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Offloading in Energy Harvesting enabled cellular Networks

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Abstract—**Offloading and energy harvesting are two important methods in the cellular communication. Offloading decreases the load on the mobile network and improves the network capacity and coverage. On the other hand, harvesting the energy from the radio frequency (RF) energy causes the devices to consume less battery and consequently prolongs the user equipments (UEs) usage. In this paper, we offer a new approach to offloading and energy harvesting in cellular networks (CNs). In our scheme, users are divided among base station (BS) and local access point (LAP) to get service. A UE is connected to BS or LAP based on their channel conditions. We formulate our resource allocation scheme as an optimization problem and solve it using dual Lagrange approach. Our simulation results show the impact of various parameters on the increase or decrease of the total sum rate of our considered model.**

Keywords- Cellular networks, offloading, energy harvesting, optimization problem.

I. INTRODUCTION

Today, with the advent of smart phones, tablets, and laptops, users tend to be active in social networks, watch video on youtube with high-definition (HD) quality, play online games, and use numerous applications causing the cellular network traffic amount to increase. In such a situation, macrocells in cellular networks can not serve the amount of traffic suitably. Data traffic offloading to a local access point (LAP) such as small cell or WiFi is one of the effective techniques to reduce the network load [1]. Usually, local access points with digital subscriber line (DSL) connect to network and subscribers transmit data to LAPs via wireless communication. Offloading to other networks can help to avoid having additional cellular network equipments. One of the solutions offered to cover demand growth of network traffic in LTE-A, is closer the network to the user through mix of macro, micro, pico, femto [2]. The important points that should be noted are criterion and procedure in offloading such as signal to interference plus noise ratio (SINR)[3, 4] or energy awareness [5]. In [6], the authors compute resources including processing bits during offloading, and optimization problem defined once considering the maximum latency in the execution of the application and once without it. A novel offloading design is introduced in [7] such that the smallest resource unit is determined as Physical Resource Block (PRB) is allocated to a single user and a two step algorithm is proposed for the two tier network.

User-initiated and operator-initiated offloading are two procedures for offloading. In [8], user-initiated procedure is considered due to simplicity in execution.

Energy harvesting of the environment such as solar, wind, and radio frequency (RF) energy in order to be used as the energy supply of communication devices is a suitable technique to reduce costs and increase the operating time. Base stations and wireless sensor networks without the need for electricity network and mobiles with no chargers can work using energy harvesting. An energy harvesting and energy storage module for BS is assumed so that their processes are independent of each other [9]. RF energy harvesting by users as a reliable source is modeled in [10] and analyzed. In addition, the minimum required average sum harvested energy of base station power transfer for downlink transmission is considered in [11]. In previous work, it is not considered the joint methods of offloading and energy harvesting. Therefore, we propose a novel optimization problem combining these techniques. The rest of this paper is organized as follows. The system model is described in Section 2. We formulate resource allocation problem in Section 3. We proposed a heuristic algorithm to solve this problem in 4. Simulation results are in 5. Finally, this paper is concluded in Section 6.

II. SYSTEM MODEL

We consider the downlink of a multiuser and two-tier network consisting of a base station (e.g. macro or micro) and a local access point (apiece with an antenna) as shown in Fig 1. We assume a set of K users denoted by $k \in \mathrm{K} = \{1,...,K\}$ in the network which are spread over the coverage area of the network. The system bandwidth is divided into two portion each further divided into N_b and N_a subcarriers denoted, respectively, by $n_b \in \{1,...,N_b\}$ and $n_a \in \{1,...,N_a\}$ where the former subcarriers are used by the BS and the latter subcarriers are used by the access point. All the transmitters and the receivers are equipped with one antenna and we assume that each user is assign to either the BS or the access point. We also assume that all the channels undergo independent flat fading and perfect CSI is assumed at both the transmitters and the receivers.

The transmission rate of user k which is assigned to the BS over subcarrier n_b is given by:

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$$r_{k,n_b} = \log_2(1+b_{k,n_b}), \tag{1}$$

$$b_{k,n_b} = \frac{p_{k,n_b}\,|h_{k,n_b}|^2}{s_{k,n_b}}, \tag{2}$$

where p_{k,n_b} is the transmit power assigned by the BS to

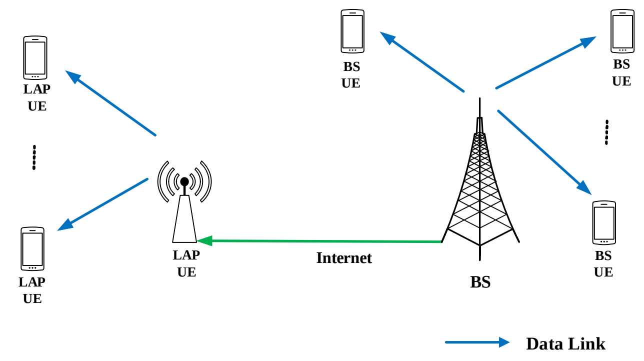

Figure 1. A tow tier cellular network, multi user, contain a base station and a local access point which is connected to network by DSL.

user k over subcarrier n_b, h_{k,n_b} is the channel gain between user k and the BS on subcarrier n_b, and s_{k,n_b} is the additive white Gaussian noise (AWGN) power. We assume that the channels undergo a Rayleigh fading meaning that the channel power gains, i.e., $g_{k,n_b} = |h_{k,n_b}|^2$, are exponentially distributed whose mean, i.e., $\bar{g}_{k,n_b} = \overline{|h_{k,n_b}|^2}$, can be calculated from the path-loss of the corresponding channels. The Path Loss of the channel is given by $\bar{g}_{k,n_b} = (d)^{-z}$

where d is distance between BS to user k in meters and z is path loss exponent. Similarly, the transmission rate of user k which is assigned to access point over subcarrier n_a is given by:

$$u_{k,n_a} = \log_2(1+x_{k,n_a}), \tag{3}$$

$$x_{k,n_a} = \frac{q_{j,n_a}\,|l_{k,n_a}|^2}{V_{k,n_a}}. \tag{4}$$

We assume that users in the network are able to harvest energy from the RF signals. More precisely, users in the network could harvest energy from the subcarriers which are not assigned to them. In this way, the can store the harvested energy into the battery for their future usage.

III. PROBLEM FORMULATION

In this paper, our objective is to user, subcarrier, and power allocation such that the total transmission rate of the network is maximized while the total harvested energy of the users is above a predefined threshold and we have transmit power constraints for the BS and the access point. Mathematically, we aim at solving the following optimization problem:

Problem 1:

$$\max_{\rho_m,\rho_w,\mathbf{P}_m,\mathbf{P}_w} \left(\sum_{k=1}^{K}\sum_{n_b=1}^{N_b} r_{k,n_b} r_{k,n_b}\right.$$

$$\text{s.t.} \quad \sum_{k=1}^{K}\sum_{n_b=1}^{N_b} r_{k,n_b}\, p_{k,n_b} \le P_{BS}^{\max},$$

$$\sum_{k=1}^{K}\sum_{n_a=1}^{N_a} r_{k,n_a}\, q_{j,n_a} \le P_{LAP}^{\max},$$

$$\sum_{k=1}^{K}\sum_{n_b=1}^{N_b} r_{k,n_b}\, p_{k,n_b}\left(\sum_{j=1}^{k}(1- r_{j,n_b})h_j\,|h_{j,n_b}|^2\right) + \sum_{k=1}^{K}\sum_{n_a=1}^{N_a} r_{k,n_a}\, q_{j,n_a}\left(\sum_{j=1}^{k}(1 - r_{j,n_a})h_j\,|l_{j,n_a}|^2\right) \ge Q^{\min},$$

$$r_{k,n_b} + r_{k,n_a} \le 1, \forall k, \forall n_b, \forall n_a,$$

$$\sum_{k=1}^{K} r_{k,n_b} \le 1, \forall n_b,$$

$$\sum_{k=1}^{K} r_{k,n_a} \le 1, \forall n_a,$$

$$r_{k,n_b} \in \{0,1\},$$

$$r_{k,n_a} \in \{0,1\},$$

$$p_{k,n_b} \ge 0,$$

$$q_{j,n_a} \ge 0,$$

where r_{k,n_b} and r_{k,n_a} are binary variables used to indicate the subcarrier assignment to users, $P_{BS}^{\max}$ and $P_{LAP}^{\max}$ are the maximum transmit power of BS and LAP, respectively, and h_j is RF to DC conversion efficiency of user j, $0 < h_j \le 1$. Also, in the above problem, constraints (5b) and (5c) ensure that the power allocated to users does not exceed the maximum available power, constraint (5d) ensures that the total harvested energy by all users should be more than the minimum value $Q^{\min}$, and constraint (5e) shows that any user can be covered by BS or LAP.

IV. RESOURCE ALLOCATION

To solve our optimization problem, we adopt the dual decomposition method [12]. We first write the Lagrange function of the optimization problem as follows:

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$$L(P_b,P_a,l_b,l_a,a)=\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}r_{k,n_b}+\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}u_{k,n_a}$$
$$+l_b(P_{BS}^{\max}-\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}p_{k,n_b})+(P_{LAP}^{\max}-\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}q_{k,n_a})$$
$$+a(\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}p_{k,n_b}h_j|h_{j,n_b}|^2+\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}q_{k,n_a}h_j|l_{j,n_a}|^2$$
$$-Q^{\min}),$$

where l_b, l_a and a are the Lagrange multipliers corresponding to constraints (5b), (5c), and (5d), respectively.

The Lagrange dual function is given by

$$g(l_b,l_a,a)=\max_{\mathbf{P}_b,\mathbf{P}_a}L(\mathbf{P}_b,\mathbf{P}_a,l_b,l_a,a)=$$
$$\max_{\mathbf{P}_b,\mathbf{P}_a}\{\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}r_{k,n_b}+\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}u_{k,n_a}$$
$$+l_b(P_{BS}^{\max}-\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}p_{k,n_b})$$
$$+l_a(P_{LAP}^{\max}-\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}q_{k,n_a})$$
$$+a(\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}p_{k,n_b}h_j|h_{j,n_b}|^2$$
$$+\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}q_{k,n_a}h_j|l_{j,n_a}|^2-Q^{\min})\},\tag{7}$$

and therefore, the dual problem is given by

$$\min_{l_b,l_a,a}\ g(l_b,l_a,a)$$
$$s.t.\quad l_b\geq 0,\ l_a\geq 0,\ a\geq 0.\tag{8}$$

A. POWER ALLOCATION

Note that, we can rewrite the Lagrange dual function as follows:

$$g(l_b,l_a,a)=\sum_{n_b=1}^{N}g_{n_b}(l_b,a)+\sum_{n_a=1}^{N}g_{n_a}(l_a,a)$$
$$+l_bP_{BS}^{\max}+l_aP_{LAP}^{\max}-aQ^{\min},\tag{9}$$

where

$$g_{n_b}(l_b,a)=\max_{\mathbf{P}_b}\{\sum_{k=1}^{K}r_{k,n_b}-l_b\sum_{k=1}^{K}p_{k,n_b}$$
$$+a(\sum_{k=1}^{K}p_{k,n_b}h_j|h_{j,n_b}|^2)\},\tag{10}$$
$$g_{n_a}(l_a,a)=\max_{\mathbf{P}_a}\{\sum_{k=1}^{K}u_{k,n_a}-l_a\sum_{k=1}^{K}u_{k,n_a}$$
$$+a(\sum_{k=1}^{K}u_{k,n_a}h_j|l_{j,n_a}|^2)\}.\tag{11}$$

which, respectively, can be equivalently written as follows:

$$g_{n_b}(l_b,a)=\max_{\mathbf{P}_b}\max_{k}r_{k,n_b}-l_b\max_{k}p_{k,n_b}$$
$$+a\max_{k}p_{k,n_b}h_j|h_{j,n_b}|^2,\tag{12}$$
$$g_{n_a}(l_a,a)=\max_{\mathbf{P}_a}\max_{k}u_{k,n_a}-l_a\max_{k}u_{k,n_a}$$
$$+a\max_{k}u_{k,n_a}h_j|l_{j,n_a}|^2.\tag{13}$$

To obtain the optimal transmit powers p_{k,n_b} and q_{k,n_a}, we take the derivatives of the Lagrange function and equate them to zero as follows:

$$\frac{dL(P_b,P_a,l_b,l_a,a)}{dp_{k,n_b}}=\frac{1}{\frac{s_{k,n_b}}{h_{k,n_b}^2}+p_{k,n_b}}$$
$$-l_b+ah_k|h_{j,n_b}|^2,\tag{14}$$

$$\frac{dL(P_b,P_a,l_b,l_a,a)}{dq_{k,n_a}}=\frac{1}{\frac{V_{k,n_a}}{l_{k,n_a}^2}+q_{k,n_a}}$$
$$-l_a+ah_k|l_{j,n_a}|^2,\tag{15}$$

whose solutions can be, respectively, obtained by:

$$p_{k,n_b}^*=[-\frac{s_{k,n_b}}{|h_{j,n_b}|^2}+\frac{1}{l_b-ah_k|h_{j,n_b}|^2}]^+,\tag{16}$$

$$q_{k,n_a}^*=[-\frac{V_{k,n_a}}{|l_{j,n_a}|^2}+\frac{1}{l_a-ah_k|l_{j,n_a}|^2}]^+.\tag{17}$$

B. Subcarrier Allocation

Now, substituting (16) and (17) into the Lagrange function, the subcarrier allocation can be obtained by

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$$g_{n_b}(l_b,a)=\max_k\{r^*_{k,n_b}-l_b p^*_{k,n_b}+ap^*_{k,n_b}\} \quad (18)$$

$$g_{n_a}(l_a,a)=\max_k\{u^*_{k,n_a}-l_a q^*_{k,n_a}+aq^*_{k,n_a}\} \quad (19)$$

where the best user for each subcarrier is given by

$$k^*_b=\arg\max_k\{r^*_{k,n_b}-l_b p^*_{k,n_b}+ap^*_{k,n_b}\}, \quad (20)$$

$$k^*_a=\arg\max_k\{u^*_{k,n_a}-l_a q^*_{k,n_a}+aq^*_{k,n_a}\}. \quad (21)$$

Given the value of k^*_b for each n_b, we set the value of $r_{k^*_b,n_b}=1$ and set $r_{k_b,n_b}=0$ for all $k_b\neq k^*_b$. Similarly, given the value of k^*_a for each n_a, we set the value of $r_{k^*_a,n_a}=1$ and set $r_{k_a,n_a}=0$ for all $k_a\neq k^*_a$. Let Ω^{BS}_k and Ω^{AP}_k be, respectively, the sets of the subcarriers assigned to user k by the BS and access point. It remains to assign the user k to either BS or the access point. To make this assignment, we first form the following equations:

$$L^{BS}_k=\sum_{n_b\in\Omega^{BS}_k} g_{n_b}(l_b,a), \quad (22)$$

$$L^{AP}_k=\sum_{n_a\in\Omega^{AP}_k} g_{n_a}(l_a,a). \quad (23)$$

Now, we assign the user k to the BS if $L^{BS}_k\geq L^{AP}_k$ and we assign the user k to the AP if $L^{BS}_k<L^{AP}_k$. In other words, we take the set Ω^{BS}_k as the final set of allocated subcarriers to user k if $L^{BS}_k\geq L^{AP}_k$ and take the set Ω^{AP}_k if $L^{BS}_k<L^{AP}_k$.

C. Solving Dual Problem

To solve the dual optimization problem, we used the subgradient approach. In this way, the Lagrange multipliers are updated as follows:

$$l^{i+1}_b=[l^i_b-d^i_1(P^{\max}_{BS}-\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}p_{k,n_b})]^+, \quad (24)$$

$$l^{i+1}_a=[l^i_a-d^i_2(P^{\max}_{LAP}-\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}q_{k,n_a})]^+, \quad (25)$$

$$a^{i+1}=[a^i-d^i_3(\sum_{k=1}^{K}\sum_{n_b=1}^{N_b}p_{k,n_b}h_j|h_{j,n_b}|^2$$
$$+\sum_{k=1}^{K}\sum_{n_a=1}^{N_a}q_{k,n_a}h_j|l_{j,n_a}|^2-Q_{min})]^+, \quad (26)$$

TABLE I. PSEUDO CODE OF THE PROPOSED ALGORITHM.

P1. Initialize l_b, l_a, a
For $k=1:K$
For $n_b=1:N_b$
P2. Calculate p^*_{k,n_b}, r^*_{k,n_b} and $g_{n_b}(l_b,a)$ via (16), (1) and (10) respectively
For $n_a=1:N_a$
P3. Calculate q^*_{k,n_a}, u^*_{k,n_b} and $g_{n_a}(l_a,a)$ via (17), (3) and (11) respectively
P4. Update l_b, l_a, a via (22), (23) and (24)respectively
Subcarrier allocation
For $k=1:K$
S1. Determine Ω^{BS}_k and Ω^{AP}_k via (20), (21) respectively
S2. If $\sum_{n_b\in\Omega^{BS}_k}\Delta_{n_b}\geq\sum_{n_a\in\Omega^{AP}_k}\Delta_{n_a}$
then related user be assigned to BS (k^{BS})
otherwise user be assigned to LAP (k^{AP})
S3. $r_{k^{BS},n_b}=1,\forall n_b\in\Omega^{BS}_k$ and $r_{k^{BS},n_b}=0$, $\forall n_b\notin\Omega^{BS}_k$
S4. $r_{k^{AP},n_a}=1,\forall n_a\in\Omega^{AP}_k$ and $r_{k^{AP},n_a}=0$, $\forall n_a\notin\Omega^{AP}_k$
end.

where d^i_1, d^i_2, and d^i_3 are updating step variables. The pseudo code of the proposed scheme is shown in table I.

V. SIMULATION RESULTS

In this section, to simulate the proposed algorithm, we set 0.9 and 0.09 for the path loss exponent of BS and LAP, multipliers $d_1=d_2$ are set to 0.0001, d_3 is set to 0.1, and AWGN power is set to 0.01 Watts. The minimum distance users of BS and LAP are 1 m and the maximum distance are 20 m and 10 m, respectively, the RF-DC conversion efficiency h_j is set to 0.5 for all users, and channel fading is supposed to be Rayleigh.

First, we evaluate the impact of increasing the number of users from 6 to 12 and assume different values of the maximum transmission power BS and LAP from 10 Watts to 100 Watts for $P^{\max}_{BS}$ and 0.1 Watts to 0.2 Watts for $P^{\max}_{LAP}$. Also, in this simulation, the number of BS and LAP subcarriers are 64. In Fig. 2, it is observed that in our multiuser model increasing transmitted power cause more power budget be assigned to each user also, increasing the number of users increases the total sum rate and thus network traffic increases.

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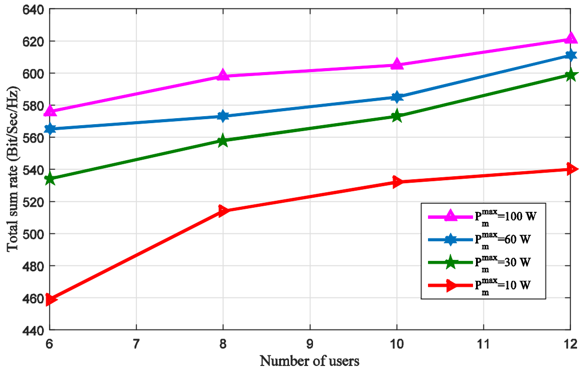

Figure 2. Total sum rate of BS and LAP users versus different number of users. n_b and n_a are 64.

In Fig. 3. we observe that with increasing the number of BS and LAP subcarriers for a given number of users increases the total sum rate. In fact, we perceive increment network capacity improves the network condition. In this stage, $P_{BS}^{\max}$ and $P_{LAP}^{\max}$ are fixed to 100 Watts and 0.2 Watts, respectively.

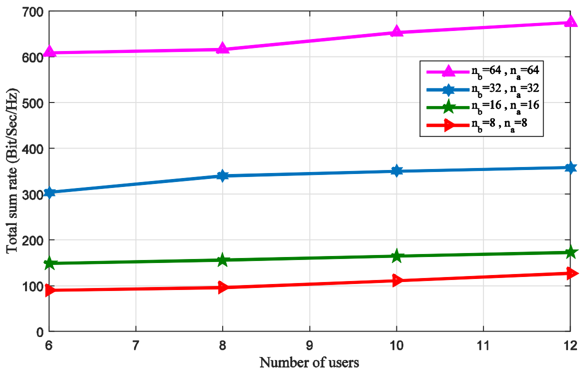

Figure 3. Total sum rate of BS and LAP users versus different number of users. $P_{BS}^{\max} = 100 Watts$ and $P_{LAP}^{\max} = 0.2 Watts$.

Next, we illustrate the impact of the minimum value of energy harvesting, i.e., $Q^{\min}$. In this simulation, the number of BS and LAP subcarriers are 8. As in Fig. 3 can be seen, by increasing the minimum value of $Q^{\min}$ from 0.1 Watts to 2 Watts, the total sum rate decreases.

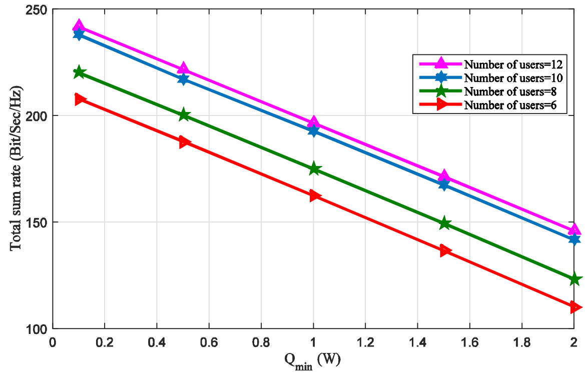

Figure 4. Effect of increase $Q^{\min}$ on the total sum rate. n_b and n_a are 8, $P_{BS}^{\max} = 100\, Watts$ and $P_{LAP}^{\max} = 0.2\, Watts$.

Finally, we study the effect of energy harvesting (EH) constraint on the total sum rate in Fig. 5. By removing this constraint, the total sum rate increases.

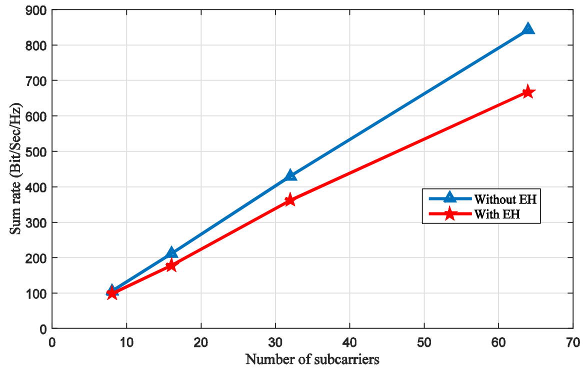

Figure 5. Effect of energy harvesting constraint on the total sum rate. $K = 12$, $P_{BS}^{\max} = 50 Watts$ and $P_{LAP}^{\max} = 0.2 Watts$

VI. Conclusion

In this paper, we proposed a novel algorithm for resource allocation in energy harvesting two tier cellular network. We formulated the resource allocation problem as an optimization problem and solved it using dual Lagrange method. Using simulations, we studied the performance of our proposed scheme under various situations. The results show that offloading improves the network performance in terms of total data rate of the network.

References

[1] Y. Li, M. Qian, D. Jin, P. Hui, Z. Wang, and S. Chen, "Multiple mobile data offloading through disruption tolerant networks," IEEE Transactions on Mobile Computing, vol. 7, no. 4, pp. 1579–1596, 2014.

[2] C. Fiandrino, D. Kliazovich, P. Bouvry, and A. Y.Zomaya, "Network-assisted offloading for mobile cloud applications," in Proc. 2015 IEEE International Conference on Communications (ICC), pp. 5833–5838, June 2015.

[3] P. Y. Kong and G. Karagiannidis, "Backhaul-aware joint traffic offloading and time fraction allocation for 5G hetnets," IEEE Transactions on Vehicular Technology, vol. PP, no. 99, pp. 1–1, 2016.

[4] Y. Sun, X. Xu, R. Zhang, and R. Gao, "Offloading based load balancing for the small cell heterogeneous network," in Proc. 2014 International

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www.SID.ir

Symposium on Wireless Personal Multimedia Communications (WPMC), pp. 288–293, Sept 2014.

[5] X. Chen, J. Wu, Y. Cai, H. Zhang, and T. Chen, "Energy-efficiency oriented traffic offloading in wireless networks: A brief survey and a learning approach for heterogeneous cellular networks," IEEE Journal on Selected Areas in Communications, vol. 33, no. 4, pp. 627–640, 2015.

[6] O. Munoz, A. Pascual-Iserte, and J. Vidal, "Optimization of radio and computational resources for energy efficiency in latency-constrained application offloading," Vehicular Technology, IEEE Transactions on, vol. 64, no. 10, pp. 4738–4755, 2015.

[7] A. Ichkov, V. Atanasovski, and L. Gavrilovska, "Analysis of two-tier lte network with randomized resource allocation and proactive offloading," Springer International Publishing, pp. 59–65, 2015.

[8] M. H. Cheung and J. Huang, "Dawn: Delayaware wi-fi offloading and network selection," IEEE Journal on Selected Areas in Communications, vol. 33, no. 6, pp. 1214–1223, 2015.

[9] H. Dhillon, Y. Li, P. Nuggehalli, Z. Pi, and J. Andrews, "Fundamentals of heterogeneous cellular networks with energy harvesting," Wireless Communications, IEEE Transactions on, vol. 13, no. 5, pp. 2782–2797, 2014.

[10] A. H. Sakr and E. Hossain, "Analysis of multi-tier uplink cellular networks with energy harvesting and flexible cell association," in Proc. 2014 IEEE Global Communications Conference, pp. 4525–4530, 2014.

[11] M. Chynonova, R. Morsi, D. W. K. Ng, and R. Schober, "Optimal multiuser scheduling schemes for simultaneous wireless information and power transfer," In Signal Processing Conference (EUSIPCO), 2015 23rd European (pp. 1989-1993). IEEE.

[12] S. Boyd and L. Vandenberghe, "Convex optimization," Cambridge University Press, 2004.

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