# Energy Efficient User Association in Heterogeneous CRAN

(Invited Paper)

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***Abstract*—Heterogeneous Cloud Radio Access Network (HCRAN) is a novel mobile network architecture for 5G systems where computational resources of the network are aggregated in the Macro Base Station (MBS). The radio signals transmitted from User Equipments (UE)s are processed by the MBS and Small Base Stations (SBS)s. Communication between MBS and SBSs takes place through the high capacity offering optical transmission links (Fronthaul (FH) Links). In this paper, we formulate the optimization problem with the goal of minimizing total power consumption in HCRAN by incorporating the dynamic power consumption of MBS, power consumption of the FH links between SBSs and MBS and switching on/off operation of SBSs. We demonstrate that the resulting problem can be transformed into Single Source Capacitated Facility Location Problem (SSCFLP). Since SSCFLP is NP-hard, we apply previously proposed heuristic algorithms for the solution, including repeated matching and perfect matching. We demonstrate that perfect matching heuristic performs closest to the optimal algorithm. We also observe that including dynamic power consumption of MBS is crucial since ignoring its contribution results in the connection of all the UEs to SBSs, with higher total power consumption. Moreover, the incorporation of dynamic part of MBS in the power analysis enables MBS to provide service to low data rate demanding UEs rather than only providing coverage.**

## I. INTRODUCTION

HCRANs emerge as a cost-effective potential solution that incorporates cloud computing into Heterogeneous Networks (HetNet)s [1]. In HCRAN based 5G system, there are MBSs and large number of SBSs densely deployed in the hotspots connected to the MBS through FH links. The fundamental feature of HCRAN is that Control Plane (CP) and Data Plane (DP) signalling are decoupled and MBS provides CP to maintain good connectivity and mobility and DP to transmit data to UEs, whereas SBSs only provide DP to boost data rate. The motivation of HCRAN is to improve cooperative processing gains in HetNets through combination with cloud computing and to simplify SBSs by connecting to a signal processing cloud. However, dense deployment of SBSs may cause huge power consumption in the network.

One important way to address the huge power consumption problem in HetNets is to introduce dynamic on/off schemes. When the network traffic is light, some BSs are switched off and their traffic is assigned to active BSs. This is achieved by smart UE association schemes where the number of active SBSs is minimized while satisfying the QoS constraints of UEs and QoS constraints are modelled in terms of outage probability [2], minimum data rate requirement [3], area spectral efficiency, which is defined as the sum of the maximum average rates of UEs per unit bandwidth per unit area [4] and bandwidth limitation of BSs [5]. Nonetheless, in the recent studies for HetNets, the MBSs are assumed to be always active to ensure the coverage, and SBSs are assumed to be switching-on/off based on the system load. However, when the SBSs are turned off, the traffic can be accomodated by the MBS as well as the rest of on SBSs. Therefore, a potential deficiency of existing strategies is that overall power models for HetNets do not include dynamic power consumption and capacity limit of MBS.

As compared to conventional HetNet structure, CRAN benefits from its flexible centralized processing structure. However, high capacity FH link consumes significant power which is comparable to the power consumed at Radio Remote Head ($RRH$) for operation and data transmission [6]. To design energy efficient UE association scheme in CRAN architecture, it is crucial to jointly consider the power consumption for RRH data transmission and the power consumption of FH links regarding the capacity of FH links. Therefore, RRHs and their corresponding FH links are turned on/off dynamically to provide energy efficient UE association, to minimize total power consumption and to satisfy the QoS and capacity constraints at the same time. Current works aim to minimize total power consumption subject to UEs' QoS targets such as minimum rate requirement and power constraints of RRHs. They investigate the power consumption for RRH data transmission and the power consumption of FH links with on/off operation of RRHs jointly. Power consumption models include power consumption of RRHs and power consumption of FH links in [7]-[9]. In [7], FH link power consumption is assumed to be constant and in [8] and in [9] FH link power consumption is stated as a function of data rate and transmit power of RRHs. Additionally, [9] includes sleep mode power consumption of FH link. On the other hand, the capacity constraints on the FH links are ignored in [7] and [8]. On the contrary, in [9] the FH link capacity is constrained to maximum number of UEs that a FH link can support. However, none of the studies consider the joint effect of capacity limitation in terms of the maximum traffic load that can be carried by the switch in the FH link associated with RRH and the power consumption as a function of data rate and power consumed per bit/s by a FH link.

The goal of this paper is to formulate the optimization problem for UE association in downlink (DL) with the goal of minimizing total power consumption in HCRAN while considering the realistic dynamic power consumption models, rate, capacity and transmission power constraints of MBS, SBSs, UEs, backhaul and FH links, and propose efficient polynomial time heuristic algorithms for the solution of this optimization problem. The main contributions of this paper are summarized as follows:

- We provide a holistic framework for UE association incorporating dynamic on/off scheme for SBSs to minimize total power consumption while accounting for the static and dynamic power consumption of MBS, static power consumption of SBS and power consumption of BH and FH links as a function of data rate for the first time in the literature. We incorporate mmWave physical layer characteristics in which we restrict the number of simultaneous transmissions by the number of RF chains by taking the advantage of massive MIMO [10].
- The usage of realistic power consumption models results in the formulation of the problem as a Single Source Capacitated Facility Location Problem (SSCFLP). Since SSCFLP is NP Complete, it cannot be solved to optimality in polynomial time. However, efficient heuristic algorithms are proposed for SSCFLP.
- We compare the performance of heuristic algorithms proposed for SSCFLP for various networks sizes and various data rate requirements based on simulations in comparison to the optimal solution.

## II. System Model

- We consider a HCRAN [1] as in Figure 1. In our model, MBS operates at 2.4 GHz and is equipped with $N_{RF,M}$ RF chains. Within the coverage of MBS, there are $K$ SBSs with $N_{RF,S}$ RF chains and they operate at mmWave frequencies. Additionally, there are $N_b$ UEs that request connection in the coverage of MBS and each UE can be served by exactly one BS, therefore UE demand is not splittable. Lastly, dynamic on/off transition of SBSs is analyzed at a certain time instant.
- MBS and Node C are connected through Backhaul (BH) link whereas SBSs and MBS are connected through FH links. FH links are assumed to be capacity constrained and capacity of a FH link is denoted as $C_{fh}$.
- We assume directional transmission in DL.

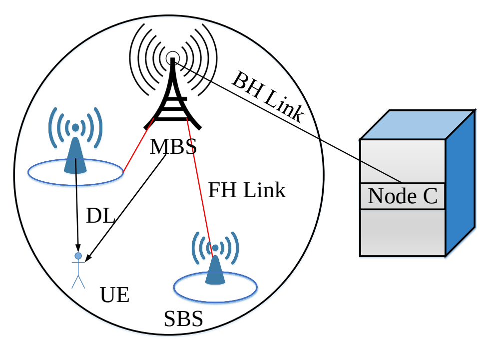


Fig. 1: HCRAN Architecture

- The BSs send Channel State Information (CSI) Reference Signal (RS) from each antenna port and the UEs estimate the attenuation levels $\alpha_{Mj}$ and $\alpha_{Sj}$ based on the received CSI-RS [11] transmitted from MBS and SBS $S$. With the information gathered about attenuation levels, MBS decides on the least power consuming UE-BS pair for each BS and UE and establishes a connection [12].
- Depending on the transmission bandwidth, BSs provide different achievable rates $R_{Mj}$ and $R_{Sj}$,

from MBS to UE $j$ and from SBS $S$ to UE $j$, respectively. The achievable rates can be formulated as in [13]:

$$R_{ij} = B_i * \log\left(1 + \frac{P_{t,iBS} * \alpha_{ij}}{|N_{RF,i}| * N_0 * B_i}\right) \quad (1)$$

where $i$ is M or S and $B_M$ and $B_S$ represent the tranmission bandwidth for MBS and SBS $S$, respectively. $P_{t,MBS}$ and $P_{t,SBS-S}$ indicate the transmission power of MBS and SBS $S$, respectively. $N_0$ is the power spectral density of the noise at each UE. Furthermore, interference is ignored due to directional transmission.

- Demanded data rate of UE $j$ is defined as $Q_j$. To fulfill the data rate requirements of UEs, RF chains can cooperate to realize directional transmission. Additionally, channel utilizations $\beta_{Mj}$ and $\beta_{Sj}$ are referred as indicators of the communication performance of the channel between MBS and UE $j$ and SBS $S$ and UE $j$, respectively [14]. It is formulated as $\beta_{ij} = \frac{Q_j}{R_{ij}}$, where $i$ is M or S.
- MBS power consumption is analyzed in two different parts, which are static power consumption $P_{Static}$ and dynamic power consumption $P_{Dynamic}$ [15], [16], (Eqn. 2). $P_{Static}$ consists of the power consumption of the rectifier, the airconditioner and the backhaul link [17]. $P_{Dynamic}$ depends on the load of the system and is formulated as $F * P_l$. $F = \frac{\sum_{j=1}^{N_b} \beta_{Mj}}{N_{RF,M}}$ is the load factor and $P_l$ consists of power consumption of power amplifier, the transceiver, the digital signal processing unit.

$$P_M = P_{Static} + P_{Dynamic} \quad (2)$$

- Each SBS $S$ can serve up to four UEs on average, therefore we assume that it is operating on full load [18]. Power consumption of a SBS includes power consumed in microprocessor $P_{mp}$, FPGA $P_{FPGA}$, transceiver $P_{tx,S}$ and power amplifier $P_{amp,S}$ as in [15]:

$$P_S = P_{mp} + P_{FPGA} + P_{tx,S} + P_{amp,S} \quad (3)$$

- The power consumed on FH link is denoted as $P_{fh,S}$ and it is a linear function of the demanded data rate of UE $j$, $Q_j$ [19].

## III. Optimization Problem

The joint optimization of UE association and switching on/off the SBSs with the objective of minimizing the system power consumption by incorporating dynamic power consumption of MBS, FH link power consumption given the capacity and rate constraints is formulated as the following SSCFLP:

$$\min \quad P_{static} + P_{dyn,M} + P_S + P_{fh,l} \quad (1a)$$

$$\text{s.t.} \quad Q_j * x_{Sj} \le R_{Sj} \quad \forall j \in [1, N_b] \quad \forall S \in [1, K] \quad (1b)$$

$$Q_j * x_{Mj} \le R_{Mj} \quad \forall j \in [1, N_b] \quad (1c)$$

$$x_{Mj} + \sum_{S=1}^{K} x_{Sj} = 1 \quad \forall j \in [1, N_b] \quad (1d)$$

$$\sum_{j=1}^{N_b} \beta_{Sj} * x_{Sj} \le N_{rf,S} \quad \forall S \in [1, K] \quad (1e)$$

$$\sum_{j=1}^{N_b} \beta_{Mj} * x_{Mj} \le N_{rf,M} \quad (1f)$$

$$\sum_{j=1}^{N_b} Q_j * x_{Sj} \le C_{fh,S} \quad \forall S \in [1, K] \quad (1g)$$

$$x_{Sj} \le T_S \quad \forall j \in [1, N_b] \quad \forall S \in [1, K] \quad (1h)$$

$$\text{Vs} \quad T_S, x_{Mj}, x_{Sj} \in \{0, 1\} \quad \forall j \in [1, N_b] \quad \forall S \in [1, K] \quad (1i)$$

where $K$ is the number of SBSs and $N_b$ is the number of UEs. The decision variables of the problem are $T_S$, which is a binary variable taking value 1 when SBS $S$ turns on in case of UE association and 0 otherwise; $x_{Mj}$, which is a binary variable taking value 1 in case of association of UE $j$ to MBS and 0 otherwise; and $x_{Sj}$, which is a binary variable taking value 1 in case of association of UE $j$ to SBS $S$ and 0 otherwise.

Objective function (1a) of the optimization problem is minimization of total power consumption, including static power consumption of MBS, $P_{Static}$, power consumption $P_{dyn,M}$ which consists of dynamic power consumption of MBS, $\sum_{j=1}^{N_b}(\beta_{Mj} * P_l * x_{Mj})$, $P_S$ opening cost of SBS $S$, $\sum_{S=1}^{K} P_S * T_S$, and $P_{fh,l}$ which is the FH link power consumption, $\sum_{S=1}^{K} P_{fh} * \sum_{j=1}^{N_b} Q_{d,j} * x_{Sj}$, Constraints (1b) and (1c) ensure that the demand of UE $j$ should be less than or equal to the achievable rate from SBS $S$ and from MBS to UE $j$, respectively. Constraint (1d) assures that UE $j$ can only be assigned to MBS or a SBS $S$. Constraints (1e) and (1f) indicate that maximum number of UEs that can be simultaneously served by a BS is less than or equal to the number of RF chains that belongs to SBS $S$, ($N_{rf,S}$), and to MBS, ($N_{rf,M}$), respectively, which is motivated by the spatial multiplexing gain of the described multi-user hybrid precoding system in [10]. Constraint (1g) implies that the total data being forwarded on FH link by the associated UEs can not exceed the total FH link capacity. Constraint (1h) shows that SBS $S$ is turned on if there exists a UE associated with it. Lastly, constraint (1i) indicates that the decision variables are binary.

## IV. Solution Methodology

The optimization problem in Section III has the form SSCFLP and SSCFLP is a special case of Capacitated Facility Location Problem (CFLP). SSCFLP is a NP-Complete problem and its NP completeness is proved by reducing CFLP to set covering problem [20]. Due to its NP-Complete nature, it cannot be solved to optimality in polynomial time. Therefore, heuristic approaches are proposed to solve it to optimality and two of the heuristic algorithms are listed as follows:

- **Repeated Matching** based heuristic uses the repeated matching approach to form new feasible UE-BS pairs from previously determined ones with the aim of minimizing total power consumption [21]. Heuristic starts by assigning each UE to a nearby BS and ordering the UE-BS pairs in decreasing cost. If matching of any UE-BS pair does not yield decrease in power consumption, firstly an improved re-allocation of the UE-BS pairs is found. Then, corresponding UE-BS pair is split and UEs assigned to the BS become unassigned. When matching is applied again, new UE-BS pairs are found and this process is repeated until no further progress is made in a fixed number of splits. Increasing number of SBSs and UEs cause great blocks indicating the cost of possible UE-SBS pairs and great number of constraints. The complexity of the algorithm is $\mathcal{O}(mn)$, where m is the number of BSs and n is the number of UEs.
- **Perfect Matching** based heuristic uses alternating random walk to form minimum power consuming UE-BS pairs [22]. Heuristic starts by associating a random UE with a random BS. Then, new association pairs are found by performing alternating random walk based on the current matching. The alternating random walk G, is updated in each turn based on the result of the previously realized random walk. The G is updated as follows: A random UE selects a random BS according to a Markov transition matrix, $M$. M is obtained by normalizing $\beta_{i,j}$ values with $N_{rf,i}$ values, $\left(\frac{\beta_{i,j}}{N_{rf,i}}\right)$, of the elements of the current matching. Each UE aims to associate with the minimum power consuming BS. This process is repeated for all UEs until each UE is assigned to the same BS, which it has been associated with in the $r^{th}$ turn. As the number of SBSs and UEs increase, the search for the less power consuming SBSs among all SBSs by the UEs takes longer than expected. The complexity of the algorithm is $\mathcal{O}(n \log m)$, where m is the number of BSs and n is the number of UEs.

## V. Performance Evaluation

The goal of this section is to evaluate the performance of previously proposed heuristic algorithms, repeated matching algorithm [21] and perfect matching algorithm [22] compared to the optimal solution, for various data rate requirements and network sizes and demonstrate the importance of incorporation of dynamic power consumption of MBS and FH link power consumption on the optimal power consumption.

Simulation results are obtained based on a network topology consisting of 10 randomly positioned SBSs and 20 randomly positioned UEs under the coverage of MBS by using IBM CPLEX Optimization Studio with MathWorks MATLAB. SBSs are randomly and uniformly located with the minimum distance of 10 meters among each other, whereas UEs are distributed randomly and uniformly within the radius of 50 m to 700 m. Simulation results are obtained and averaged based on 5000 random configurations.

The system is analyzed based on uniform random single-path (UR-SP) Channel Model [13], which well captures the dominant path in highly directional propagation environments at mmWave frequencies. The links are assumed to be in Line-of-Sight ($LoS$), where no obstacles reside between transmit and receive antennas, or in Non-Line-Of-Sight ($NLoS$), where partial or full obstructions exist between the transmit and receive antennas, or in outage. The attenuation of the links are determined considering large scale statistics that arise primarily from the free space loss and the environment affecting the degree of refraction, diffraction, reflection and absorption. The dependence of the path loss on distance summarizing large scale statistics is modeled as $PL(d) = PL(d_0) + 10 * \eta_j * \log_{10}\left(\frac{d_{ij}}{d_0}\right) + X_{\sigma_j}$, where $PL(d_0)$ is the free space path loss in dB at a reference distance $d_0$, $\eta_j$ is the pathloss exponent and $X_{\sigma_j}$ is a zero mean Gaussian random variable with $\sigma_j^2$ variance. The parameters of the model used in the simulations are $\eta_j$=1.9 and $\sigma_j$=1.1 for LoS and $\eta_j$=4.5 and $\sigma_j$=10 for NLoS, $\sigma_j$=8.9 for MBS, $PL(d_0)$=30 dB, $N_0$=-134dBm/MHz, $C_{fh}$=4.45 Gbps, $N_{rf,M}$=8, $N_{rf,S}$=4, $P_{fh}$=0.1W/Mbps and power consumption values of MBS and SBS are summarized in [15]. We investigate the network with high and low $Q_j$ values (compared to maximum achievable rates in

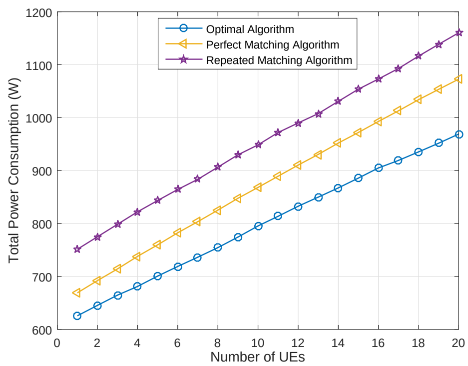


Fig. 2: Total power consumption at high data rates

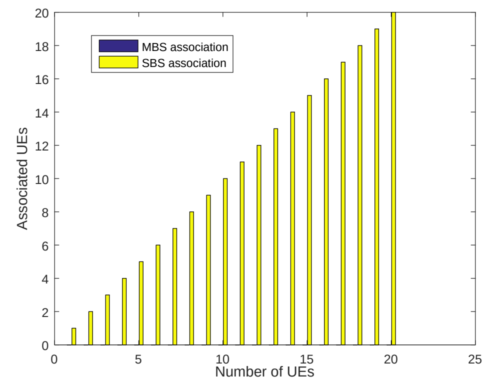


Fig. 3: UE Association distribution at high data rates

LTE (300 Mbps in downlink) [23]). High $Q_j$ values are uniformly distributed between (0.3-2) Gbps and low $Q_j$ values are uniformly distributed between (0.05-0.2) Gbps.

Fig. 2 illustrates the power consumption performance of optimal algorithm, perfect matching algorithm and repeated matching algorithm for different number of UEs in the presence of high data rate demanding UEs. Perfect matching algorithm performs closer to the optimal algorithm than repeated matching because a closed set is formed by using primal heuristic and the UE has the option to visit on SBSs to find the best minimum power consuming SBS in a pre-defined iteration number. On the other hand, in repeated matching algorithm the number of on SBSs is not constrained and a SBS can switch to on mode if it is able to provide service to any of the UEs.

Fig. 3 illustrates the optimal UE association distribution in the presence of high data rate demanding UEs. For high data rates, each $\beta_{Mj}$ value, $\frac{Q_j}{R_{Mj}}$, may exceed the capacity of MBS. As shown in Fig. 3, UEs prefer to get associated with SBSs. In this case, MBS is assumed to only provide coverage.

Fig. 4 demonstrates the power consumption performance in the presence of high data rate demanding UEs for three different schemes and increasing number of UEs. Total power consumption is constant for the optimal algorithm without considering $P_{fh,l}$, whereas the total power consumption of the optimal algorithm and the optimal algorithm without $P_{dyn,M}$ are identical and increase with the increasing number of UEs. With the incorporation of $P_{fh,l}$, the power consumption begins to increase due to increase in UE number and corresponding data rate demands. This demonstrates that at high data rates MBS only provides coverage and SBSs carry the traffic.

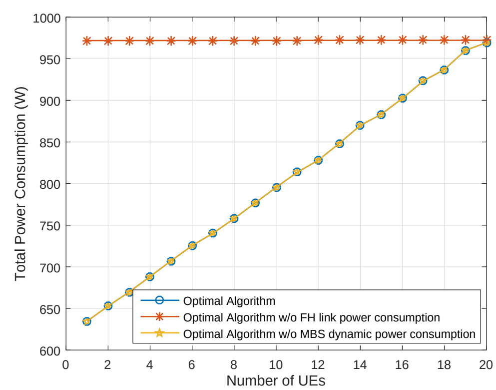


Fig. 4: Power consumption at high data rates

Fig. 5 illustrates the importance of $P_{fh,l}$ in presence of data intensive applications for increasing number of UEs. As in Eqn. 1a, $P_{fh,l}$ is an important decision criteria for the algorithm to assign UEs to SBSs. If $P_{fh,l}$ is not included in the objective function (Eqn. 1a), the algorithm turns on as many SBSs as possible as long as they provide service to UEs.

Fig. 6 represents optimal UE association in the presence of low data rate demanding UEs. For low number of UEs in the system, optimal algorithm assigns UEs to MBS to minimize the total power consumption because MBS is able to provide service to UEs with corresponding $\beta_{Mj}$ values and the power consumed due to switching on an SBS exceeds the dynamic power consumption of MBS. Following this, as the number of UEs increases, though $\beta_{Mj}$ values are small relative to MBS capacity, the service demand begins to exceed MBS capacity and $P_{dyn,M}$ increases with $F$. To minimize total power consumption, UEs prefer to associate to SBSs instead of

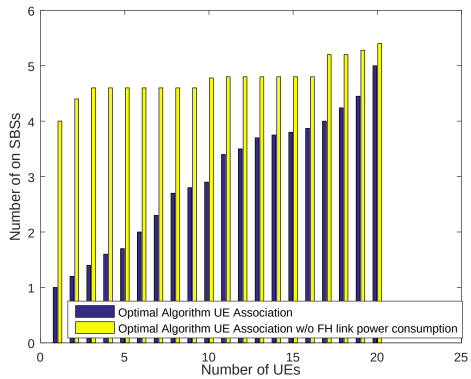


Fig. 5: UE Association distribution at high data rates

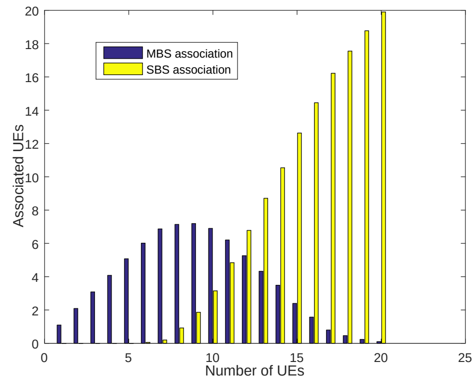


Fig. 6: UE Association distribution at low data rates

associating to the MBS because for increasing number of UEs $P_{dyn}$ exceeds $P_S$ value and association to SBSs is rewarding in terms of power consumption minimization.

Fig. 7 demonstrates the power consumption performance in presence of low data rate demanding UEs for three different schemes for different number of UEs. The optimal algorithm without $P_{dyn,M}$ leads to very high power consumption. If the effect of $P_{dyn,M}$ is neglected in the network, the algorithm begins to assign UEs to the SBSs and the FH link leads to a linear increase in power consumption with the demanding data rate. Moreover, there is a slight difference in the total power consumption between the optimal algorithm and the optimal algorithm without considering $P_{fh,l}$. Since FH link has small effect on decreasing the total power consumption, the algorithm continues to assign UEs to the MBS and SBSs until the power consumption due to association to MBS exceeds the power consumed by SBSs. At that point, the algorithm begins to assign UEs to the SBSs. Lastly, once the number of UEs is high enough such that all UEs are assigned to SBSs, the optimal algorithm without $P_{dyn,M}$, the optimal algorithm without considering $P_{fh,l}$ and the optimal algorithm result in the same power consumption.

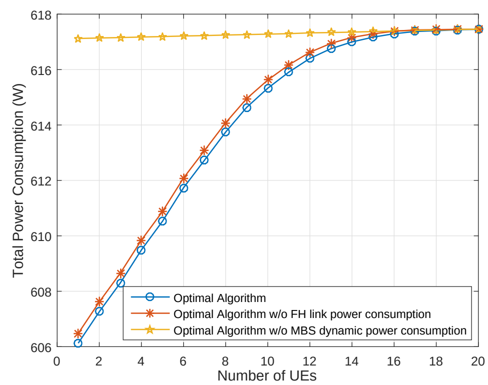


Fig. 7: Power consumption for low data rates

## VI. Conclusion

In this paper, we study the effect of dynamic power consumption of MBS and power consumption of FH link on the energy efficient UE association with the goal of minimizing total power consumption subject to achievable rate and capacity constraints. With the utilization of realistic power consumption models, we model the optimization problem as a SSCFLP, which is known to be NP-Complete. We compare the performance of the efficient heuristic algorithms proposed for SSCFLP with the optimal algorithm and realize that perfect matching algorithm performs closest to the optimal solution. Moreover, if we include dynamic power consumption of MBS in the power analysis, we observe that MBS provides service to low data rate demanding UEs rather than only providing coverage.

As future work, we aim to concentrate on decoupled Uplink ($UL$)/DL UE association scheme in HCRAN with the goal of minimizing total network power consumption. Besides the power consumption model used in this work, power consumption in such association scheme requires the incorporation of power consumption of UEs in UL and power consumption of the FH links due to UL data transmission between SBSs and MBS. Therefore, we plan to compare the performance of coupled and decoupled UE association and investigate the effect of UL data rates on total network power consumption.

## REFERENCES


[1] M. Peng, Y. Li, Z. Zhao and C. Wang, "System architecture and key technologies for 5G heterogeneous cloud radio access networks," *in IEEE Network*, vol. 29, no. 2, pp. 6-14, March-April 2015.

[2] J. Gong, Z. Niu, Z. Yang, P. Yang, and S. Zhou, "Green Mobile Access Network with Dynamic Base Station Energy Saving," *MobiCom' 09*, September 2009.

[3] L. Dong, G. Wu, Z. Xu and S. Li, "Energy efficient pico base station switching-on/off in heterogeneous cellular network with minimum rate requirement," *2014 Sixth International Conference on Wireless Communications and Signal Processing (WCSP)*, Hefei, 2014, pp. 1-6.

[4] K. Son, E. Oh and B. Krishnamachari, "Energy-efficient design of heterogeneous cellular networks from deployment to operation," *Computer Networks*, vol. 78, pp. 95–106, Feb. 2015.

[5] N. Yu, Y. Miao, L. Mu, H. Du, H. Huang and X. Jia, "Minimizing Energy Cost by Dynamic Switching ON/OFF Base Stations in Cellular Networks," *in IEEE Transactions on Wireless Communications*, vol. 15, no. 11, pp. 7457-7469, Nov. 2016.

[6] J. Zuo, J. Zhang, C. Yuen, W. Jiang and W. Luo, "Energy Efficient User Association for Cloud Radio Access Networks," in IEEE Access, vol. 4, no. , pp. 2429-2438, 2016.

[7] Y. Shi, J. Zhang and K. B. Letaief, "Group Sparse Beamforming for Green Cloud-RAN," *in IEEE Transactions on Wireless Communications,* vol. 13, no. 5, pp. 2809-2823, May 2014.

[8] C. Pan, H. Zhu, N. J. Gomes and J. Wang, "Joint Precoding and RRH Selection for User-Centric Green MIMO C-RAN," *in IEEE Transactions on Wireless Communications,* vol. 16, no. 5, pp. 2891-2906, May 2017.

[9] C. Pan, H. Zhu, N. J. Gomes and J. Wang, "Joint User Selection and Energy Minimization for Ultra-Dense Multi-channel C-RAN With Incomplete CSI," *in IEEE Journal on Selected Areas in Communications,* vol. 35, no. 8, pp. 1809-1824, Aug. 2017.

[10] A. Alkhateeb, G. Leus and R. W. Heath, "Limited Feedback Hybrid Precoding for Multi-User Millimeter Wave Systems," *in IEEE Transactions on Wireless Communications*, vol. 14, no. 11, pp. 6481-6494, Nov. 2015.

[11] Y. Sano, A. Fukuda, S. Okuyama, Y. Kakishima and C. NA, "LTE-Advanced Release 13 Multiple Antenna Technologies and Improved Reception Technologies", *NTT Docomo Technical Jounal*, vol. 18, no. 2, pp. 62-71, 2015

[12] T. S. Rappaport, G. R. MacCartney, M. K. Samimi and S. Sun, "Wideband Millimeter-Wave Propagation Measurements and Channel Models for Future Wireless Communication System Design," *in IEEE Transactions on Communications*, vol. 63, no. 9, pp. 3029-3056, Sept. 2015.

[13] G. Lee, Y. Sung and J. Seo, "Randomly-Directional Beamforming in Millimeter-Wave Multiuser MISO Downlink," *in IEEE Transactions on Wireless Communications*, vol. 15, no. 2, pp. 1086-1100, Feb. 2016.

[14] G. Athanasiou, P. C. Weeraddana, C. Fischione and L. Tassiulas, "Optimizing Client Association for Load Balancing and Fairness in Millimeter-Wave Wireless Networks," *in IEEE/ACM Transactions on Networking*, vol. 23, no. 3, pp. 836-850, June 2015.

[15] M. Deruyck, W. Vereecken, W. Joseph, B. Lannoo, M. Pickavet, and L. Martens, "Reducing the power consumption in wireless access networks: overview and recommendations," *Progress In Electromagnetics Research*, vol. 132, pp. 255-274, 2012.

[16] O. Arnold, F. Richter, G. Fettweis and O. Blume, "Power consumption modeling of different base station types in heterogeneous cellular networks," *2010 Future Network & Mobile Summit*, Florence, 2010, pp. 1-8.

[17] S. Tombaz, P. Monti, K. Wang, A. Vastberg, M. Forzati and J. Zander, "Impact of Backhauling Power Consumption on the Deployment of Heterogeneous Mobile Networks," *2011 IEEE Global Telecommunications Conference - GLOBECOM 2011*, Houston, TX, USA, 2011, pp. 1-5.

[18] I. Ashraf, F. Boccardi and L. Ho, "Power savings in small cell deployments via sleep mode techniques," 2010 IEEE 21st International Symposium on Personal, Indoor and Mobile Radio Communications Workshops, Instanbul, 2010, pp. 307-311.

[19] R. Ramamonjison, A. Haghnegahdar and V. K. Bhargava, "Joint Optimization of Clustering and Cooperative Beamforming in Green Cognitive Wireless Networks," *in IEEE Transactions on Wireless Communications*, vol. 13, no. 2, pp. 982-997, February 2014.

[20] J. Krarup and P. Pruzan, "The Simple Plant Location Problem: Survey and Sythesis," *European Journal of Operation Research*, vol.12, pp.36-81, 1983.

[21] M. Ronnqvist, S. Tragantalerngsak, and J. Holt, "A repeated matching heuristic for the single-source capacitated facility location problem," *European Journal of Operation Research*, vol.116, pp. 51-68, 1999.

[22] M. Kapralov, "Algorithms for Bipartite Matching Problems with Connections to Sparsification and Streaming," *Ph.D Dissertation, Stanford University*, April 2012.

[23] 3GPP TS 36.213: "Evolved Universal Terrestrial Radio Access (E-UTRA); Physical layer procedures"