2018 IEEE 29th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)

Concurrent CCO and LB Optimization in Emerging HetNets: A Novel Solution and Comparative Analysis

Ahmad Asghar, Hasan Farooq and Ali Imran
Telecommunication Engineering, Department of Electrical and Computer Engineering
The University of Oklahoma
Tulsa, Oklahoma 74135, USA
Email: {ahmad.asghar, hasan.farooq, ali.imran}@ou.edu

***Abstract*—Optimizing parameters to achieve optimal trade-off between coverage and capacity is a well known research problem in 5th Generation mobile cellular networks. Introduction of ultra dense heterogeneous networks is bound to exacerbate this problem by adding a third conflicting objective i.e., load balancing between macro and small cells. Existing solutions on load balancing are not suited for this purpose since they balance cell loads at the cost of spectral efficiency, a key measure of resource efficiency in 5G networks. To tackle these challenges, we propose a novel solution for joint optimization of coverage, capacity and load in ultra dense heterogeneous networks that does not compromise spectral efficiency or subscriber satisfaction. The proposed solution incorporates antenna tilt, transmit power and cell offset parameters into a single objective. We compare two different versions of our proposed solution with existing coverage optimization [1], and coverage, capacity and load optimization [2] algorithms, as well as coverage optimization and load balancing solutions for HetNets to highlight its advantages. Simulation results show that the proposed solution improves service quality while also offering higher residual capacity compared to nearest benchmark.**

***Index Terms*—Heterogeneous Networks; Self Organizing Networks; Coverage and Capacity Optimization; Load Balancing; Joint Optimization.**

I. Introduction

Development guidelines for 5th Generation mobile cellular networks (5G MCNs) emphasize the need for higher network capacity and user quality of service (QoS) than ever before [3]. Among the solutions proposed in literature to achieve this capacity gain for 5G MCNs, the deployment of ultra dense heterogeneous networks (UDHNs) is considered the most promising [4]. However, significantly increased network density and the associated increase in number of parameters to be continually configured and optimized in UDHNs mean the legacy semi-manual optimization and operation of the network will simply no longer be a technically or economically viable option in 5G MCNs [4].

To cope with this challenge, researchers have already proposed several self organizing network (SON) solutions which can autonomously optimize MCN performance [5]. Among the SON use cases adapted by the 3rd Generation Partnership Project (3GPP), coverage and capacity optimization (CCO) function and load balancing (LB) function [6] are of top-most importance vis-a-vis UDHNs. The CCO SON function aims to optimize network coverage without compromising network capacity in terms of signal-to-noise and interference ratio (SINR). The LB SON function on the other hand strives to optimize network parameters to ensure that traffic load across cells remains balanced in spite of spatio-temporal changes in user traffic. Due to the transmit (Tx) power imbalance between macro and small cells in UDHNs, it is obvious that the MCN operator must employ both these SON functions concurrently to ensure that network coverage and subscriber QoS demands are satisfied.

Given their relative importance compared to other SON functions, CCO and LB have received considerable attention from the research community [5]. However, the concurrent operation of CCO and LB in real networks creates conflicts due to their dependency on the same optimization parameters including Tx powers, antenna tilts, and cell individual offsets (CIOs), to name a few [7]. Aside from the explicit parametric conflicts between CCO and LB SON functions, the dependence of cell load on SINR also creates an implicit conflict between them. Many more users are associated with the macro cell compared to small cells due to its higher Tx power. This translates into higher resource occupancy at macro cell, thus causing more interference to co-channel cells. Higher interference to neighboring cells, in turn, degrades SINR of users associated with them. This drives up the number of required physical resources at those cells to achieve same data rates, and so the cascade effect continues. A more detailed study of the relationship between SINR and cell load in UDHNs is presented in [8].

In order to overcome the aforementioned load im-

978-1-5386-6009-6/18/$31.00 ©2018 IEEE

balance problem between macro and small cells, 3GPP introduced the CIO parameter [9]. CIO can be used to forcefully associate users to small cells based on a virtual received power increment. This method, however, ignores the consequent degradation in SINR experienced by users forced to associate with the small cell [10]. It also fails to account for the impact of Tx powers and antenna tilts on SINR, cell loads and user association [11]. As a result, simple CIO based LB not only compromises CCO objective, it also sacrifices overall spectral efficiency making it a far less ideal solution in UDHNs for 5G and beyond.

In light of these challenges, it is imperative that any solution designed to optimize coverage, capacity and load in emerging UDHNs must build on model that incorporates the impact of cell load on SINR and simultaneously optimizes all three parameters that affect these these conflicting and intertwined objectives namely, Tx power, antenna tilt, and CIOs.

II. Related Work

Studies targeting CCO SON function generally consider SINR, or some derivative of it, as the target optimization metric with coverage included as a constraint [12]. Conversely, studies on LB SON function often achieve load sharing between cells by changing user associations through adaptation of Tx powers [13] and CIOs [10]. However, conflicts between the two SON functions have only recently come under greater scrutiny [7]. Lateef et. al. [7] have identified the implications of the conflict between CCO and LB SON functions not just from the perspective of parametric clash but also in terms of their impact on coverage, SINR and load.

The case for a joint study of load and SINR, given their coupling, is made in [14] where the authors argue that any algorithm that targets user quality of experience must consider cell load on top of SINR, since their combination represents a truer picture of user experience rather than simply considering SINR. This is because, only optimizing SINR may result in users with high SINR but more congested cells resulting in poor QoS (caused by blocking). On the other hand mere balancing of load among cells, e.g. through CIOs, may result in less congested cells but very low user SINR resulting in overall reduced spectral efficiency, capacity and QoS (due to high bit error rate).

Because of the ability to account for the relationships between underlying parameters and metrics, the most effective method of deploying CCO and LB concurrently is by formulating the objectives of the functions together in terms of their optimization parameters [7]. One such methodology is presented in [2] where the authors propose to co-design CCO and LB SON functions using antenna tilts and CIOs for a macro cell only network. The objective formulated in [2] targets minimization of cell loads using a heuristic algorithm that iterates through antenna tilt configurations until the optimal load distribution is achieved.

III. Proposed Approach and Contributions

The contributions and results obtained through this study advocate for joint optimization of coverage, capacity and load over traditional single-objective optimization, especially in wake of UDHNs for 5G and beyond. These contributions and findings are summarized as follows:

- This study offers an analysis of the interaction between SINR and cell load in conjunction with analytical insights into how cell Tx powers and antenna tilts affect this relationship.
- We present a joint CCO-LB solution that is based on maximizing SINR (CCO objective) with LB achieved through the very objective function by maximizing geometric mean which is inherently fair, instead of arithmetic mean of SINR.
- To emphasize this, we present and analyze two variants of our solution i.e., with and without geometric mean based fairness. Both methods are compared with the CCO solution proposed in [1] and CCO-LB solution in [2] in Section IV. Furthermore, we compare our joint CCO-LB solution with CCO and LB for UDHNs to highlight the need for SON coordination in UDHNs.

IV. System Model

A. Network and User Specifications

We consider a network layout with hexagonal tri-sector macro cells with at least one randomly deployed omni-directional small cell per sector. Macro and small cells use the same frequency spectrum with universal frequency re-use. An LTE like physical layer is considered with bandwidth divided into physical resource blocks (PRBs) of fixed spacing. For conciseness, the downlink direction is chosen for the analysis as this is where most imbalance in coverage of macro cells and small cells occurs. User association is calculated for a snapshot of network user distribution. Furthermore, we use knowledge of desired user throughput, which can be modelled as a spatio-temporal function of subscriber behavior, subscription level, service request patterns, as well as the applications being used with the help of big data analytics as recently proposed in [4]. We use this to estimate the load generated by a user.

B. Parameters and Measurements

The following network information is assumed to be available to both UEs and cells.

1) Cell Load: For the given system model, we define instantaneous cell load as the ratio of PRBs occupied in a cell during a transmission interval to total PRBs available in the cell. This information is available as a standard measurement in LTE called "UL/DL total PRB usage" [6] and can be broadcast to the UEs. To determine cell load, we first calculate the number of PRBs η_u^c allocated to each user u in cell c. This is given as:

$$\eta_u^c = \frac{1}{\omega_B}\left(\frac{\hat{\tau}_u}{f(\gamma_u^c)}\right) \tag{1}$$

where $\hat{\tau}_u$ represents the (desired) throughput of user $u \in \mathbb{U}_c$, where $\mathbb{U}_c$ is the set of all active users associated with cell c who have requested resources from the cell, γ_u^c represents the SINR of user u when associated with cell c and ω_B is the bandwidth per PRB. $f(\gamma_u^c)$ denotes the downlink spectral efficiency for given SINR. If we consider features such as multi-input multi-output (MIMO), or coding scheme and scheduling gains, $f(\gamma_u^c)$ can be defined as $f(\gamma_u^c) := A\log_2(1 + B\gamma_u^c)$, where variables A and B can be used to model throughput gains (per PRB) from different physical layer features. For simplicity, and without loss in generality, we assume $A = B = 1$.

Ratio of the sum of requested PRBs in a cell to the cell bandwidth N_b^c gives the cell load η_c:

$$\eta_c = \frac{1}{N_b^c}\left(\frac{1}{\omega_B}\left(\sum_{\mathbb{U}_c}\frac{\hat{\tau}_u}{log_2(1+\gamma_u^c)}\right)\right) \tag{2}$$

where N_b^c is the total number of PRBs at cell c. If there is no cap on desired user throughput, the range of cell load is $\eta_c \in [0, \infty)$. However, when $\eta_c > 1$, the cell in reality will be fully loaded and new incoming users, for whom there are no more resources left, will be blocked.

2) Received Power: In LTE networks, downlink RSRP from nearby base stations is continuously monitored by the UEs and reported to the serving eNB for a number of purposes. In this study, we use downlink RSRP to calculate coverage probability in the network.

3) Cell Individual Offset: CIO can be defined as a combination of multiple cell association parameters introduced by the 3GPP [9]. More specifically, CIO includes cell hysteresis, cell offsets, and event related offsets which are used by the UE to decide association with a cell. CIO information can easily be broadcast by each cell and decoded by the UEs as part of standard operation. In this study we treat CIO as a simple virtual increment in RSRP.

4) Antenna Tilt: The channel gain G_u^c from macro cells to users is dependent on the 3D antenna pattern of the macro cell transmitter. For this purpose, we use the theoretical antenna gain model provided by the 3GPP [15] which is given as:

$$G_u^c = 10^{-1.2\left(\lambda_v\left(\frac{\psi_u^c - \psi_{tilt}^c}{B_v}\right)^2 + \lambda_h\left(\frac{\phi_u^c - \phi_{azi}^c}{B_h}\right)^2\right)} \tag{3}$$

where ψ_u^c is the vertical angle between user u and the antenna of cell c, ψ_{tilt}^c is the tilt angle of the antenna, λ_h and λ_v are the weighting factors for horizontal and vertical beam patterns, ϕ_u^c is the horizontal angle of user u from cell c, ϕ_{azi}^c is the azimuth of cell c, and B_h and B_v are horizontal and vertical beamwidths of the antenna of cell c. If we assume that λ_h, λ_v, B_h, and B_v are fixed and substitute $x_u^c = (\phi_u^c - \phi_{azi}^c)^2$ in (3), we can simplify (3) as:

$$G_u^c = 10^{\mu(\psi_u^c - \psi_{tilt}^c)^2 + \nu x_u^c} \tag{4}$$

where $\mu = -1.2(\lambda_v/B_v^2)$ and $\nu = -1.2(\lambda_h/B_h^2)$ are fixed antenna characteristics.

5) Signal-to-Interference and Noise Ratio: Equation (2) demonstrates the relationship between cell load and downlink SINR. To develop a joint CCO-LB solution, we need to model SINR as a function of the optimization parameters and use it to estimate cell load in (2). Based on the system model and standard free space pathloss model, SINR for user u can be estimated as a function of antenna tilts and transmit power. Additionally, SINR is dependent on the resources occupied in interfering cells which is more reflective of average temporal interference compared to fully loaded systems which are used to obtain lower-bound SINR.

$$\gamma_u^c = \frac{P_t^c G_u 10^{\mu(\psi_u^c - \psi_{tilt}^c)^2 + \nu x_u^c}\delta a\left(d_u^c\right)^{-\beta}}{\kappa + \sum_{\forall i \in \mathbb{C}/c}\hat{\eta}_i P_t^i 10^{\mu\left(\psi_u^i - \psi_{tilt}^i\right)^2 + \nu x_u^i}\delta a\left(d_u^i\right)^{-\beta}} \tag{5}$$

where c and i represent serving and interfering cells respectively, P_t^x is the Tx power of cell x, G_u is the user equipment gain, δ is random shadow fading, a is the pathloss constant, d_u^x is the distance of user u from cell x, β is the pathloss exponent, and κ is the thermal noise power. Here, $\hat{\eta}_i$ denotes actual cell load in a cell such that $\hat{\eta}_i \in [0, 1]$ and is used exclusively for SINR calculation.

V. Joint CCO-LB SON Function

We propose to formulate the joint CCO-LB SON function objective as a maximization function of mean SINR per user per cell. We present formulations for two cases: 1) when desired user throughput is unknown, and 2) when desired user throughput is known. The first formulation, called Fair CCO-LB formulation, uses geometric mean for averaging SINR over cells and users, and is given as:

$$\max_{P_t^c, \psi_{tilt}^c, P_{CIO}^c}\left(\prod_{\mathbb{C}}\left(\prod_{\mathbb{U}_c}\gamma_c^u\right)^{\frac{1}{|\mathbb{U}_c|}}\right)^{\frac{1}{|\mathbb{C}|}} \tag{6}$$

The outer geometric mean in (6) dampens SINR and, consequently, load disparity between cells. Thus, the LB goal is integrated into the objective. On the other hand, the inner geometric mean protects cell-edge users from being unfairly treated while maximizing the overall SINR. Conversely, if the desired user throughput is already known or can be predicted, for example using the framework presented in [4], we can replace the inner geometric mean on user SINR in cell c with the arithmetic mean as it is bound to provide an improved or equivalent result. This gives us the alternate joint CCO-LB formulation we call Greedy CCO-LB:

$$\max_{P_t^c, \psi_{tilt}^c, P_{CIO}^c} \left(\prod_{\mathbb{C}} \frac{\left(\sum_{\mathbb{U}_c} \gamma_c^u \right)}{|\mathbb{U}_c|} \right)^{\frac{1}{|\mathbb{C}|}} \tag{7}$$

The formulations in (6) and (7) inherit two basic constraints to achieve full objectives of both CCO and LB SON function i.e.:

i The minimum received downlink power P_u^c for ϖ ratio of users must meet or exceed the minimum coverage threshold P_{th}^c: $\frac{1}{|\mathbb{C}|} \sum_{\mathbb{C}} \frac{1}{|\mathbb{U}_c|} \sum_{\mathbb{U}_c} 1 \left(P_{r,u}^c \geqslant P_{th}^c \right) \geqslant \varpi$;

ii Cell load, as defined in (2), for every cell has to be less than or equal to the cell load thresholds set by operator policies: $\eta_c \leqslant \eta_{th}^c \forall c \in \mathbb{C}$

Additionally, the set $\mathbb{U}_c$ is determined using novel load-aware user association scheme proposed in [11] and given as:

$$\mathbb{U}_{j,t} := \{ \forall u \in \mathbb{U} \mid \\ j = \arg\max_{\forall c \in \mathbb{C}} \left(\left(\frac{1}{\eta_{c,t-1}} \right)^{\alpha} * \left(\acute{P}_{r,u}^c \right)^{(1-\alpha)} \right) \} \tag{8}$$

where $\mathbb{U}_{j,t}$ is the set of all active and idle users at time t for whom the product of the RSRP (+CIO) $\acute{P}_{r,u}^c$ and the normalized residual cell capacity is maximized for cell *j*. $\mathbb{U}_{c,t}$ or, simply, $\mathbb{U}_c$ is a subset of $\mathbb{U}_{j,t}$ which contains only the active users in cell c and is used in the equations (2) and (5) since only the active users can contribute to cell load. $\alpha \in [0, 1]$ is a weighting factor introduced to allow trading between the impact of RSRP and cell load measurements on user association. The proposed user association methodology adds a layer of load-awareness on top of the load bound SINR and the constraint for cell load. This ensures user QoS requirements are met for a greater range of optimization parameters settings, thus expanding the feasible solution space for the objective functions in (6) and (7).

Based on the discussion above, the final Fair and Greedy CCO-LB solutions are given as:

$$\max_{P_t^c, \psi_{tilt}^c, P_{CIO}^c} \left(\prod_{\mathbb{C}} \left(\prod_{\mathbb{U}_c} \gamma_c^u \right)^{\frac{1}{|\mathbb{U}_c|}} \right)^{\frac{1}{|\mathbb{C}|}} \tag{9a}$$

$$\max_{P_t^c, \psi_{tilt}^c, P_{CIO}^c} \left(\prod_{\mathbb{C}} \frac{\left(\sum_{\mathbb{U}_c} \gamma_c^u \right)}{|\mathbb{U}_c|} \right)^{\frac{1}{|\mathbb{C}|}} \tag{9b}$$

$$\textbf{subject to} = \begin{cases} \frac{1}{|\mathbb{C}|} \sum_{\mathbb{C}} \frac{1}{|\mathbb{U}_c|} \sum_{\mathbb{U}_c} 1 \left(P_{r,u}^c \geqslant P_{th}^c \right) \geqslant \varpi, \\ \eta_c \leqslant \eta_{th}^c \forall c \in \mathbb{C} \end{cases} \tag{9c}$$

where $\mathbb{U}_c$ is determined using (8).

A. Solution Methodology

Due to the non-convexity of SINR expression in (5), we must resort to non-convex optimization techniques to solve (9a) and (9b). Here we use genetic algorithm because of its ability to efficiently search through large solution spaces and find near-optimal solution in reasonable time. Other techniques that could possibly be used include pattern search, ant colony optimization, simulated annealing, and sequential quadratic programming. However, a comparison between these techniques is not a focus of this study.

TABLE I: Parameter Settings for Simulation

System Parameters	Value
Number of Base Stations	7
Sectors per Base Station	3
Small Cells per Sector	1
Number of UE per Sector	25
Transmission Frequency	2 GHz
Transmission Bandwidth	10 MHz
Network Topology	Hexagonal
Macro Cell Tx Power	Max: 46 dBm, Min: 40 dBm
Macro Cell Antenna Tilt	Max: 15°, Min: 0°
Small Cell Tx Power	Max: 30 dBm, Min: 27 dBm
Small Cell CIO	Max: 10 dB, Min: 0 dB
Cellular System Standard	LTE
Macro Cell Height	25 m
Small Cell Height	10 m
Inter-site Distance (Macro)	500 m

VI. Simulation and Results

A. Simulation Setup

We employ a 3GPP standard compliant network simulator [15] to generate a typical UDHN and UE distributions, while Monte Carlo simulations are used to estimate average solution performance. Wrap around model is used to simulate interference in an infinitely large network thus avoiding boundary effect. To model realistic networks, UEs are distributed non-uniformly in all the sectors such that a fraction of UEs are clustered around randomly located hotspots in each sector which may not coincide with small cells. Complete simulation parameters are given in Table I.

B. Results

Fig. 1 shows comparison of the downlink SINR for Fair and Greedy CCO-LB solutions against the CCO algorithm proposed in [1] referred to henceforth as SOT, the CCO-LB algorithm JOINT1 presented in [2], CCO algorithm for UDHNs and LB algorithm for UDHNs. The joint CCO-LB solutions offer SINR > 10 dB for more than 70% of users. In comparison, with SOT and JOINT1 only 20% and 30% of users have SINR above 10 dB while CCO for UDHNs has 60% users and LB for UDHNs has 55% users with SINR above 10dB. We also see that Fair CCO-LB solution performs slightly better compared to Greedy CCO-LB for cell edge users i.e. the lower half of UEs with Greedy CCO-LB giving slightly better performance for the top half.

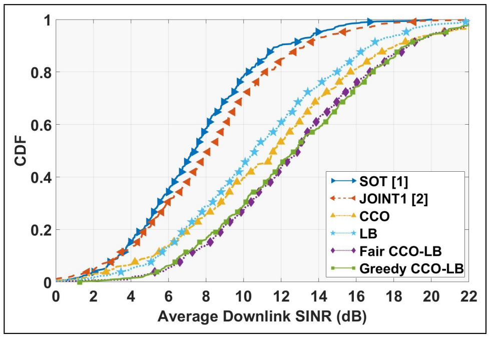

Fig. 1: Downlink SINR CDF - SOT [1], JOINT1 [2], CCO, and LB vs. Fair CCO-LB and Greedy CCO-LB

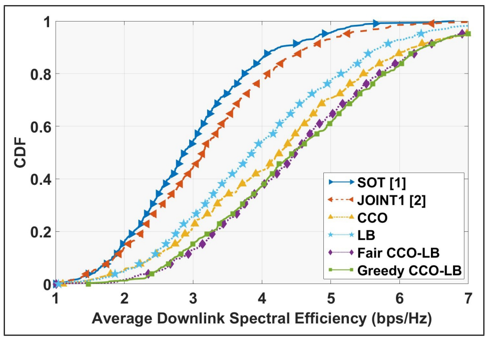

Fig. 2: Downlink Spectral Efficiency CDF - SOT [1], JOINT1 [2], CCO, and LB vs. Fair CCO-LB and Greedy CCO-LB

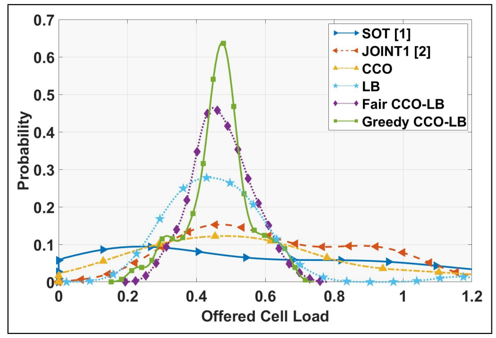

Fig. 3: Cell Load Distribution - SOT [1], JOINT1 [2], CCO, and LB vs. Fair CCO-LB and Greedy CCO-LB

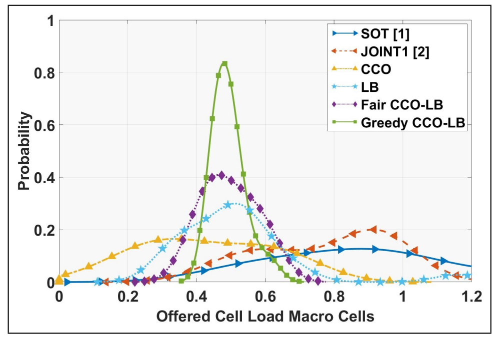

Fig. 4: Macro Cell Load Distribution - SOT [1], JOINT1 [2], CCO, and LB vs. Fair CCO-LB and Greedy CCO-LB

Recall that using CIOs alone for LB has negative impact on SINR [10]. But when CIOs are adapted through the proposed joint CCO-LB solution in conjunction with Tx power and tilts, we still achieve a gain in SINR despite using CIOs. This is a major improvement compared to most CIO optimization solutions where SINR degradation is considered inevitable[1]. This rationalizes the need to include all three optimization parameters in the proposed CCO-LB solution, compared to existing studies which use one or two parameters at a time.

The difference between benchmark algorithms is also worth noting here. CCO only and LB only SON functions for UDHNs perform better because they include small cell parameters in the optimization process, whereas SOT and JOINT1 only optimize macro cell parameters. Furthermore, SOT performs worse than JOINT1 since it is a CCO only solution whereas JOINT1 is a joint CCO-LB solution for macro cellular networks.

Similarly, Fig. 2 presents comparison of spectral efficiency for the simulated algorithms. Results show that Fair and Greedy CCO-LB outperform JOINT1 in terms of spectral efficiency by nearly 1.25 bps/Hz, and SOT by nearly 1.75 bps/Hz for 50th percentile users. Furthermore, they offer 0.2 bps/Hz and 0.8 bps/Hz higher spectral efficiency compared to CCO and LB functions for UDHNs.

Fig. 3 presents a comparison of cell load distribution for all cells in the network for Fair and Greedy CCO-LB, SOT, JOINT1, CCO and LB SON solutions. Results show that the proposed CCO-LB solutions have a very small variance around the mean value. In comparison, SOT shows the widest disparity among cell loads followed closely by CCO solution for HetNets. This is primarily due to the fact that both solutions focus on coverage and capacity but do not consider cell loads. This disparity is further contextualized by the load distributions for JOINT1 and LB solutions which show more symmetric load distributions.

Figs. 4 and 5 present the load distributions for macro cells and small cells respectively. Both versions of the proposed CCO-LB solution are better at balancing load between macro cells and small cells compared to SOT, JOINT1 and CCO solutions, with LB the closest to them. Most importantly, balanced loads between macro and small cells means proposed Fair and Greedy CCO-LB solutions actually increase capacity in the system thereby satisfying CCO objective at the same time.

This is further evidenced by the residual cell capacity across the network, as shown in Fig. 6. The box plots show residual capacity distributions while the points show average residual capacity of all cells. The average

[1]Part of observed gain also stems from the load aware cell association method presented in (8) and used in implementation of (9). In this study we set $\alpha = 0.5$. Further investigation of different α values is presented in [11].

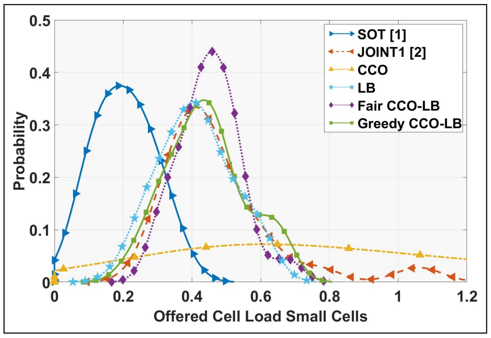

Fig. 5: Small Cell Load Distribution - SOT [1], JOINT1 [2], CCO, and LB vs. Fair CCO-LB and Greedy CCO-LB

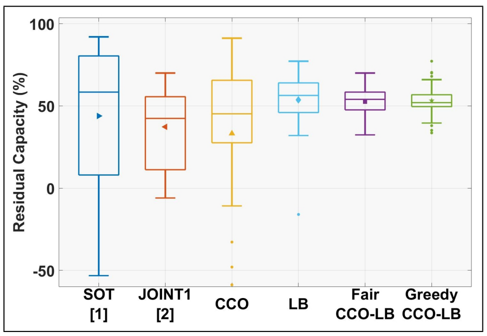

Fig. 6: Residual Cell Capacity - SOT [1], JOINT1 [2], CCO, and LB vs. Fair CCO-LB and Greedy CCO-LB

cell residual capacity of Fair and Greedy CCO-LB are 52% and 54% respectively compared to 44% for SOT, 37% for JOINT1, 33% for CCO, and 53% for LB SON function. However, the key observation from Fig. 6 is the compactness of residual capacity distribution for Fair and Greedy CCO-LB solution. This shows that not only do these solutions provide better load distributions across the network, they also increase residual capacity for transit users, a feature that is highly desirable in UDHNs due to the high expected user mobility.

VII. Conclusion

This paper explores the impact of cell Tx powers, antenna tilts and CIO parameters on network coverage, capacity and load, with special focus on UDHNs for future 5G MCNs. We postulate that the most efficient way forward in terms of CCO and LB SON function co-existence is their joint formulation, and propose a novel joint coverage, capacity and load optimization formulation with integrated load fairness that incorporates the impact of Tx powers, antenna tilts and CIOs on the three KPIs. Additionally, we present a Fair and Greedy formulation for joint CCO-LB to cater for the two situations of unknown and known desired user throughputs, along with a comparison of the two. The proposed joint CCO-LB solutions are compared against a coverage optimization [1], joint CCO-LB [2], CCO for UDHNs, and LB for UDHNs SON functions. Results show that the proposed joint CCO-LB solution results in higher SINR and spectral efficiency compared to benchmark algorithms while also providing better load distribution, and improved user QoS.

Acknowledgment

This material is based upon work supported by the NSF under Grant Numbers 1559483, 1619346, and 1730650. For details, visit: www.ai4networks.com

References

[1] A. Imran, M. A. Imran, A. Abu-Dayya, and R. Tafazolli, "Self Organization of Tilts in Relay Enhanced Networks: A Distributed Solution," *IEEE Transactions on Wireless Communications*, vol. 13, no. 2, pp. 764–779, February 2014.

[2] A. J. Fehske, H. Klessig, J. Voigt, and G. P. Fettweis, "Concurrent Load-Aware Adjustment of User Association and Antenna Tilts in Self-Organizing Radio Networks," *IEEE Transactions on Vehicular Technology*, vol. 62, no. 5, pp. 1974–1988, Jun 2013.

[3] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K. Soong, and J. C. Zhang, "What Will 5G Be?" *IEEE Journal on Selected Areas in Communications*, vol. 32, no. 6, pp. 1065–1082, June 2014.

[4] A. Imran, A. Zoha, and A. Abu-Dayya, "Challenges in 5G: how to empower SON with big data for enabling 5G," *IEEE Network*, vol. 28, no. 6, pp. 27–33, Nov 2014.

[5] O. G. Aliu, A. Imran, M. A. Imran, and B. Evans, "A Survey of Self Organisation in Future Cellular Networks," *IEEE Communications Surveys Tutorials*, vol. 15, no. 1, pp. 336–361, First 2013.

[6] 3GPP, "TR 36.902 - Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Self-configuring and self-optimizing network (SON) use cases and solutions," 2011.

[7] H. Y. Lateef, A. Imran, M. A. Imran, L. Giupponi, and M. Dohler, "LTE-advanced self-organizing network conflicts and coordination algorithms," *IEEE Wireless Communications*, vol. 22, no. 3, pp. 108–117, June 2015.

[8] A. J. Fehske, I. Viering, J. Voigt, C. Sartori, S. Redana, and G. P. Fettweis, "Small-Cell Self-Organizing Wireless Networks," *Proceedings of the IEEE*, vol. 102, no. 3, pp. 334–350, March 2014.

[9] 3GPP, "TS 36.331 - LTE; Evolved Universal Terrestrial Radio access (E-UTRA); Radio Resource Control (RRC); Protocol specification," 2016.

[10] I. Siomina and D. Yuan, "Load balancing in heterogeneous LTE: Range optimization via cell offset and load-coupling characterization," in *Proc. International Conference on Communications (ICC)*. IEEE, June 2012, pp. 1357–1361.

[11] A. Asghar, H. Farooq, and A. Imran, "A Novel Load-Aware Cell Association for Simultaneous Network Capacity and User QoS Optimization in Emerging HetNets," in *Proc. 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*. IEEE, Oct 2017.

[12] K. Huang, V. K. N. Lau, and Y. Chen, "Spectrum sharing between cellular and mobile ad hoc networks: transmission-capacity trade-off," *IEEE Journal on Selected Areas in Communications*, vol. 27, no. 7, pp. 1256–1267, September 2009.

[13] A. AlAmmouri, H. ElSawy, and M. S. Alouini, "Load-aware modeling for uplink cellular networks in a multi-channel environment," in *Proc. 25th Annual International Symposium on Personal, Indoor, and Mobile Radio Communication (PIMRC)*. IEEE, Sept 2014, pp. 1591–1596.

[14] J. G. Andrews, S. Singh, Q. Ye, X. Lin, and H. S. Dhillon, "An overview of load balancing in hetnets: old myths and open problems," *IEEE Wireless Communications*, vol. 21, no. 2, pp. 18–25, April 2014.

[15] 3GPP, "TS 25.814 - Technical Specification Group Radio Access Network; Physical layer aspects for evolved Universal Terrestrial Radio Access (UTRA)," 2006.