Maximum number of iterations	100
c_1	2
c_2	2
w	0.9–0.4

is also obvious from Fig. 4 that increasing the biasing values from 5 to 15 dB will significantly decrease the coverage probability. This is an expected result as CRE UEs are not associated with the BS that provides the strongest received power; instead, they are served by the strongest biased received power. In other words, the unbiased strongest received power provided by a macro BS becomes the dominant interfering signal when biasing is implemented. The reason that the coverage probability decreases as the biasing value increases is because a high biasing value such as 15 dB will increase the number of CRE UEs who suffer from high interference that comes from their unbiased strongest BS. With JT-CoMP, a CRE UE is served by the two strongest BSs which can be unbiased BS (macro BS) and biased BS (small cell BS) or two biased small cell BSs.

It is expected that the SINR of a CRE UE will improve since JT-CoMP does not only cancel the dominant interfering signal but it also converts it into a useful signal. When CRE UEs operate in CoMP mode, the percentage of UEs that achieve higher than 0 dB is 69%, 64% and 54% when the biasing values are 5 dB, 10 dB and 15 dB, respectively. As shown from Figs. 4 and 5, dB biasing with CoMP outperforms the traditional approach (0 dB biasing with no CoMP) in terms of coverage probability. This SINR improvement is achieved because cell-edge UEs in the traditional approach (no biasing and no CoMP) become CRE UEs that are served by JT-CoMP when biasing is implemented. Although it is expected that increasing the biasing values to 10 dB and 15 dB with CoMP will improve the coverage probability as more UEs will operate in CoMP mode, this is not true as can be seen in Fig. 4. The main reason for this to happen is because a high biasing value will cause a CRE UE to be served by two biased small cell BSs and leave this UE suffer from high interference that comes from the unbiased strongest macro BS. PSO that assigns each small cell BS a specific biasing value and controls the number of CRE UEs per BS has a comparable performance in terms of coverage probability with 5 dB CoMP and outperforms all other compared biasing approaches. Overall, biasing with no CoMP significantly decreases

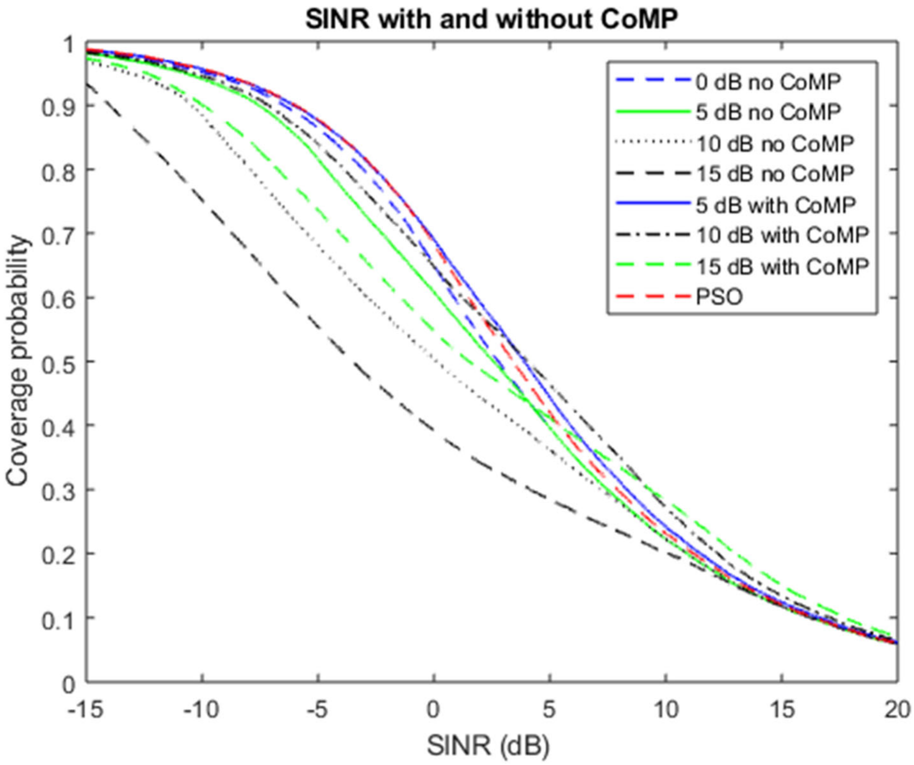

Fig. 4 Biased user association coverage probability with and without CoMP. This figure shows the coverage probability for biased user association with and with no CoMP. The figure shows that implementing coordinated multipoint significantly improve the coverage probability

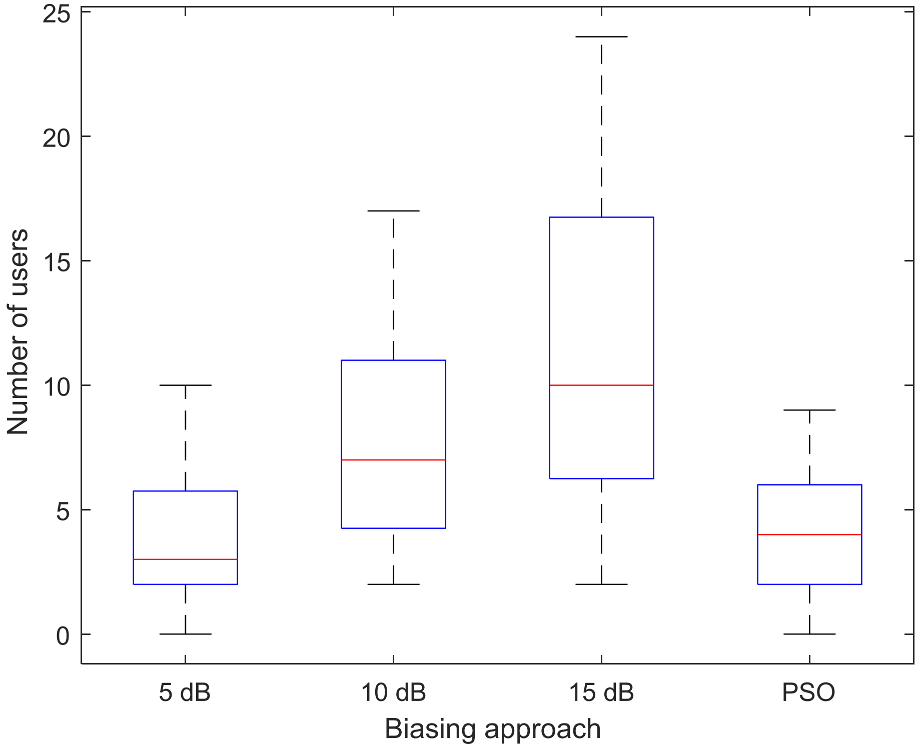

Fig. 5 Number of users associated to each BS for per-tier (0–15 dB) and per-BS (PSO) biasing approaches. This figure shows the load per base station when different biasing approached are used

the coverage probability while the best coverage probability is achieved with per-BS biasing using PSO and with 5 dB CoMP. A 5 dB CoMP outperforms other biasing approaches because if a high biasing is applied, a CRE user will be served by the strongest two biased small cell BSs while it still receives severe interference from unbiased macro BS that provides the strongest received power.

Figure 5 shows a boxplot that represents the number of CRE UEs with per-tier biasing and per-BS biasing (PSO) for biasing values of 5 dB, 10 dB and 15 dB. The figure shows that as the biasing value increases from 5 to 15 dB, the number of CRE UEs per BS will increase. In the case of a 5 dB bias, some users start to offload from the macro BS to small cell BSs. However, the macro BS is still heavily loaded. Increasing the biasing value from 5 to 10 dB and 15 dB starts to balance the load between the macro BS and small cells; nevertheless, these biasing values cause some small cell BSs to be overloaded as shown in Fig. 5. By applying PSO, the number of CRE UEs per BS is controlled to ensure that a small cell BS is not overloaded. This controlling is performed by following the constraint in (19) which restricts a BS to have a biasing value that will cause its CRE UEs exceed a specific percentage. From Fig. 5, with a load control parameter of 2%, it is shown that the mean and maximum of CRE UEs is 4 and 9 which indicates the effectiveness of PSO in controlling the number of CRE UEs per BS.

Figure 6 shows the number of UEs per BS when the load control parameter is 2%, 3%, 4%, and 5%. As Fig. 6 shows, increasing the load control parameter causes load imbalance where some BSs become heavily loaded while other BSs become lightly loaded. This indicates that it is essential to keep the load controlling parameter as small as possible to achieve better load balancing.

Figure 7 compares the performance of biasing with no CoMP and biasing with CoMP in terms of average user throughput and average CRE UE's throughput. From Fig. 7, it is clear that the average user throughput decreases when biasing with no CoMP is implemented. Biasing value with no CoMP of 5 dB, 10 dB and 15 dB achieve average user throughput of 0.48 Mbps, 0.42 Mbps and 0.38 Mbps respectively. Since no interference mitigation technique is applied to reduce the interference received by CRE UEs when biasing with no CoMP is implemented, the average user throughput degrades. The throughput degradation becomes higher when the biasing value increases from 5 dB to 15 as a higher biasing value will increase the number of CRE UEs as shown in Fig. 5. The throughput of CRE UEs with no CoMP is zero for all biasing values since a CRE UE with no CoMP achieves an SINR less than 0 dB (proven in Section 2.2) which results in a zero

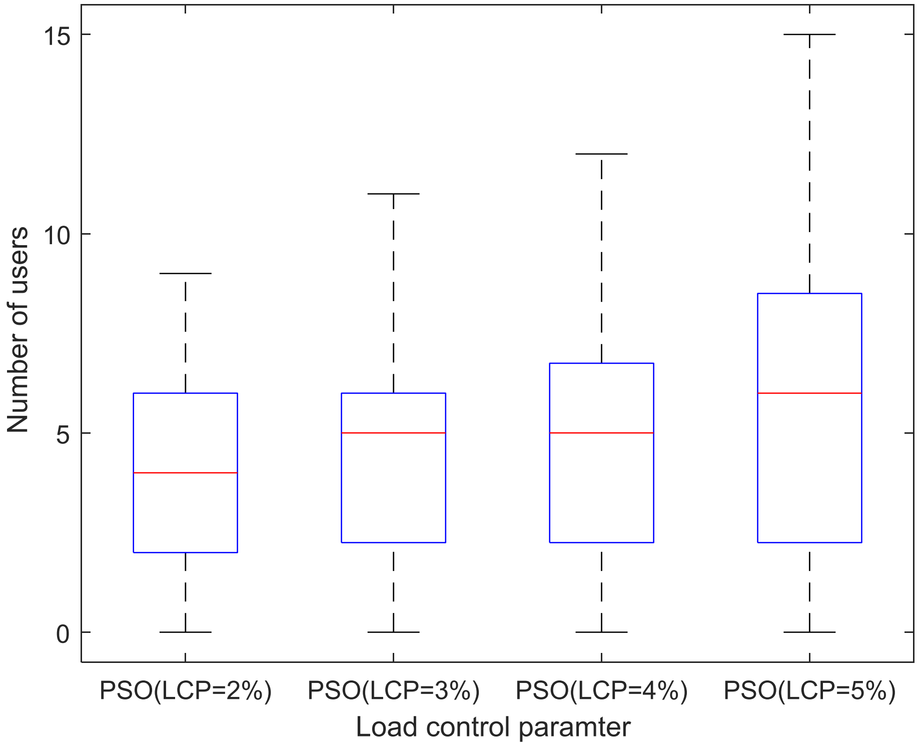

Fig. 6 Number of users per BS for different load control parameter. This figure shows the load per base station when the per base station biasing using particle swarm optimisation is implemented. It shows how particle swarm optimisation can control the number of users that are located at the cell expansion area

throughput based on the calculation of (11). The performance of 5 dB biasing with CoMP outperforms the traditional approach, per-tier biasing with no CoMP and per-tier biasing with 10 dB and 15 dB CoMP in terms of average user throughput and CRE UEs throughput. This improvement happens because the 5 dB CRE UEs improve their SINR as shown in Fig. 4 when they are served by JT-CoMP and as a result improving their throughput. The average user throughput and CRE UEs' throughput decrease as the biasing value increases from 5 to 10 dB due to the increase in the number of CRE UEs. A high number of CRE UEs will consume the available bandwidth since a physical resource block that is reserved by the strongest BS cannot be reused by the second strongest BS. Also, some users that start to operate in JT-CoMP mode when the biasing value is increased from 5 to 10 dB achieve a marginal SINR gain that does not compensate for the loss of bandwidth. Increasing the biasing value from 10 to 15 dB will further decrease the average user throughput and the CRE throughput as a 15 dB bias value will include many CRE UEs. As shown in Fig. 7, PSO with 2% load control parameter provides significant improvement in terms of average user throughput and CRE throughput. It is also clear that PSO outperforms all other compared approaches that include the tradition approach, per-tier biasing with no CoMP and per-tier biasing with CoMP. PSO achieves this throughput improvement since it can generate per-BS biasing values that can control the number of CRE UEs. In other words, PSO chooses effective biasing values that avoid allowing a user to operate in JT-CoMP mode if its SINR gain does not compensate for the bandwidth loss.

5 Conclusion

This paper utilises PSO to search for the best biasing values that can be assigned to each small cell BS with the objective of balancing and controlling the number of CRE UEs that can associate with each small cell BS while the maximum achievable throughput is still maximised. CRE UEs suffer from high interference since they are not associated with the best serving BS. This work has proved that a CRE UE will always achieve an SINR that is less than 0 dB. As a result, it is crucial to implement an interference management approach that can reduce the interference that occurs at the CRE area when biasing is implemented. As an interference mitigation technique, JT-CoMP has been implemented in this work to serve UEs that are located in the CRE area. By implementing JT-CoMP, the dominant interfering signal after biasing (the best signal before biasing) can be converted into a useful signal; thus, improving the SINR and

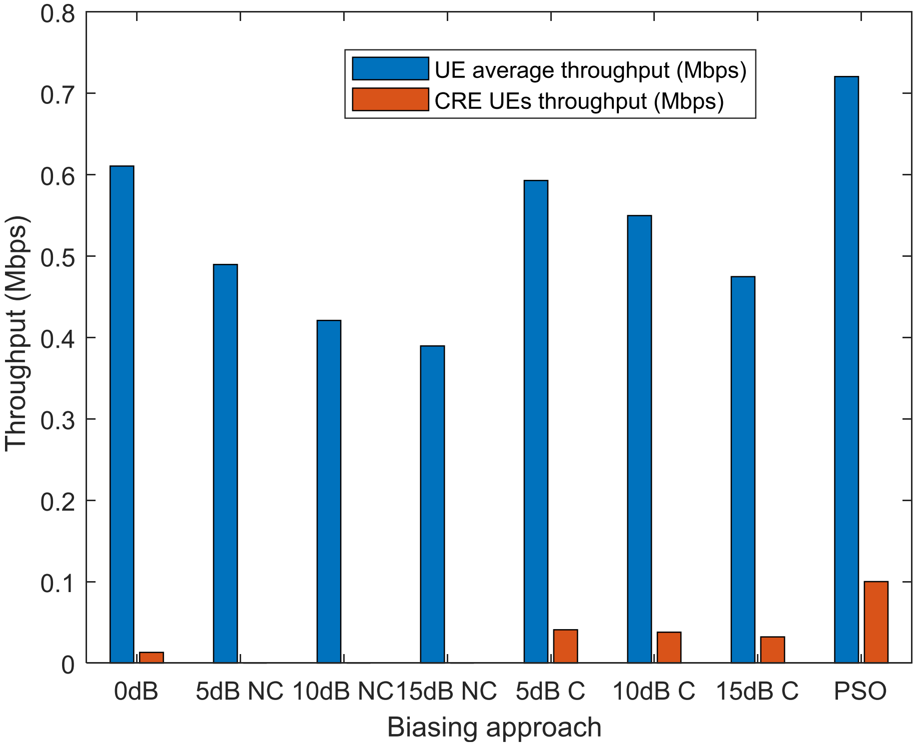

Fig. 7 Average UE throughput and CRE throughput for different biasing approaches. NC and C refers to no CoMP and CoMP, respectively. In this figure, the average user throughput and the throughput of cell range expansion for biased user association with and without CoMP are shown. From the figure, per base station biasing using particle swarm optimisation outperforms the per-tier biasing with and with no CoMP

throughput of CRE UEs. Comparing per-tier biasing with no CoMP, per-tier biasing with CoMP and per-BS biasing using PSO with CoMP, results have shown that per-tier biasing with no CoMP degrades the coverage probability, average user throughput and the throughput of CRE UEs since CRE UEs will experience high interference from their neighbouring macro BSs. For per-tier biasing with CoMP, unlike 10 dB and 15 dB, a 5 dB can improve the throughput of CRE UEs and it also provides slight average user throughput improvement. Results have shown also that increasing the biasing value with and without CoMP will degrade the overall performance since the number of CRE UE will increase. A high bias value such as 15 dB decreases the user average throughput from 0.61 to 0.38 Mbps (– 37.7%) with no CoMP and from 0.61 to 0.47 Mbps (– 22.9%) with CoMP. By controlling the number of CRE UEs per-BS using PSO, PSO has shown that it can significantly improve the average user throughput and the throughput of the CRE UEs and its performance is better than per-tier biasing with no CoMP and per-tier biasing with CoMP. Comparing PSO with 5 dB CoMP (the best per-tier biasing approach), per-BS biasing using PSO improves the average throughput from 0.59 to 0.72 Mbps (22%) and it improves the average throughput of a CRE UE from 0.04 to 0.1 Mbps (+ 150%).

Abbreviations

BSs: Base stations; CRE: Cell expansion area; CSE: Cell spectral efficiency; QoS: Quality of service; HetNets: Heterogeneous networks; JT-CoMP: Coordinated multipoint joint transmission; PSO: Particle swarm optimisation; SINR: Signal-to-interference noise ratio; UEs: User equipments; SIR: Signal-to-interference ratio

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Authors' contributions

All authors contributed to the overall methodology of the work and discussed the results. Tareq performed the simulation and wrote the first full draft of the paper. David, Alister and John provided some helpful comments and edits that helped to improve the quality of the paper. All authors have read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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