Energy Efficient Resource Sharing in Multi-Operator Heterogeneous Cloud RAN

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***Abstract*—In this paper, we consider a multi-operator heterogeneous cloud radio access network, where operators share their small cells. A formulation for the energy efficiency of the shared network is suggested and an energy-efficient resource allocation algorithm is proposed for the user assignment and power allocation in the multi-operator network. The problem is formulated as a mixed-integer optimization problem and solved using Lagrange Dual Decomposition method. Numerical results proved the benefits of sharing in terms of network energy efficiency, power consumption and users satisfaction. It also showed the efficiency of the proposed algorithm in achieving additional power saving in a multi-operator Heterogeneous Cloud RAN.**

***Index Terms*—5G, Heterogeneous Cloud RAN, small cell sharing, energy efficiency, resource allocation, mixed-integer optimization**

I. Introduction

With the fifth generation technology, mobile networks evolution targets massive capacity and connectivity and guarantees impressive broadband capabilities for users and industrial [1-4]. In 5G, small cell deployment plays a major role to increase capacity and enhance service quality. Therefore, wireless network densification in Heterogeneous Networks (HetNets), presents a promising strategy for operators in order to handle the increasingly capacity demand and the need for anywhere and anytime connection. Although, network densification with a high number of small cells (in Ultra Dense Networks), will raise the energy consumption and the inter-cell interference. Cloud Radio Access Networks (C-RAN) introduces a new trend for wireless network, where small cell deployment can be achievable through virtualization; femtocells and picocells are created by Remote Radio Heads (RRHs) instead of low power base stations (BSs) and access points, and the infrastructure workload is computed at the Base Band Processing Units (BBU), which can be shared among different operators in the Cloud [5-7]. This network architecture reduces the energy consumption of the wireless infrastructure, improves the cooperative gains between adjacent base stations and helps to suppress inter-tier interference and to manage interference between small cells. Heterogeneous Cloud Radio Access Network (H-CRAN) integrates cloud computing with Heterogeneous Networks (HetNets) in order to increase performance gain. For network operators, time is crucial while upgrading their networks and the great challenge resides in preserving deployment and energy cost with the dramatic traffic increase as well as environmental preservation for greener future networks. RAN sharing is an efficient approach that helps to reduce deployment time and cost, and maximize efficiency and competitiveness [8-11]. Based on H-CRAN, RAN sharing plays a great role in the future wireless network generation, to enhance performance and reduce the energy cost [12]. 5G network architecture will rely on CRAN and Network sharing [13][14]. In this paper, we consider a multi-operator H-RAN, where a number of operators decide to share their small cells within a solution to expand capacity, enhance user satisfaction with additional power saving and higher energy efficiency. We assume that every operator will share its small cells, such that mobile users can be connected to one of its home operator small cells or a small cell of another operator in the sharing system. In this context, we propose a resource allocation algorithm for the user assignment and power allocation, based on the maximization of the energy efficiency for the shared network. First, we model the energy efficiency (EE) in a multi-operator H-CRAN and we derive an expression with a number M of LPN (low power nodes, i.e., small cells). Next, we formulate our objective with a mixed-integer non-convex optimization problem. And then, we solve the formulated problem using Lagrange Dual Decomposition method. We study the system of two operators and we investigate the case of sharing different bandwidths. Moreover, we compare our proposed algorithm to fixed power allocation algorithm, where LPNs transmit with a fixed power, and we show how the proposed algorithm improves the energy efficiency and power consumption. The remainder of the paper is organized as follows: section 2 presents some related works to H-CRAN and network sharing. In section 3, we introduce the system model and the energy modeling. The problem formulation and the proposed resource allocation algorithm are described in section 4. Numerical results and discussions are given in section 5. Finally, the conclusion is given in section 6.

II. Background and Related Works

In HetNets, the energy efficiency and power consumption are very important and affect directly the operator benefits. In [15], the authors considered a heterogeneous dense-urban network served by N operators sharing their small cell base stations. The objective of the work is to reduce the energy consumed by the small cells. The authors approach is based on varying the sharing ratio between the operators, by reducing the average number of activated small cells. In H-CRAN the small cells are made using LPN RRH. Additional power reduction can be achieved with dynamic resource allocation and user assignment approaches. In [16], authors approach is based on RRH deactivation. RRH on/off mechanism is developed using iterative algorithm. And, user-RRH association is performed based on the selection of the active RRH satisfying channel quality requirements. The majority of works that tackle joint resource and power allocation in an all active small cell network were done in the context of heterogeneous network managed by a single operator. In [17], authors considered an H-CRAN and analyzed the Energy Efficiency (EE) of the network formed by a number of RRH and a HPN (High Power Node, i.e., Macro Cell). They proposed an algorithm for the joint optimization of resource blocks assignment and power allocation subject to RRH and HPN selection and interference elimination. Other works, [12][18][19] , used game theory for the user assignment and power allocation in small cell networks. In [18], Authors studied the power allocation in heterogeneous small cell networks by considering the delay-aware QoS requirement, effective capacity (EC), total circuit power consumption and energy efficiency. The power allocation decision problem was modeled using non-cooperative supermodular game. In [19], authors proposed an algorithm to solve resource allocation problem and maximize the total system EE in Ultra Dense Networks. The resource allocation problem was modeled using a mixed integer fractional problem. This maximizing problem of the total system EE was decomposed into two sub-optimization problems and solved in a hierarchical approach. The second sub-optimization problem for power allocation was transformed into a two-stage Stackelberg game, where Macro BS is a follower and all small cell BSs are leaders. In our work, we consider a multi-operator H-CRAN, where operators share only their small cells implemented using LPN. We assume that all operators share a number of LPNs and the latter remain always active. In fact, shared LPNs will offer additional bandwidth helping operators to increase capacity and user satisfaction and to achieve higher rates. Since energy consumption and efficiency will be a question in this context, we are interested in our approach in maximizing the EE of the shared H-CRAN. First, we provide a simplified formulation for the EE in the shared network consisting of LPNs/RRHs of N operators. And we present the resource allocation algorithm in the multi-operator H-CRAN, taking into account the shared LPNs of different operators. Our algorithm, aims to manage the operators shared resources in a way to maximize the EE of the whole shared network and to improve operators and mobile users satisfaction in the same time. The minimization of power consumption is achieved through user assignment optimization and dynamic power allocation. Our algorithm is based on a mixed integer fractional programming problem which is converted and solved using Lagrange Dual Decomposition method.

III. System Model and EE Modeling

We consider an area served by N Mobile Network Operators (MNOs) deploying their own H-CRAN and we consider a total number of mobile users $S = \sum_{n=1}^{N} S_n$. Note that without sharing, a MNO n,$n = 1...N$, will serve only users from its S_n clients, while with sharing it may serve any user of the set S. The H-CRAN, of each MNO in the considered area, consists of one HPN (Macro base station) and M_n LPN, thus the total number of LPNs serving the considered area is $M = \sum_{n=1}^{N} M_n$. We assume that the macro site location of the HPNs of all operators is shared, and the nth MNO dedicates B_n MHz, $n = 1...N$, for small cell layer [20], i.e. LPN m will use the bandwidth Bm allocated by its MNO. Besides, we consider the minimum transmission rate as the QoS requirement for the mobile users and we denote the rate constrained QoS requirements as ξ_R. The channel-to-interference-plus-noise ratio (CINR) for the sth user associated with the mth LPN of operator n is[17]:

$$\sigma_{s,m} = \frac{d_s^m h_s^m}{B_m N_0} \tag{1}$$

where d_s^m and h_s^m denote the path loss and the channel gain, respectively, from the mth LPN to the sth user. N_0 denotes the estimated power spectrum density of both the sum of noise and weak inter-RRH interference.

A. Total data rate of the shared network

Remember that the MNOs LPNs are shared and users can be paired with any LPN among the M LPNs. Thus, the sum data rate for the overall shared network with M LPNs and S users can be written as[21]:

$$R_t(a,p) = \sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} B_m \log_2(1 + \sigma_{s,m} p_{s,m}) \tag{2}$$

where $s \in \{1...S\}$ and S denotes the total number of users. The $S \times M$ matrices $a = [a_{s,m}]_{S \times M}$ and $p = [p_{s,m}]_{S \times M}$ represent the user association and power allocation decisions, respectively, where $a_{s,m}$ is defined as the user pairing variable, such that $a_{s,m} \in \{1, 0\}$ determines whether the user s is associated to LPN m or not. And, $p_{s,m}$ denotes the transmit power allocated to user s from mth LPN.

B. Total power consumption of the shared H-CRAN

In our H-CRAN, the total power consumption $P(a,p)$ is a function of the transmit power and the circuit power. For the fronthaul, the total power consumption of the mth LPN is given as in [17]:

$$P_m(a,p) = \phi_{eff} \sum_{s=1}^{S} a_{s,m} p_{s,m} + P_{circuit} + P_{frl} \tag{3}$$

where ϕ_{eff}, $P_{circuit}$ and P_{frl} denote the efficiency of the power amplifier, circuit power, and power consumption of the fronthaul link, respectively. And, the total power consumption of the shared network can be written as:

$$P_t(a,p) = \phi_{eff} \sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} p_{s,m} + M \times P_{circuit} + M \times P_{frl} \tag{4}$$

Hence, we can provide the EE formulation for a multi-operator H-CRAN where M LPNs are shared.

C. Energy Efficiency of the shared H-CRAN

The EE ratio for a multi-operator H-CRAN, where MNO are sharing only their LPNs, can be written as:

$$\begin{aligned} \Gamma &= \frac{R_t(a,p)}{P_t(a,p)} \\ &= \frac{\sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} B_m \log_2(1+\sigma_{s,m} p_{s,m})}{\phi_{eff} \sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} p_{s,m} + M \times P_{circuit} + M \times P_{frl}} \end{aligned} \tag{5}$$

IV. Cloud Energy-Efficient Resource Allocation

A. Resource allocation optimization problem

In this section, we present the optimization problem adopted by our energy-efficient resource allocation algorithm to perform an optimal user association and power allocation, in order to maximize the EE of the shared H-CRAN. Our allocation problem is subject to the required QoS, ξ_R, and the maximum transmit power allowed for LPNs, P_{max}. Thus, the EE maximization problem in the shared H-CRAN can be formulated as:

$$\max_{(a,p)} \Gamma = \frac{\sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} B_m \log_2(1+\sigma_{s,m} p_{s,m})}{\phi_{eff} \sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} p_{s,m} + M \times P_{circuit} + M \times P_{frl}}$$

$$s.t \begin{cases} \sum_{m=1}^{M} a_{s,m} = 1; \forall s \\ \sum_{s=1}^{S} a_{s,m} p_{s,m} \le P_{max}; \forall m \\ R_{s,m} \ge \xi_R; \forall m \forall s \\ a_{s,m} \in \{0,1\}, p_{s,m} \ge 0; \forall m \forall s \end{cases} \tag{6}$$

where $R_{s,m} = a_{s,m} B_m \log_2(1+\sigma_{s,m} p_{s,m})$. The first constraint restricts that each user cannot be allocated to more than one LPN at the same time. The second constraint corresponds to the maximum transmit power of the LPN. And, the third constraint corresponds to the rate constrained QoS requirements specified by the minimum data rate ξ_R. The shared H-CRAN EE problem is a mixed-integer programming problem, and it is a non-convex optimization problem; due to the objective function and the user allocation constraint. This type of problems is difficult to be solved directly with the classical convex optimization methods. Therefore, we have to proceed according to the resolution in the following subsection.

B. Optimization problem resolution

First, we will convert our problem to the following form :

$$\max_{\{a,p\}} R_t(a,p) - \rho^* \cdot P_t(a,p) \tag{7}$$

subject to the same constraints in equation (6). Where ρ is a nonnegative variable, and ρ^* is its optimal value such that $\rho^* = R_t(a^*,p^*)/P_t(a^*,p^*)$. ρ^* is achieved if and only if $\max_{\{a,p\}} R_t(a,p) - \rho^* \cdot P_t(a,p) = R_t(a^*,p^*) - \rho^* \cdot P_t(a^*,p^*) = 0$, where $\{a,p\}$ is any feasible solution of the problem in (6) satisfying the constraints. Note that the problem in (7) is feasible with a subtractive form objective function. The equivalent function $F(\rho) = \max_{\{a,p\}} R_t(a,p) - \rho \cdot P_t(a,p)$ is a strictly monotonic decreasing function in ρ, and $F(\rho) \ge 0$. Next, we adopt an iterative resolution. At each iteration, ρ is updated and the problem in (7) is solved, it ensures that ρ increases. The iterative algorithm can be viewed as a two nested loops. The principal loop updates $\rho^{(i+1)}$ using the $R_t(a^{(i)},p^{(i)})$ and $P_t(a^{(i)},p^{(i)})$ obtained in the previous iteration. In the second loop, using the value $\rho^{(i)}$, we solve the problem in (7) to find the optimal user allocation $a^{(i)}$ and power allocation $p^{(i)}$. The iterative algorithm can be described as follows:

1) *Set the convergence condition ϵ and the initial value $\rho^{(1)} = 0$.*
2) *Set the iteration index $i = 1$ and begin the iteration (principal loop).*
3) *for $1 \le i \le I_{max}$*
4) *Solve the problem in (7) with $\rho^{(i)}$ (second loop);*
5) *Obtain $a^{(i)}, p^{(i)}, P_t^{(i)}(a^{(i)},p^{(i)}) and R_t^{(i)}(a^{(i)},p^{(i)})$;*
6) *if $R_t^{(i)}(a^{(i)},p^{(i)}) - \rho^{(i)} P_t^{(i)}(a^{(i)},p^{(i)}) < \epsilon$ then*
7) *Set $\{a^*,p^*\} = \{a^{(i)},p^{(i)}\}$ and $\rho^* = \rho^{(i)}$;*
8) *break;*
9) *else*
10) *Set $\rho^{(i+1)} = \frac{R_t^{(i)}(a^{(i)},p^{(i)})}{P_t^{(i)}(a^{(i)},p^{(i)})}$ and i$= i+1$;*
11) *end if*
12) *end for*

The problem in the *i*th loop can be solved by the dual decomposition method [17]. By rearranging the constraints (2) and (3) of the problem in (6), the Lagrangian function of the primal objective function is given by:

$$\begin{aligned} L(a,p,\beta,\lambda) &= \sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} B_m \log_2(1+\sigma_{s,m} p_{s,m}) \\ &- \rho^{(i)} (\phi_{eff} \sum_{m=1}^{M} \sum_{s=1}^{S} a_{s,m} p_{s,m} + M \times P_{circuit} + M \times P_{frl}) \\ &+ \sum_{s=1}^{S} \beta_s [\sum_{m=1}^{M} a_{s,m} B_m \log_2(1+\sigma_{s,m} p_{s,m}) - \xi_R] \\ &+ \sum_{m=1}^{M} \lambda_m (P_{max} - \sum_{s=1}^{S} a_{s,m} p_{s,m}) \end{aligned} \tag{8}$$

where $\beta = (\beta_1, \beta_2 ... \beta_S)$ is the Lagrange multiplier vector associated with the required minimum data rate constraints, and $\lambda = (\lambda_1, \lambda_2 ... \lambda_M)$ is the Lagrange multiplier vector for the total transmits power constraint. The Lagrangian dual function can be expressed as:

$$g(\beta,\lambda) = \max_{\{a,p\}} L(a,p,\beta,\lambda) \tag{9}$$

and the dual optimization problem is reformulated as:

$$\begin{aligned} &\min_{\{\beta,\lambda\}} g(\beta,\lambda) \\ &s.t.\ \beta \geq 0, \lambda \geq 0. \end{aligned} \tag{10}$$

We use the dual decomposition method to solve this dual problem, which is first decomposed into M independent problems as:

$$\begin{aligned} g(\beta,\lambda) = \sum_{m=1}^{M} g_m(\beta,\lambda) - \rho^{(i)}(M \times P_{circuit} \\ + M \times P_{frl}) - \sum_{n=1}^{N} \beta_s \xi_R + \sum_{m=1}^{M} \lambda_m P_{max} \end{aligned} \tag{11}$$

where

$$\begin{aligned} g_m(\beta,\lambda) = \max_{\{a,p\}} \sum_{s=1}^{S} [(\beta_s+1) a_{s,m} B_m \log_2(1+\sigma_{s,m}) \\ - \rho^{(i)} \phi_{eff} a_{s,m} p_{s,m} - \lambda_m a_{s,m} p_{s,m}] \end{aligned} \tag{12}$$

With the KarushKuhnTucker conditions, the optimal power allocation is derived by:

$$p^*_{s,m} = [w^*_{s,m} - \frac{1}{\sigma_{s,m}}]^+ \tag{13}$$

where $[x^+] = \max\{x, 0\}$ and the optimal waterfilling level $w^*_{s,m}$ is derived as:

$$w^*_{s,m} = \frac{(\beta_s+1)B_m}{\ln 2(\rho^{(i)}\phi_{eff} + \lambda_m)} \tag{14}$$

Then, substituting the optimal power allocation obtained by (13) into the decomposed optimization problem (12), we can derive the optimal user allocation indicator as:

$$a^*_{s,m} = \begin{cases} 1, s = \arg\max\limits_{1 \leq s \leq S} K_{s,m} \\ 0\,, otherwise \end{cases} \tag{15}$$

where
$K_{s,m} = [(\beta_s+1)\log_2(w^*_{s,m}\sigma_{s,m})]^+ - \frac{(\beta_s+1)}{\ln 2}[1 - \frac{1}{w^*_{s,m}\sigma_{s,m}}]^*$

V. Numerical Results

We consider two operators sharing a total of $M = 8$ LPNs in a $1Km^2$ area zone. We assume that operators LPNs are offering the same bandwidth of $B_1 = B_2 = 10MHz$. And, the path-loss model is expressed as $31.5+40*\log(d)$ from the LPN to the user, where d denotes the distance in meters [17]. Note that the users are randomly distributed. The QoS requirements for the rate is assumed to be $\xi_R = 120Kbit/s$. For the circuit power consumption we use the value $P_{circuit} = 0.1$, and for the power efficiency $\phi_{eff} = 2$. The power consumption of the fronthaul link P_{frl} is assumed to be $0.2W$[17].

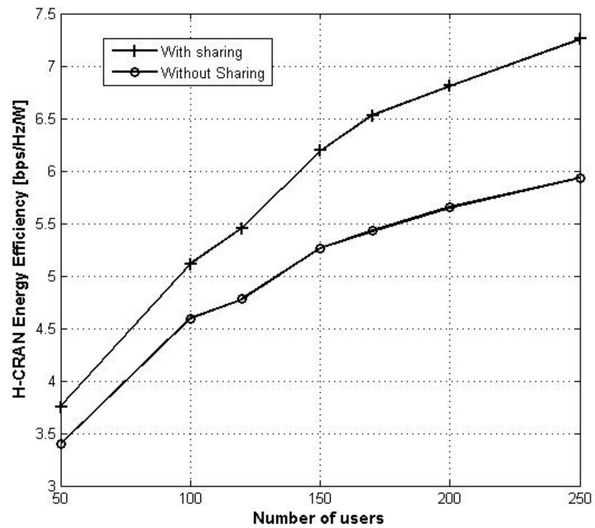

Fig. 1. Energy Efficiency of the multi-operator H-CRAN with and without Sharing

A. H-CRAN energy efficiency and sharing

Figure 1 shows the H-CRAN EE in function of the number of users in the served area, with and without sharing. Without sharing, users of the *nth* MNO can be associated only to LPNs of this MNO. Therefore, the EE of the small cell layer, without sharing, is calculated as the following: $EE_w = \frac{\sum_{n=1}^{N}\sum_{m=1}^{M_n}\sum_{s=1}^{S_n} a_{s,m} B_n \log_2(1+\sigma_{s,m} p_{s,m})}{\phi_{eff}\sum_{n=1}^{N}\sum_{m=1}^{M}\sum_{s=1}^{S} a_{s,m} p_{s,m} + M \times P_{circuit} + M \times P_{frl}}$. Results show that the total EE is increasing with the number of users and it is higher in the shared H-CRAN. In fact, our proposed algorithm achieves an optimal user assignment and power allocation that guarantees higher transmission bit rate with lower transmit power, which improves the EE efficiency. Besides, when sharing LPN, more users are granted service which improves the shared H-CRAN EE.

The variation of the number of served users after sharing the H-CRAN is represented in Fig. 2. It shows that the number of served users is greater with sharing. In fact, when operators share their LPNs, the service probability of the following users will increase:

a) Users out of coverage of the home operator LPNs and in the coverage of a partner operator LPN.
b) Users in the coverage of a home LPN which is already serving the maximum number of users and there is an available LPN for a partner operator in his coverage.

Thus, instead of being rejected, these users are served through a shared LPN, which increases the total number of served users.

B. MNO's EE

Going deeper for the EE analysis, Fig. 3 shows the EE of each MNO, in function of the number of users in the served area, with and without sharing. One can see that the EE of each cooperating operator is improved through sharing. And,

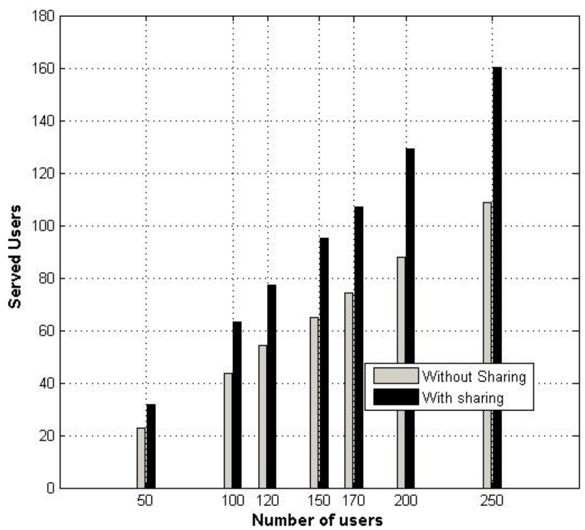

Fig. 2. Number of Served Users in the shared H-CRAN $B_1 = B_2 = 10MHz$

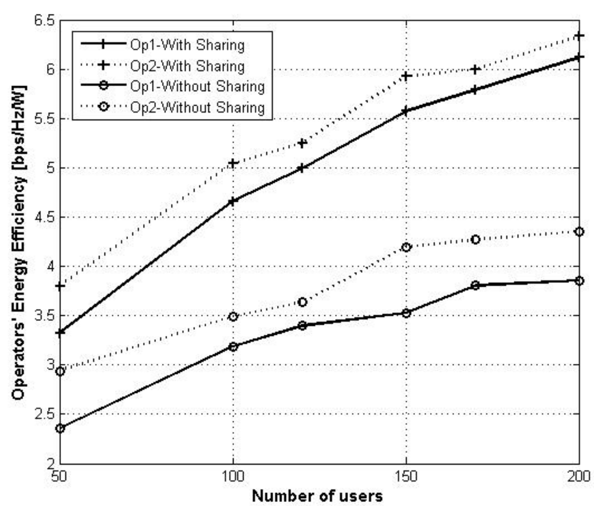

Fig. 3. Operators EE with and without Sharing, $B_1 = B_2 = 10MHz$

the increase in EE for the both operators is the same, since they share the same bandwidth.

C. Effect of the bandwidth on the EE

Figure 4 shows the EE variation for the operators, when sharing different bandwidths; Op_1 and Op_2 are with $B_1 = 10MHz$ and $B_2 = 20MHz$, respectively. EE improvement is achieved for both operators, but how much this EE is increased differs with the shared bandwidth. Results show better improvement of the EE for the second operator Op_2, which shares the highest bandwidth. The EE of Op_1 is also improved due to the fact that some $Op_1's$ users are served through $Op_2's$ LPNs. This verifies the benefit of sharing for all partners and even for the operator with limited resources.

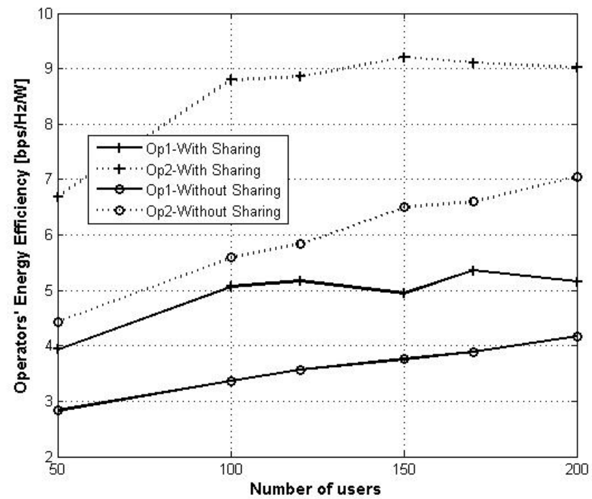

Fig. 4. Improvement of the EE when operators share different bandwidths $B_1 = 10MHz$ and $B_2 = 20MHz$.

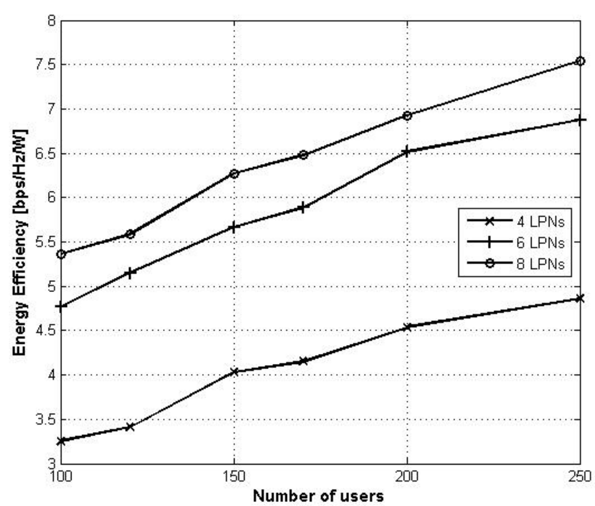

Fig. 5. Total EE of a shared H-CRAN with different LPN Number

D. Effect of the LPN number on the EE

Figure 5 shows the total EE of the shared H-CRAN for different number of LPN $M = 4, 6$ and 8. Results show that when number of LPNs increases, the total EE of the shared H-CRAN increases. In fact, when the number of LPNs increases the service coverage is extended, and thus the number of served users increases, and, as we showed in Fig.2, the energy efficiency increases.

E. Comparison of the proposed algorithm and Fixed Power algorithm

In this subsection we evaluate our algorithm in comparison with the Fixed power allocation algorithm in terms of total EE of the shared H-CRAN. With the Fixed power allocation

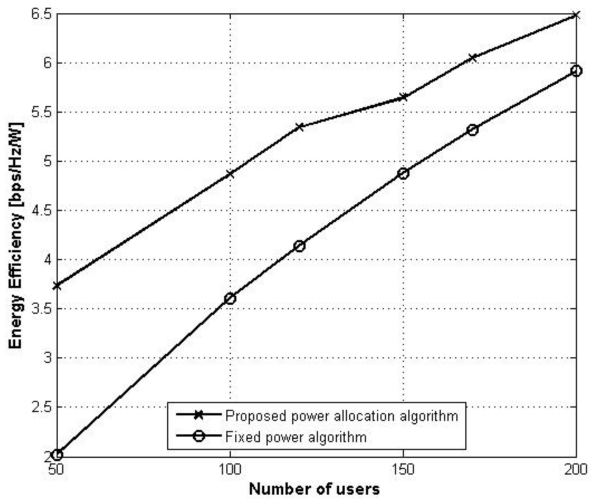

Fig. 6. Total EE performance comparisons using our proposed power allocation algorithm and Fixed power allocation algorithms

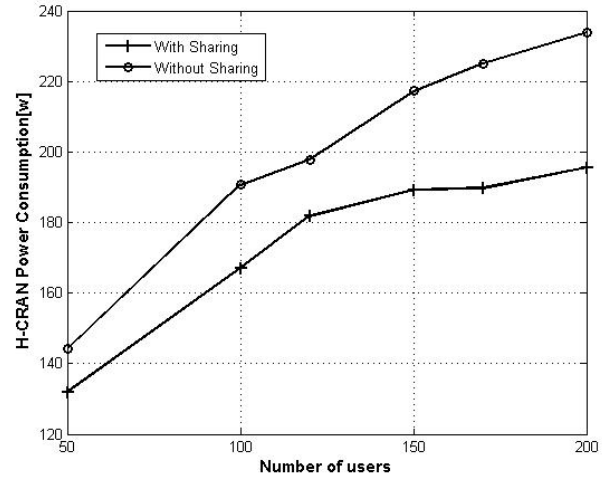

Fig. 7. Total Power Consumption with and without Sharing

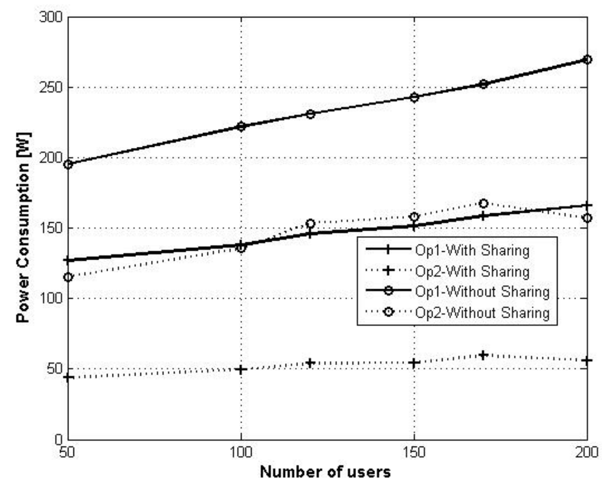

Fig. 8. Power Consumption for each operator with and without sharing

algorithm, the same and fixed power is assigned for the user service. The total EE of these two algorithms is shown in Fig. 6, with respect to the number of users in the served area. As it is expected, the total EE performance is better with our algorithm, guaranteeing a dynamic power allocation. It achieves the best selection among the available LPNs in the user coverage, in a way to reduce the transmit power.

F. Total power consumption and sharing

In this subsection, we highlight the advantage of our approach for energy efficient power allocation and user assignment and we represent the variation of the total power consumption of the H-CRAN with and without sharing. Figure 7 shows the variation of the total power consumption in function of the number of users. Results show how the power consumption is lower when operators share their LPNs. Besides, when sharing the total power consumption increases slower especially at high number of users. In fact, a mobile user at the border of the LPN coverage consumes higher amount of power. But, when operators share their LPNs, and using our algorithm, this user will be assigned to the closest LPN of another operator, which decreases the power consumption.

Figure 8 shows the power consumption of each operator with and without sharing in the case of $B_1 = 10MHz$ and $B_2 = 20MHz$. Results show that the power consumption is reduced to the half approximately. Even for the operator with the highest bandwidth which supplies service for more users, his power consumption is reduced and it is kept lower than the power consumption of its partner. Our proposed algorithm guarantees an energy efficient user association to the shared LPN. Results for the power consumption show how sharing promises operators to increase the user satisfaction without affecting its network performance.

VI. CONCLUSION

In this paper, we model the EE for a multi-operator H-CRAN where the operators share their LPN to find Energy Efficient Resource Allocation scheme. In particular, the access selection and power allocation are optimized. To deal with the optimization of selection, a non-convex fractional programming optimization problem is formulated, and the corresponding Lagrange dual decomposition method is proposed. Simulation results showed the efficiency of the proposed algorithm and that network gains with sharing over the network gains without sharing are significant. Furthermore, sharing decreases the user rejection and reduces power consumption. To ensure subscribers satisfaction and network performance, a new approach for access selection is needed which take cost as an important issue. Future work will consider the financial issues for the H-CRAN sharing and investigate the best pricing scheme for operators' cooperation.

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References

[1] Ericsson, "5G Systems", White Paper, 2017.
[2] HUAWEI, "5G: A Technology Vision", TechReport, 2013.
[3] 5GPPP, "5G Vision", TechReport, 5GPPP, 2015.
[4] NGM, "NGMN 5G whitepaper", White Paper, 2015.
[5] Checko, A., Christiansen, H., Yan, Y., Scolari, L., Kardaras, G., Dittmann, M., and Berger, L., "Cloud RAN for Mobile Networks-A Technology Overview", IEEE Communications Surveys Tutorials, 2015: v. 17, 405-42.
[6] 5G innovation Center, University of Surrey, I. f. C. S., "5G Whitepaper: The Flat Distributed Cloud (FDC) 5G Architecture Revolution", Whitepaper, 2016.
[7] Marotta, M. A., Kaminski, N., Gomez-Miguelez, I., Granville, L. Z., Rochol, J., DaSilva, L. and Both, C. B., "Resource sharing in heterogeneous cloud radio access networks", IEEE Wireless Communications, 2015: v. 22, 74-82.
[8] NEC Corporation,"RAN Sharing: NEC's approach towards active radio access network sharing", TechReport 2013.
[9] Farhat, S., Samhat, A., Lahoud, S., and Cousin, B., "Radio Access Network Sharing in 5G: Strategies and Benefits", Wireless Personal Communication, 2017: v.96,2715-2740.
[10] Markendahl,J. and Ghanbari, A., "Shared Smallcell Networks: Multi-Operator or Third Party Solution - Or Both? ", Fourth International Workshop on Indoor and Outdoor Small Cells, 2013.
[11] Markendahl, J., Molleryd,A. and Ghanbari, B., "Network Cooperation Between Mobile Operators-Why and How Competitors Cooperate? ", IMP conf. 2013.
[12] Vincenzi, Matteo, Angelos Antonopoulos, Elli Kartsakli, John Vardakas, Luis Alonso, and Christos. Verikoukis, "Cooperation Incentives for Multi-Operator C-RAN Energy Efficient Sharing", IEEE ICC, 2017.
[13] ASDReports, "Mobile Network Sharing Report 2010-2015".
[14] Accedian Networks, "RAN Sharing Solutions Accedian Networks", TechReport,2015.
[15] Lee, Ying Loong, Li-Chun Wang, Teong Chee Chuah, and Jonathan Loo, "Joint Resource Allocation and User Association for Heterogeneous Cloud Radio Access Networks", 28th International Teletraffic Congress, 2016.
[16] Malanchini, Ilaria, and Markus Gruber, "How operators can differentiate through policies when sharing small cells",
[17] Mugen, P., Zhang, K., Jiang, J., Wang, J., and Wang Wenbo, "Energy-Efficient Resource Assignment and Power Allocation in Heterogeneous Cloud Radio Access Networks", IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 64, NO. 11 64, no. 11 (November 2015), 5275-5287.
[18] Xu, Liang, Yuming Mao, Supeng Leng, Guanhua Qiao, and Quanxin Zhao, "Energy-Efficient Resource Allocation Strategy in Ultra Dense Small-cell Networks:a Stackelberg Game Approach", IEEE ICC, 2017.
[19] Zhang, Haijun, Mengying Sun, Keping Long, Min Sheng, and Victor C.M. Leung, "Supermodular Game Based Energy Efficient Power Allocation in Heterogeneous Small Cell Networks", IEEE ICC, 2017.
[20] Fooladivanda, D., and Rosenberg, F., "Joint Resource Allocation and User Association for Heterogeneous Wireless Cellular Networks", IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 12, NO. 1, 2013.
[21] Abdulkafi, A. A., S.K. Tiong, D. Chieng, A. Ting, A. M. Ghaleb, and J. Koh, "Modeling of Energy Efficiency in Heterogeneous Network", Research Journal of Applied Sciences, Engineering and Technology, 6(17): 3193-3201,2013.