The Place Coverage (TPC) - Three-stage User Association and Rate Maximization for 5G SD-RAN Systems

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Abstract*—This paper analyzes the problem of optimum user association and sum rate maximization for software defined radio access networks (SD-RANs) with access node diversity for fifth generation (5G) wireless networks. We consider four complementary types of access nodes namely, a massive multiple-input multiple-output (MIMO) base station (BS), MIMO BSs, small cells (SCs), and indoor and outdoor distributed antenna systems (DAS). The SD-RAN user association problem is solved through a novel three-stage optimization scheme called the place coverage (TPC). TPC divides the user equipments (UEs) into two sets of indoor and outdoor UEs. Initially, TPC associates indoor UEs with the indoor DAS access nodes. Next, outdoor UEs are associated with the outdoor DAS access nodes, SCs, MIMO BSs, and the massive MIMO BS. Finally, the remaining resources of indoor and outdoor access nodes are used to serve the UEs that have not been served. The scope of TPC is multifold. First, TPC reflects the closest model to a real-world diverse 5G network. Secondly, servicing the indoor UEs with iDAS antennas results in lower power load per user for the access network resulting in better coverage, quality, and data speed. Thirdly, TPC provides reduced radiation levels for indoor UEs. Numerical results show that TPC provides significant sum rate and fairness gains over the received signals strength (RSS) based association schemes [1]. Moreover, TPC provides comparable performance levels as the optimum association scheme based on exhaustive search while bringing significant complexity reduction.

I. Introduction

Fifth generation (5G) wireless systems are anticipated to provide $1-10$ Gbps data rates to millions of devices [2]. This is an order of magnitude increase in data rate compared to current forth generation (4G) wireless systems. 5G systems are expected to cater for a vast variety of users, from high-end devices that require high data-rates such as augmented reality headsets, laptops, and mobile phones to low-end devices with low data-rate requirements such as wireless sensors [3]. In order to support such diverse variety of users, a paradigm shift in wireless networks that converges the existing and future wireless technologies is required. The major wireless access technologies with essential and complementary roles in future 5G roll-outs include massive multiple-input multiple-output (MIMO), MIMO, distributed antenna systems (DAS), and small cell (SC) technologies. To ensure successful 5G roll-outs, we believe that these four major access technologies must be combined via a central mechanism to ensure the dynamic coverage and capacity required by future 5G users.

Massive MIMO wireless systems are known to be a major feature of 5G systems [4]. Due to the significantly improved degrees of freedoms offered by these large antenna arrays, massive MIMO systems can mitigate the effects of small-scale fading and interferences [5]. Furthermore, linear beamforming and precoding methods will become optimal, and power efficiencies can be increased unbounded in massive MIMO systems [5]. We believe that massive MIMO is a crucial enabling component of the 5G access network which together with legacy MIMO base stations (BSs), a.k.a. macro BSs, can cater for today's increasing user data requirements.

Compared to macro BSs, SCs a.k.a. micro BSs are low-powered short-range wireless access nodes with static/fixed non-distributed structures where each SC needs it's own backhaul and power. SCs have their BSs collocated with their antennas and are controlled by the network operators through a central controller [6]. Despite the connectivity boost provided by SCs [6], SCs have major challenges that make multiple SC solutions not very competitive when it comes to scaling coverage. These challenges include interference mitigation techniques, the need for multiple hand-offs for roaming UEs, and high-complexity dedicated backhaul and power resource requirements per SC [6].

To overcome the limitations and challenges of SCs, DAS can be employed as a complimentary access technology. DAS are spatially separated set of antenna elements that are connected to a common central processing unit, a.k.a. the BS hotel [7]. DAS can be combined with MIMO technologies to provide connectivity to a set of UEs within a stadium, airport, or a metro station. Similar to SCs, DAS can offload the traffic of nearby BSs while providing high data rates to a relatively dense set of users. Unlike SCs, DAS has a dynamic network design. In DAS the radio resources are centralized in the BS hotel and not co-located with antennas. Thus, radio resources can be aggregated and used to support multiple operators. Benefits of DAS over the SC technology include simulcast capabilities for interference mitigation, easy capacity enhancements, and low implementation complexities [7].

Software defined network (SDN) is a network architecture which separates network management from the physical infrastructure [8]. The main advantage of SDN is its scalability and adaptability to new services due to the central control of network resources [8]. SDN is already implemented in wired networks using OpenFlow protocol [9]. Use of SDN for Wi-Fi and WiMAX networks is analyzed in [10], and use of SDN for cellular systems, i.e. software-defined radio access network (SD-RAN) is surveyed in [8] and [11]. Introducing SDNs to 5G wireless systems facilitates the dynamic implementation in software of crucial functions such as user association, resource allocation, and rate maximization. The central control of these functions is crucial to the management of the diverse resources of the 5G access network. Hence, we believe that the diverse pool of 5G access networks' resources comprising massive MIMO BS, MIMO BSs, SCs, and DAS, can be best managed through an SDN-based controller.

According to [12], one view of 5G networks is a *hyper-connected vision*, where multiple pre-existing and new technologies are converged to provide high coverage and data rates. Thus, in initial deployments of 5G wireless networks, different types of access technologies including the massive MIMO, macro BSs, SCs, and DAS will coexist with each other. Hence we believe that the analysis of our system model is important for the future of wireless communications. To the best of authors knowledge, this is the first research paper which analyzes a system with all four types of access technologies, namely massive MIMO BS, macro BSs, SCs, and DAS.

Previous Research: In [13], Li et al. analyze a system with SCs, massive MIMO BSs, and full duplex communications for three duplexing scenarios to maximize network's achievable sum rate. However, SCs are assumed to be single antenna nodes where each can only serve one UE. The main focus of [13] is to design a system with multiple access nodes without consideration of user association. In [14], a system with SCs and massive MIMO BSs is analyzed. The main focus of this paper is to design transmission protocols to minimize interference and obtain a certain data rate for UEs. In [15], Xu et al. analyze user association for a system with single massive MIMO BS (named as the macro-cell) and multiple MIMO BSs (named as SCs). Three centralized user association schemes are proposed to maximize the sum rate, fairness, and resource allocation. In comparison, our system model is more diverse and practical and the association methods presented in [15] cannot be extended to our model. In [16], an SD-RAN with massive MIMO BSs and MIMO BSs is analyzed with data compressions. Here, the main focus is data compression, user association, and virtualization of SD-RAN resources with capacity limited fronthaul links. Liu et al. in [17] propose a distributed UE association scheme for fair user association in massive MIMO enabled HetNets. However, the proposed system model in [17] only contains a single massive MIMO BS and multiple single antenna pico BSs.

Our contribution: In this paper, we analyze the user association and sum rate maximization problem for a diverse SDN-based RAN that uses the four major access technologies featuring in 5G. Realizing the importance of in-building coverage and that the bulk of traffic originates in buildings [18], we design a novel three-stage optimization scheme called TPC which caters for place coverage, i.e. delivering capacity and guaranteeing coverage for 5G users while honoring "the place" at which the UE is located. More specifically, we associate indoor UEs to iDAS nodes by solving indoor UE association problem (IAP). Then, we associate outdoor UEs with outdoor access nodes by solving outdoor UE association problem (OAP). Finally, the UEs

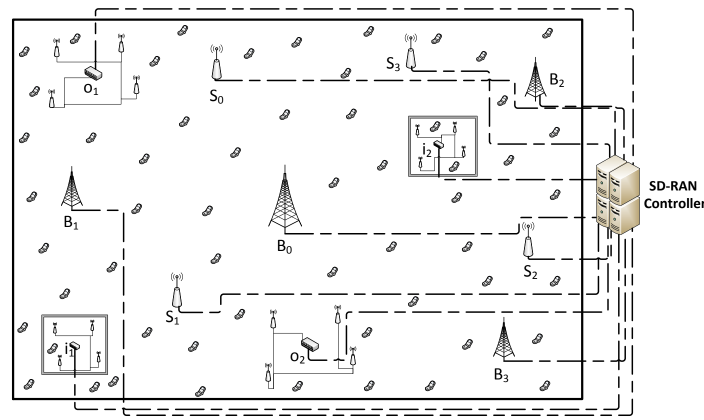

Fig. 1. A wireless system with three MIMO BSs ($L = 3$), four SCs ($L' = 3$), two oDAS, and two iDAS. All the access nodes are connected to the SD-RAN controller through high speed backhaul connections.

that are not connected through IAP and OAP will be assigned to remaining available access nodes by solving converging UE association problem (CUAP). Note that, IAP minimizes the use of macro BSs by assigning indoor UEs to iDAS. This avoids high building penetration losses ($\sim 20-50$ dB) and leads to less power consumption, higher capacity, and less production cost for indoor traffic.

Notation: $\mathbf{Z}^H$ and $[\mathbf{Z}]_k$ denote the Hermitian-transpose and kth diagonal element of matrix, $\mathbf{Z}$, respectively. $|S|$ denotes the cardinality of set S. $\mathbf{I}_M$ and $\mathbf{O}_{M\times N}$ are the $M \times M$ Identity matrix and $M \times N$ matrix of all zeros, respectively. A complex Gaussian random variable X with mean μ and standard deviation σ is denoted as $X \sim \mathcal{CN}\left(\mu, \sigma^2\right)$.

II. Network Model

The massive MIMO BS is denoted by B_0 and consists of M_0 antennas where M_0 is a very large number (in current practical systems $M_0 \sim 100-200$ [5]). There are L macro BSs within the considered cell, and they are denoted as B_l where $l \in \{1, \ldots, L\}$. Each BS, B_l consists of M_l antennas for $l \in \{1, \ldots, L\}$. For notational simplicity, we refer to both the massive MIMO BS and macro BSs as BSs and denote them by B_l where $l \in \{0, \ldots, L\}$ and B_0 represents the massive MIMO BS. BSs are connected to the SD-RAN controller through wired backhaul links. The capacity cap of the backhaul link for B_l is assumed to be $\mathcal{C}_{B_l}$. The set of all BSs is denoted by $\mathcal{B}$. Furthermore, there are $L'+1$ SCs, and the jth SC is denoted by S_j where $j \in \{0, \ldots, L'\}$. S_j contains T_j antennas and is capable of serving multiple UEs. SCs are connected to the SD-RAN controller through wired backhaul links, and the capacity cap of the backhaul link of S_j is assumed to be $\mathcal{C}_{S_j}$ for $j \in \{0, \ldots, L'\}$. The set of SCs is denoted by $\mathcal{S}$.

The set of oDAS is represented by $\mathcal{O}$ and $|\mathcal{O}| = Q$. Each oDAS is denoted by o_m where $m \in \{1, \ldots, Q\}$. o_m consists of D_{o_m} spatially distributed antenna elements. The set of iDAS is represented by $\mathcal{I}$ and $|\mathcal{I}| = Q'$. Each iDAS is denoted by i_n where $n \in \{1, \ldots, Q'\}$. i_n consists of D_{i_n} spatially distributed antenna elements. DAS are connected to the SD-RAN controller through high speed backhaul links and the capacity of these links are limited to $\mathcal{C}_{o_m}$ and $\mathcal{C}_{i_n}$ for $o_m \in \mathcal{O}$ and $i_n \in \mathcal{I}$, respectively. Note that unlike SCs, $\mathcal{C}_{i_n}$ and $\mathcal{C}_{o_m}$ are dynamically distributed between iDAS and oDAS antennas, respectively. The total backhaul capacity of the system is given by $\mathcal{C}$.

The UEs in the system are categorized into two sets. The set of indoor UEs is denoted by $\mathcal{N}_I$, and the set of outdoor UEs is represented by $\mathcal{N}_O$. The cardinalities of above mentioned sets are N_{in} and N_{out}, respectively. The UEs in $\mathcal{N}_I$ are denoted as p_k for $k \in \{1, \ldots, N_{in}\}$. Similarly, the UEs in $\mathcal{N}_O$ are denoted by q_k where $k \in \{1, \ldots, N_{out}\}$. All UEs are single antenna nodes. A system with $L = 3$, $L' = 3$, $|\mathcal{O}| = 2$, and $|\mathcal{I}| = 2$ is shown in Fig. 1.

III. SINR Formulation

In this section, we formulate the received SINR expression at UEs for several association scenarios. In here, Ψ_{r,B_l}, Ψ_{r,S_j}, Ψ_{r,o_m}, and Ψ_{r,i_n} represents the received SINR when UE r is connected to B_l, S_j, o_m, or i_n for $r \in \mathcal{N}_I \cup \mathcal{N}_O$, $l \in \{0, \ldots, L\}$, $j \in \{0, \ldots, L'\}$, $m \in \{0, \ldots, Q\}$, and $n \in \{0, \ldots, Q'\}$, respectively. These SINR expressions will be used to formulate an optimization problem for TPC.

Note that all of the considered access nodes, i.e. BSs, SCs, iDAS, and oDAS, are assumed to have multiple antennas and therefore, can use beamforming for transmission purposes. Initially, we present the channel and system model for the communication links between UEs, BSs, and SCs and formulate the received SINR expressions. Next, we formulate the SINR expressions when UE r connects to access node G for $r \in \mathcal{N}_I \cup \mathcal{N}_O$ and $G \in \mathcal{B} \cup \mathcal{S} \cup \mathcal{O} \cup \mathcal{I}$. Let A_G be the number of antennas at G. The wireless channel from r to G is represented by $\mathbf{h}_{r,G} = \beta_{r,G}\tilde{\mathbf{h}}_{r,G}$ where $\beta_{r,G}$ is the pathloss and shadowing coefficient and $\tilde{\mathbf{h}}_{r,G} \in \mathcal{CN}_{A_G \times 1}\left(\mathbf{0}_{A_G \times 1}, \mathbf{I}_{A_G}\right)$ represents the Gaussian small scale fading coefficients vector. Here, we have assumed that there is no correlation among the channel matrices of different antenna elements in a single access node. Assuming channel reciprocity, the uplink channel to G from r is written as $\mathbf{h}_{G,r} = \mathbf{h}_{r,G}^T$. Furthermore, the pathloss coefficient $\beta_{r,G} \propto \left(\frac{d_0}{d_{r,G}}\right)^{\eta_{r,G}}$, where d_0 is the reference distance, $d_{r,G}$ is the distance between r and G, and $\eta_{r,G}$ is the pathloss coefficient corresponding to the channel between r and G. Similarly, the wireless channel from access node B ($B \neq G$) to r is given by $\mathbf{h}_{B,r}$. Here, $B \in \mathcal{A}_P$ is used to denote the interfering access nodes to r and $\mathcal{A}_p$ is the set of all the interfering access nodes.

Access nodes will use precoding and beamforming to support multiple UEs. Let $\mathcal{F}_G$ be the set of UEs serviced by G and $\mathcal{F}_G = \{\, r \mid f_{r,G} = 1 \,\}$. Here, the association factor $f_{r,G}$ denotes the respective association between $r \in \mathcal{N}_I \cup \mathcal{N}_O$ and the access node $G \in \mathcal{B} \cup \mathcal{S} \cup \mathcal{O} \cup \mathcal{I}$. As an example, $f_{q_k,B_1} = 1$ means that the outdoor UE q_k is associated with BS B_1. Without loss of generality, we assume that a UE is only associated with one of the available access nodes. The number of UEs served by G is $|\mathcal{F}_G| = U_G$. Furthermore, the $A_G \times U_G$ wireless channel from all of the users served by G can be written as $\mathbf{H}_G = \left[\mathbf{h}_{r_1,G} \;\; \mathbf{h}_{r_2,G} \;\; \ldots \mathbf{h}_{r_{U_G},G}\right]$. This matrix can be decomposed as $\mathbf{H}_G = \hat{\mathbf{H}}_G \mathbf{D}_G^{\frac{1}{2}}$, where $\mathbf{H}_G \sim \mathcal{CN}_{A_G \times U_G}\left(\mathbf{0}_{A_G \times U_G}, \mathbf{I}_{A_G} \otimes \mathbf{I}_{U_G}\right)$ accounts for small-scale fading, and $\mathbf{D}_G = \operatorname{diag}\left(\beta_{r_1,G}, \cdots, \beta_{r_{U_G},G}\right)$ represents large-scale fading. The $A_G \times U_G$ beamforming matrix at G is given as $\mathbf{W}_G$. Thus, we write the received signal at r, when serviced by G as

$$y_r = \sqrt{P_G}\mathbf{h}_{G,r}\mathbf{W}_G\mathbf{x}_G + \sum_{B \in \mathcal{A}_p, B \neq G} \sqrt{P_B}\mathbf{h}_{G,r}\mathbf{W}_B x_B + n_r, \quad (1)$$

where P_G is the transmit power at G, $\mathbf{x}_G$ is the $U_G \times 1$ transmitted signal at G, P_B is the transmit power at B, $\mathbf{x}_B$ is the $U_B \times 1$ transmit signal from B, and $n_r \in \mathcal{CN}\left(0, \sigma_r^2\right)$ is the additive white Gaussian noise (AWGN) at r. In the numerical analysis and simulations, we use ZF precoding as follows [19] [1]

$$\mathbf{W}_G = \mathbf{H}_G^*(\mathbf{H}_G^T\mathbf{H}_G^*)^{-1}. \quad (2)$$

By using the above values, we derive the SINR at r, as

$$\Psi_{G,r} = \frac{P_G\beta_{G,r}^2}{\sum_{B \in \mathcal{A}_p, B \neq G} P_B \left|\mathbf{h}_{G,r}\mathbf{W}_B\right|^2 + \sigma_r^2}. \quad (3)$$

Here in (3), $\mathbf{h}_{G,r}$ is a random variable and for our simulation results we use the average value (with respect to $\mathbf{h}_{G,r}$) of the interference on the UE by other access nodes of the system. Thus we can simplify the SINR in (3) as

$$\Psi_{G,r} = \frac{P_G\beta_{G,r}^2}{\sum_{B \in \mathcal{A}_p, B \neq G} P_B \beta_{B,r}^2 + \sigma_r^2}. \quad (4)$$

IV. Problem Formulation

In this section, we formulate the steps of TPC for data rate maximization of the SD-RAN. $R_{r,G}$ refers to the achievable data rate when UE r connects to the access node G where $r \in \mathcal{N}_I \cup \mathcal{N}_O$ and $G \in \mathcal{B} \cup \mathcal{S} \cup \mathcal{O} \cup \mathcal{I}$. The objective of the optimization problem is to maximize the overall sum rate of the system by finding the optimum association factors f_{r,B_l}, f_{r,S_j}, f_{r,o_m}, and f_{r,i_n}.

The optimum user association scheme for sum rate maximization involves the association of UEs to the available access nodes (indoor or outdoor) without preference. This results in exhaustive association parameter searches which are subject to multiple constraints. In this paper, we propose TPC, a sub optimal three stage UE association scheme, which consists of three sub-problems. The first sub-problem associates the UEs with iDAS. The second sub-problem associates outdoor UEs with oDAS, SCs, and BSs. The last optimization problem connects the remaining UEs , i.e. the ones that are not currently associated with any access nodes, to the remaining resources of the available access nodes. As seen from simulation results in Section V, the performance degradation of TPC compared to the optimum method based on exhaustive search is negligible.

[1]Similar results can be obtained for other precoding methods such as matched filter and minimum mean square error estimation. However, in this paper we have only included results for ZF precoding.

The first optimization problem, which we refer to as iDAS association problem (IAP) hereafter, is given as

$$\underset{f_{p_k,i_n}}{\text{maximize}} \quad \sum_{p_k \in \mathcal{N}_I} \sum_{i_n \in \mathcal{I}} R_{p_k,i_n} \tag{5}$$

$$\text{subject to} \quad R_{p_k,i_n} \leq f_{p_k,i_n} \log\left(1 + \Psi_{p_k,i_n}\right), \tag{6}$$

$$\sum_{i_n \in \mathcal{I}} f_{p_k,i_n} \leq 1, \tag{7}$$

$$f_{p_k,i_n} \geq 0, \tag{8}$$

$$\sum_{p_k \in \mathcal{N}_I} f_{p_k,i_n} \leq D_{i_n}, \tag{9}$$

$$\sum_{i_n \in \mathcal{I}} R_{p_k,i_n} \leq C_{i_n}. \tag{10}$$

In this optimization problem, we intend to maximize the sum rate of indoor UEs by finding the optimum UE allocation coefficients f_{p_k,i_n}. The constraint (6) results from the relationship between the maximum achievable channel capacity and SINR of a channel. The next constraint (7) limits the sum of all possible associations of p_k to 1. Constraint (8) limits the association factors to positive values. Furthermore, to perform beamforming at an access node, the number of UEs connected to that node should be less than or equal to the number of antennas at that access node [20]. This constraint is given in (9). The backhaul capacity of each access node is enforced in the final constraint (10). We denote the UEs that are associated to iDAS nodes via IAP by $\mathcal{N}_{S,I}$.

Next, we maximize the total data-rate of the outdoor UEs by associating them with one of the oDAS, SCs, or BSs. For simplicity let $\mathcal{A}_P = \mathcal{B} \cup \mathcal{S} \cup \mathcal{O}$, where this denotes the available outdoor access nodes. The second optimization problem which we refer to as outdoor UE association problem (OAP) is formulated as follows:

$$\underset{f_{q_k,G}}{\text{maximize}} \quad \sum_{q_k \in \mathcal{N}_O} \sum_{G \in \mathcal{A}_P} R_{q_k,G} \tag{11}$$

$$\text{subject to} \quad R_{q_k,G} \leq f_{q_k,G} \log\left(1 + \Psi_{q_k,G}\right), \tag{12}$$

$$\sum_{G \in \mathcal{A}_P} f_{q_k,G} \leq 1, \tag{13}$$

$$f_{q_k,G} \geq 0, \tag{14}$$

$$\sum_{q_k \in \mathcal{N}_O} f_{q_k,G} \leq A_G, \tag{15}$$

$$\sum_{q_k \in \mathcal{N}_O} R_{q_k,G} \leq C_G, \tag{16}$$

$$\sum_{q_k \in \mathcal{N}_O} \sum_{G \in \mathcal{A}_P} R_{q_k,G} + \sum_{p_k \in \mathcal{N}_{S,I}} \sum_{i_n \in \mathcal{I}} R_{p_k,i_n} \leq C. \tag{17}$$

The constraints presented above are similar to the the constraints in IAP with an additional constraint (17). This emanates from the total capacity limit of the system. We denote the UEs that are associated to nodes via OAP by $\mathcal{N}_{S,O}$.

The final stage of the algorithm is to associate the remaining set of UEs to the remaining resources of available access nodes. For simplicity, let $\mathcal{N}_R = (\mathcal{N}_O - \mathcal{N}_{S,O}) \cup (\mathcal{N}_I - \mathcal{N}_{S,I})$ and $\mathcal{B}_P$ denote the remaining UEs and available access nodes, respectively. We formulate the optimization sub-problem named as converging UE association problem (CUAP) as follows:

$$\underset{f_{r,G}}{\text{maximize}} \quad \sum_{r \in \mathcal{N}_R} \sum_{G \in \mathcal{B}_P} R_{r,G} \tag{18}$$

$$\text{subject to} \quad R_{r,G} \leq f_{r,G} \log\left(1 + \Psi_{r,G}\right), \tag{19}$$

$$\sum_{G \in \mathcal{B}_P} f_{r,G} \leq 1, \tag{20}$$

$$f_{r,G} \geq 0, \tag{21}$$

$$\sum_{r \in \mathcal{N}_R} f_{r,G} \leq A_G, \tag{22}$$

$$\sum_{r \in \mathcal{N}_R} R_{r,G} \leq C_G, \tag{23}$$

$$\sum_{r \in \mathcal{N}_O} \sum_{G \in \mathcal{B}_P} R_{r,G} + \sum_{q_k \in \mathcal{N}_O} \sum_{G \in \mathcal{A}_P} R_{q_k,G} + \sum_{p_k \in \mathcal{N}_{S,I}} \sum_{i_n \in \mathcal{I}} R_{p_k,i_n} \leq C. \tag{24}$$

The constraints presented above are similar to constraints used in OAP.

Note that by limiting the overall backhaul capacity of the SD-RAN, (24) inter-relates the three sub-problems IAP, OAP, and CUAP and guarantees the convergence of TPC.

V. Simulation Results

In this section, we evaluate the performance of TPC using comprehensive simulation results. To evaluate the performance of our purposed method, we use two other UE association methods as our benchmarks as follows:

1) Method 1 associates the UEs with the access node that provides the highest received signal strength (RSS). This is widely known in literature as RSS UE association [1].
2) Method 2 demonstrates the UE association results for a system which does not utilize DAS. Instead of DAS, the capacity that belonged to DAS antennas is distributed among MIMO BSs and SCs.
3) Method 3 (Optimum UE association) associates the UEs by using the CUAP only. More specifically, IAP and OAP are not implemented and both indoor and outdoor UEs are associated with the available indoor and outdoor access nodes without limitations. Note that the optimum UE association method involves an exhaustive search for the association parameters.

Apart from using the total sum rate of the system as a performance metric, we also look at the fairness of capacity distribution among the UEs. To measure fairness, we use Jain's fairness index which is widely used in literature [1] in user association methods. The Jain's fairness index for a set of n users with data rates R_i can be calculated as

$$\mathcal{J} = \frac{\left(\sum_{i=1}^{n} R_i\right)^2}{n \sum_{i=1}^{n} R_i^2}. \tag{25}$$

In our simulation model, we have 4 iDAS and 2 oDAS nodes which are randomly distributed in the cell. The massive MIMO BS is assumed to be placed at the center of the cell. MIMO BSs, SCs, and UEs are randomly distributed. The noise power at UEs is assumed to be 1 ($\sigma_r = 1$). Other simulation parameters are given in Table I.

TABLE I
THE SIMULATION PARAMETERS.

Parameter	value
Size of the cell	$62500m^2$
Size of an iDAS and oDAS	$156m^2$
Density of MIMO BSs	5 per cell
Density of SCs	10 per cell
Capacity of massive MIMO BS	80 Mbps
Capacity of a MIMO BS	20 Mbps
Capacity of a SC	15 Mbps
Capacity of an oDAS and iDAS antenna element	5 Mbps
Maximum number of UEs connected to a DAS element	5
Maximum number of UEs connected to a SC	10
Maximum number of UEs connected to a MIMO BS	20
Maximum number of UEs connected to massive MIMO BS	80
Transmit power of a MIMO and massive MIMO BS	4W
Transmit power of a SC	2W
Transmit power of an iDAS/oDAS antenna	1W
Pathloss coefficient (η_i) for indoor to indoor transmission	1.8
Pathloss coefficient (η_o) for outdoor to outdoor transmission	2.4
Pathloss coefficient ($\eta_{i,o}$) for indoor to outdoor transmission	5

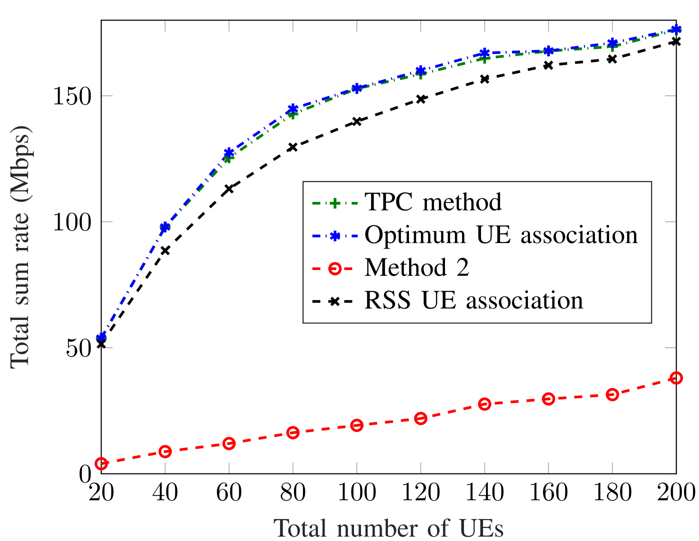

Fig. 2. Total sum rate of the system with different number of UEs.

In Fig. 2 and Fig. 3, SD-RAN performance is evaluated based on two metrics, i.e. achievable sum-rate and system fairness. In

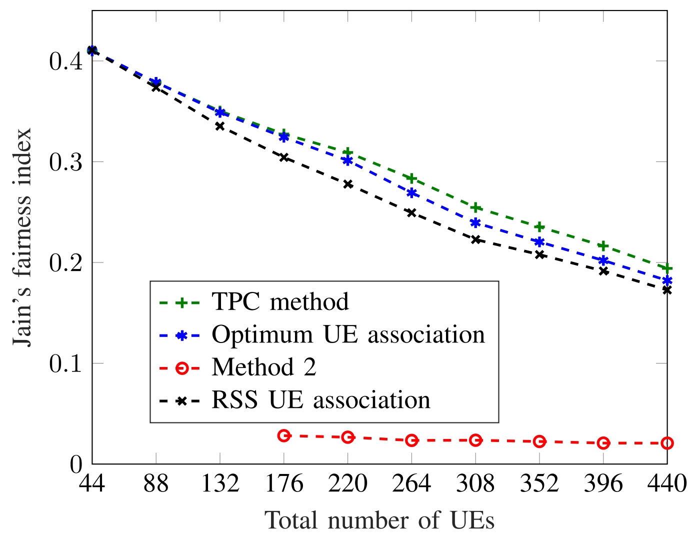

Fig. 3. The Jain's fairness index of the sytem under different number of UEs.

here, we assume that the maximum backhaul capacity is 1000 Mbps, i.e. $C = 1000$ Mbps. Furthermore, Knowing that bulk of traffic is generated by indoor users, we assume that the ratio between the number of indoor users per iDAS node and the outdoor UEs is fixed at 0.2.

As is evident from Fig. 2, TPC obtains similar sum rates as optimum UE association while the number of UEs are increased. Thus, we can see that the performance of our sub-optimal TPC is very similar to more complex optimal approaches. Also, TPC significantly outperforms method 2. As an example when the number of UEs is 176, TPC provides a sum rate of 140Mbps while method 2 only provides a sum rate of 19Mbps. This shows the importance of having DAS to cater for areas with high UE density. Also, our method outperforms the widely used RSS UE association method. As an example, with the same number of antennas, method 1 obtains only a sum rate of 120Mbps. Thus, for this case TPC provides a sum rate gain of 17%, which is very significant. Also, Fig.3 shows that although the fairness decreases with the number of UEs, TPC outperforms all other considered association methods when it comes to fairness.

In Fig. 4 and Fig. 5, the sum rate and the fairness of the system is plotted when the number of outdoor UEs is kept fixed at 100 and the number of UEs in a single DAS is varied between 0 to 60. As seen from Fig. 4, although TPC, method 1, and method 3 provide the same sum rate when the number of DAS UEs is small, TPC and method 3 outperform method 1 when the number of DAS UEs is increased. Also, it can be seen that when the number of DAS UEs is increased, Method 2 cannot provide any sum rate gains. This is due to the fact that it does not incorporate DAS antennas in its system model. Fig. 5 shows the fairness index of the system for different association methods. As for the previous case, TPC provides the highest fairness among all methods.

In conclusion, simulation results show that TPC offers higher sum rate and fairness for the proposed system compared to method 1 and method 2, and that the performance degradation compared to method 3 due to the use of the sub-optimal approach

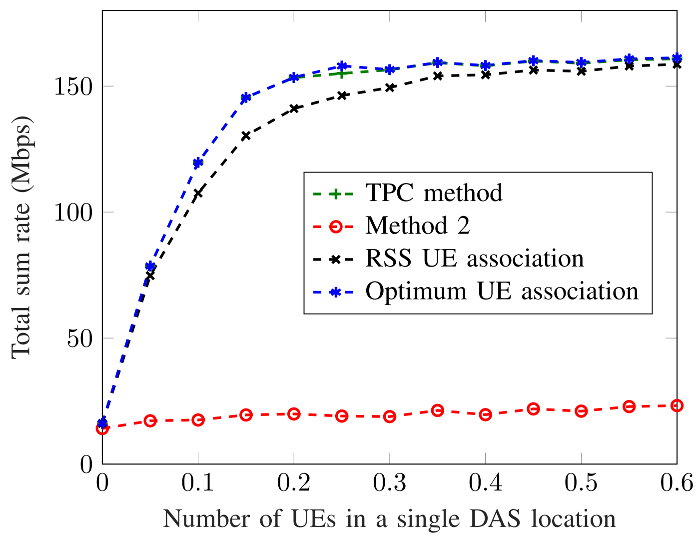

Fig. 4. Total sum rate of the system with different number of UEs in a single DAS.

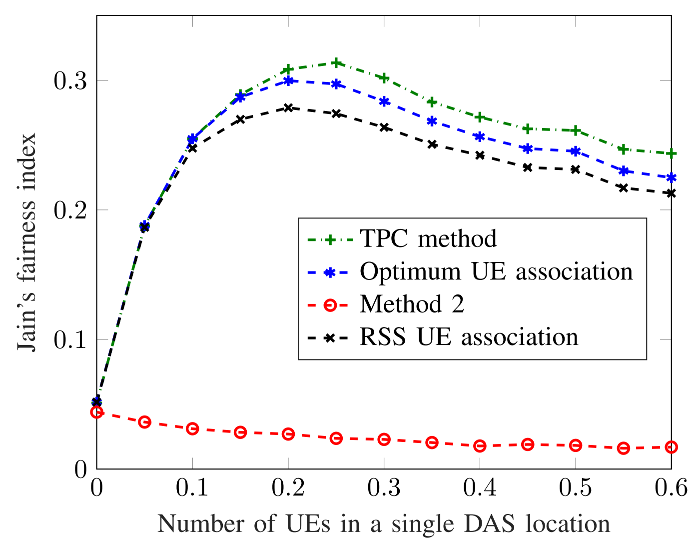

Fig. 5. The Jain's fairness index of the sytem with different number of UEs in a single DAS.

is negligible.

VI. Conclusion

In this paper, we propose a system model for an SDN-based RAN for 5G systems which consists of a massive MIMO BS, MIMO BSs, SCs, oDAS, and iDAS and solve a centralized optimization problem to maximize the overall sum rate of the system. The UEs in the system are categorized as outdoor and indoor. We decompose the problem of sum rate maximization into three separate sum rate maximization problems named as IAP, OAP, and CUAP. Specifically, indoor UEs are associated with indoor DAS by IAP and outdoor UEs are associated with outdoor access points by OAP. Finally, in CUAP, the remaining outdoor and indoor UEs are associated with any of the remaining available access nodes to maximize the overall sum rate of the SD-RAN. Our numerical results show that the proposed TCP method performs better than the RSS based UE association methods both in sum rate and fairness. Also, TPC outperforms the other more numerically complex UE association methods that were considered for comparison purposes. Furthermore, our simulation results justifies the importance of the use of DAS to cater for places with high UE density. For future work, we will investigate the resulting capacity utilization performance of access nodes and sum rate performance of individual UEs of TPC.

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