Energy Efficient Resource Allocation in Small Cells with WiFi Unlicensed Bands Sharing

Lei Zhu[1(✉)], Haijun Zhang[2], and Xuebin Li[1]

[1] Beijing University of Chemical Technology, Beijing, China
zhuleibuct@126.com
[2] Beijing Advanced Innovation Center for Materials Genome Engineering, Beijing Engineering and Technology Research Center for Convergence Networks and Ubiquitous Services, Institute of Artificial Intelligence, University of Science and Technology Beijing, Beijing, China
haijunzhang@ieee.org

Abstract. Unlicensed spectrum has long been considered a powerful candidate for addressing spectrum resource shortages. The emergence of small cells makes network coverage more seamless, switching, and a better user experience. This paper introduces small base station (SBS) to enable not only the information transmission on the WLAN unlicensed spectrum, but also the communication with connected terminals through the licensed spectrum. The energy efficiency (EE) in small cells with WiFi unlicensed band sharing is studied. We first build a two-layer network model containing small cells and macro cells. In particular, the subchannel allocation and power optimization problems are jointly studied using the alternative direction method of multipliers (ADMM) algorithm. Then, to obtain an optimization scheme, a radio resource scheduling strategy is proposed, taking into account Quality of Service (QoS) requirements, maximum transmit power, and same layer interference. The effectiveness and optimal solution of the method are shown by simulation results.

Keywords: Energy efficiency · Small cells · Unlicensed band · ADMM

1 Introduction

Recently, with the explosive development of data service, data traffic has increased dramatically, and the contradiction between high-bandwidth wireless services and shortage of spectrum resources has become prominent. Unlicensed band is widely regarded by industry and researchers as a promising technology. The 2.4 GHz and 5 GHz unlicensed bands used by WiFi as the main candidate for cellular network are getting more and more attention [1]. Signal transmission on the WLAN unlicensed frequency band in the cellular network can effectively

V. C. M. Leung et al. (Eds.): 5GWN 2019, LNICST 278, pp. 141–151, 2019.
https://doi.org/10.1007/978-3-030-17513-9_10

alleviate the information congestion problem caused by the shortage of licensed spectrum. Considering the application of unlicensed frequency bands in WiFi systems, it is necessary to not affect the performance of WiFi systems when studying the maximum system capacity under cellular networks over unlicensed spectrum.

Although the unlicensed band has the advantages of strong anti-interference performance and fast transmission speed, the 5 GHz unlicensed band has short wavelength, fast attenuation and short transmission distance. In view of this, the wireless researchers are investigating a promising solution for small cells that combines with unlicensed band to provide ubiquitous networking and seamless switching for mobile users. As an important part of heterogeneous networks, small cells are considered to be effective techniques for increasing system capacity and expanding coverage of cellular networks [2]. Especially in the indoor environment, relevant scholars have done a lot of research work to transfer the traffic of the macro cells to the small cells.

The combination of small cells and unlicensed band in cellular networks has been of concern to the research community for a long time. An unlicensed spectrum partitioning strategy based on Quality of Service (QoS) is proposed in [3]. Although the coexistence of the WiFi and the cellular network is guaranteed, at the cost of system capacity. In [4], the author uses the method of transmitting blank subframes by the base station (BS) at low power for unlicensed spectrum sharing. In [5], an integrated femto-WiFi (IFW) device was introduced that can be applied in both licensed and unlicensed spectrum. Currently LTE-Unlicensed (LTE-U) has also been proposed as a promising technology. The above work is on account of the fair use of unlicensed band by the WiFi system and the cellular network. According to the author's understanding, there is currently no joint use of licensed band and unlicensed band to achieve system energy efficiency maximization via the alternative direction method of multipliers (ADMM) research.

In this paper, the energy efficiency (EE) in small cells with WiFi unlicensed band sharing is studied. We have developed a system model, then the system EE is formulated into a convex function, and constraints such as QoS requirements and maximum transmit power are considered. A radio resource scheduling scheme based on ADMM is given and verified by simulation.

The following is the organizational structure of this paper. System model and problem modeling for sharing unlicensed bands between small cells and WiFi systems are presented in the Sect. 2. In Sect. 3, the ADMM algorithm is introduced and the optimization problem in Sect. 2 is solved by ADMM. In Sect. 4, the tendency and effectiveness of the proposed radio resource scheduling strategy are verified by simulation, followed by conclusion in Sect. 5.

2 System Model

We assume a downlink transmission in a multi-small cell network. In Fig. 1, under the macro base station, the WiFi system coexists with a small cell that can occupy both the licensed band and the unlicensed band. Then we envisioned a two-tier network, the cellular network terminal can be connected to the small cell, and can perform information transmission on the licensed band communication as well as on the unlicensed band of the WLAN. Let K $= \{1, 2, 3, ..., k, ..., K\}$ and S $= \{1, 2, 3, ..., s, ..., S\}$ denote the SBSs set and the small cell users set respectively. Macro users are represented by M $=\{1, 2, 3, ..., m, ..., M\}$. The bandwidth of this two-layer network is assumed as W, which is divided into N subchannels. And we assume that each channel fading is the same.

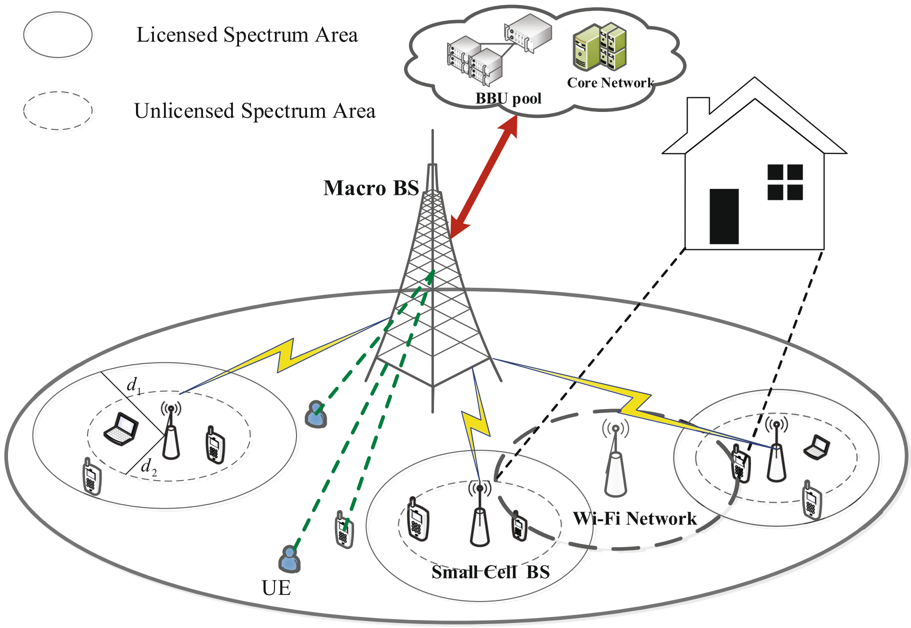

Fig. 1. Network architecture of small cells and WiFi coexistence.

In our architecture, each SBS has two coverage areas with radius d_1 and d_2 respectively. d_1 indicates the SBS users associated with a SBS in a licensed frequency band. Similarly, d_2 is the area covered by the unlicensed band under the SBS. Within this range, SBS can occupy unlicensed bands for information transmission. To guarantee the QoS of SBS and alleviate the interference of WiFi system on SBS under unlicensed band, d_1 and d_2, and the power of WiFi system must meet the following conditions, given by [9]

$$P_0 \times G(d_1 - d_2) \leq \xi \qquad (1)$$

where the P_0 is the transmission power of the WiFi system, which is a fixed value, $G(d)$ is large-scale fading (path loss) over unlicensed frequency band, and ξ is the interference threshold of the WiFi system.

We assume that one channel can only be assigned to one user in a communication connection, and $a_{k,s,n} \in \{0, 1\}, \forall k, s, n$ represents the channel status.

2.1 Licensed Frequency Band Area

Let $g^1_{k,s,n}$ be the channel gain between terminal s and SBS k on subchannel n. $p_{k,s,n}$ denotes transmit power on subchannel n between SBS terminal s and small cell k. The SINR from SBS k is received on channel n on SBS user s is given by:

$$\gamma^1_{k,s,n} = \frac{p_{k,s,n} g^1_{k,s,n}}{I_1 + \delta^2} \tag{2}$$

At the same time, we also consider the same layer interference:

$$I_1 = \sum_{l,l \neq k}^{K} p_{l,s,n} g^1_{l,s,n} \tag{3}$$

I_1 indicates same layer interference (generated when the same channel is occupied by other small base stations). δ^2 denotes the system additive white Gaussian noise (AWGN) power at SBS k.

The data transmission rate on subchannel n between the kth SBS and the terminal s can be defined as:

$$\mathrm{C}^1_{k,s,n} = \frac{W}{N} \log_2(1 + \gamma^l_{k,s,n}) \tag{4}$$

Therefore the total capacity under the licensed band is

$$C^1 = \sum_k \sum_s \sum_n \mathrm{C}^1_{k,s,n} \times a_{k,s,n} \tag{5}$$

2.2 Unlicensed Frequency Band Area

Let $g^2_{k,s,n}$ denote the channel gain from base station k to terminal s on subchannel n in the unlicensed band. I_2 indicates interference from other WiFi systems on the same subchannel. If the subchannel of the unlicensed band is not occupied, $I_2 = 0$. The SINR on the unlicensed band subchannel n from the SBS k to the user s is thus given

$$\gamma^2_{k,s,n} = \frac{p_{k,s,n} g^2_{k,s,n}}{I_2 + \delta^2} \tag{6}$$

In the unlicensed band, the rate from k SBS to user s on channel n can also be defined as

$$\mathrm{C}^2_{k,s,n} = \frac{W}{N} \log_2(1 + \gamma^2_{k,s,n}) \tag{7}$$

Then the total capacity under the licensed band is

$$C^2 = \sum_k \sum_s \sum_n \mathrm{C}^2_{k,s,n} \times a_{k,s,n} \tag{8}$$

2.3 Problem Formulation

So the total capacity of the entire system is given:

$$C_T = C^1 + C^2 \tag{9}$$

And the total energy consumption of the system is expressed as

$$P_T = \sum_k p_{C,k} + \sum_k \sum_s \sum_n a_{k,s,n} p_{k,s,n} \tag{10}$$

where $p_{C,k}$ is the circuit power consumed by the SBS k, and $\sum\limits_k \sum\limits_s \sum\limits_n a_{k,s,n} p_{k,s,n}$ is the total transmit power consumed by the SBSs.

Our objective function is to maximize system EE (the ratio of total system capacity and total energy consumption) on the premise of guaranteeing the QoS, so we get the following optimization problem:

$$\begin{aligned}
&\max_{a_{k,s,n}, p_{k,s,n}} \frac{C_T}{P_T} \\
&s.t. \\
&C1 : \sum_k a_{k,s,n} \leq 1, \forall s, n \\
&C2 : a_{k,s,n} \in \{0, 1\}, \forall k, s, n \\
&C3 : \sum_n a_{k,s,n} p_{k,s,n} \leq p_{\max}, \forall s, k \\
&C4 : \sum_n a_{k,s,n} C_{k,s,n} \geq R_s, \forall s, k \\
&C5 : P_0 \times G(d_1 - d_2) \leq \xi.
\end{aligned} \tag{11}$$

where constraints C1 and C2 represent subchannel allocation constraints, limiting each channel to only one user per communication connection. While constraint C3 represents the total power constraint, and $p_{\max}$ indicates the maximum value of each SBS transmit power. The C3 limits that the total transmit power of subchannel must be lower than the maximum value of the SBS. C4 is the system QoS guarantee, the sth user capacity must be greater than the QoS minimum requirement R_s. Constraint C5 is designed to alleviate interference from the WiFi system after the SBS occupies the unlicensed band.

3 Energy Efficient Optimization Using ADMM

In this section, the ADMM algorithm is introduced, the principle of the algorithm is briefly introduced, and the optimization problem obtained hereinbefore is transformed into a convex optimization that can be solved by the ADMM algorithm. A radio resource allocation scheduling scheme based on ADMM is proposed.

3.1 Principle of the ADMM

The ADMM algorithm [11] is a simple and effective method, which is very suitable for solving distributed convex optimization problems, especially large-scale problems in related fields.

The ADMM algorithm solves functions in the form:

$$\begin{aligned} &\min_{x_1,x_2} f_1(x_1) + \mathrm{f}_2(x_2) \\ &\mathrm{s.t.} Ax_1 + Bx_2 = c \end{aligned} \tag{12}$$

where variables $x_1 \in R^{m\times 1}$ and $x_2 \in R^{r\times 1}$, where $A \in R^{p\times m}$, $B \in R^{p\times r}$, and $c \in R^{p\times 1}$. The augmented Lagrangian is given as:

$$\begin{aligned} &L_\rho(x_1, x_2, y) = f(x_1) + g(x_2) + y^T(Ax_1 + Bx_2 - c) \\ &+\tfrac{\rho}{2}||Ax_1 + Bx_2 - c||_2^2 \end{aligned} \tag{13}$$

After scaling the augmented Lagrangian dual variable and combining the quadratic terms, the ADMM can be slightly modified to become scaled form. At this time, the augmented Lagrangian:

$$\begin{aligned} &L_\rho(x_1, x_2, \mu) = f_1(x_1) + f_2(x_2) \\ &-\tfrac{\rho}{2}||\mu||_2^2 + \tfrac{\rho}{2}||x_1 - x_2 + \mu||_2^2 \end{aligned} \tag{14}$$

where $\mu = \frac{1}{\rho}y$ denotes the scaled-dual variable. In this case, according to parameters μ, ADMM is further expanded as:

$$\begin{aligned} &x_1^{t+1} := \arg\min_{x_1}(f_1(x_1) + \tfrac{\rho}{2}||Ax_1 + Bx_2^t - c + \mu^t||_2^2) \\ &x_2^{t+1} := \arg\min_{x_2}(f_2(x_2) + \tfrac{\rho}{2}||Ax_1^{t+1} + Bx_2 - c + \mu^t||_2^2) \\ &\mu^{t+1} := \mu^t + Ax_1^{t+1} + Bx_2^{t+1} - c \end{aligned} \tag{15}$$

There is no essential difference between the scaled form and the previous form, while the scaled form is more efficient and convenient to use and will be used in this paper.

3.2 Problem Soving via ADMM

Before using the ADMM algorithm to solve the optimization problem, Eq. (11) can be rewritten as:

$$\begin{aligned} &\min_{a_{k,s,n}, p_{k,s,n}} -G(\tilde{A}, \tilde{P}) \\ &s.t. \\ &\mathrm{C1, C2, C3, C4, C5} \end{aligned} \tag{16}$$

Algorithm 1. Radio resource scheduling according to ADMM.

Initialization: Initialize the value of matrix A and matrix B; each SBS k gets the channel state information of all terminals; then initialize x^0, z^0, μ^0 and $\rho > 0$;
for $t = 0, 1, 2, ...,$ **do**
  while $F(A, P) > \xi$ (stop criterion threshold) **do**
    1) calculate x^{t+1} according to formula (20)
    2) take x^{t+1} and μ^t into the formula (21), update z^{t+1};
    3) update μ^{t+1} via (22);
  end while
  if $F(A, P) > \xi$;
  To the last step;
end for
Output optimized subchannel matrix A and power matrix P;

where $-G(\tilde{A}, \tilde{P}) = \lambda P_T - C_T$. According to [12] the formula can be expressed as:

$$\begin{aligned} \lambda P_T - C_T = \lambda(\sum_k p_{C,k} + \sum_k \sum_s \sum_n a_{k,s,n} p_{k,s,n}) \\ - a_{k,s,n} \sum_k \sum_s \sum_n (\mathrm{C}^1_{k,s,n} + \mathrm{C}^2_{k,s,n}) \end{aligned} \tag{17}$$

Then an indicator function $f(z)$ is given, when $\mathrm{z} \in \Psi (\Psi = C1 \cap C2 \cap C3 \cap C4 \cap C5)$, $f(\mathrm{z}) = 0$; otherwise, $f(\mathrm{z}) = +\infty$. The optimization problem (16) can be rewritten as

$$\begin{aligned} \min_{a_{k,s,n}, p_{k,s,n}} & -G(\tilde{A}, \tilde{P}) + f(\mathrm{z}) \\ s.t. & \mathrm{X} - \mathrm{z} = 0 \end{aligned} \tag{18}$$

where X is a variable vector containing substitution variables $\{a_{k,s,n}, p_{k,s,n}\}$; The same factor z is an auxiliary vector, including auxiliary variables $\{\mathrm{z}_a, \mathrm{z}_p\}$. We can get the augmented Lagrangian in scaled form:

$$\begin{aligned} L_\rho(X, z, \mu) = -G(\tilde{A}, \tilde{P}) + f(z) \\ -\frac{\rho}{2}||\mu||^2_2 + \frac{\rho}{2}||X - z + \mu||^2_2 \end{aligned} \tag{19}$$

where μ denotes the scaled dual-variable vector, including scaled dual-variables $\{\mu_a, \mu_p\}$, and ρ denotes a constant penalty parameter. The iterations of scaled form can be formulated as

$$\begin{aligned} \mathrm{X}^{t+1} := \arg\min_{\mathrm{x}} \{ -G(\tilde{A}, \tilde{P}) \\ + \frac{\rho}{2} \sum_k \sum_s \sum_n [(a_{k,s,n} - z^t_a + \mu^t_a)^2 \\ + (p_{k,s,n} - z^t_p + \mu^t_p)^2] \} \end{aligned} \tag{20}$$

$$\mathrm{z}^{t+1} := \arg\min_{\mathrm{z}}\{\frac{\rho}{2}\sum_{k}\sum_{s}\sum_{n}[(a_{k,s,n}^{t+1} - z_a + \mu_a^t)^2 + (p_{k,s,n}^{t+1} - z_p + \mu_p^t)^2]\} \quad (21)$$

$$\mu^{t+1} := \mu^t + \mathrm{x}^{t+1} - \mathrm{z}^{t+1} \quad (22)$$

Based on the above analysis, we can summarize Algorithm 1. The convergence and effectiveness of the radio resource scheduling according to ADMM will be discussed in the next section.

4 Simulation Results

In this section, we prove the tendency and effectiveness of the proposed radio resource allocation scheduling scheme by giving simulation results. WiFi system is randomly distributed in the macro cell. Single SBS coverage radius d_1 and d_2 are 200 m and 20 m. The maximum transmit power of the macro BS is 8.91 mW, and maximum transmit power of the small BS is 2.95 mW. The AWGN power is 3.98 W. The unlicensed band path loss calculation formula is $G(d) = 15.3 + 50\log_2(d)$ [15]. The interference threshold ξ of the WiFi system is -77 dB.

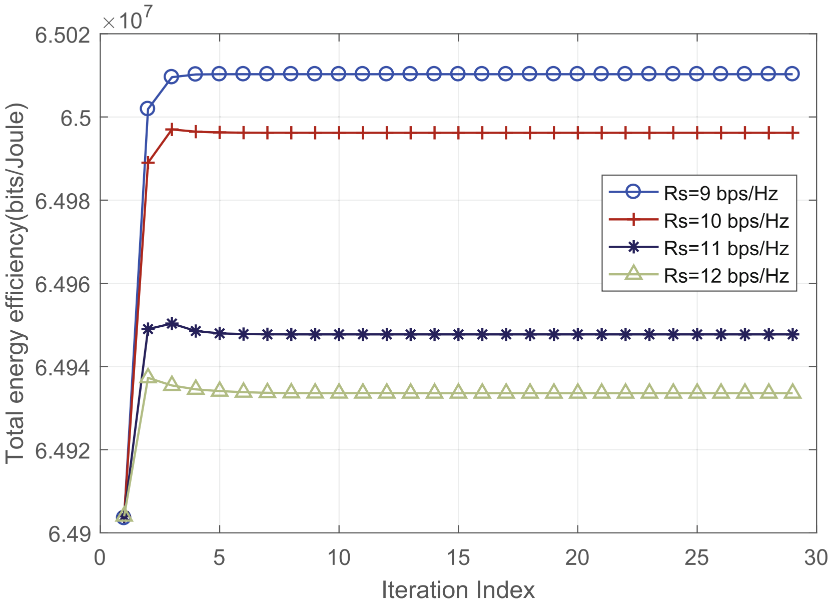

Fig. 2. Total energy efficiency versus iteration index with different QoS demands.

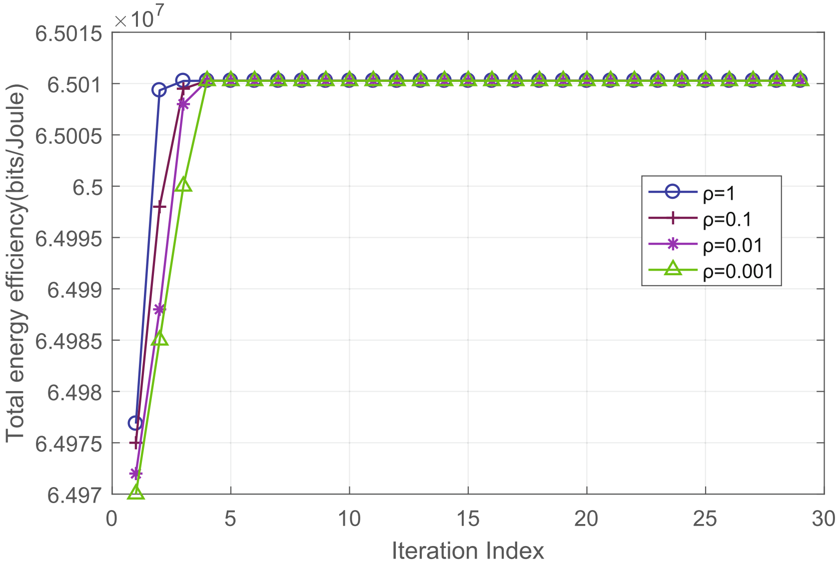

Fig. 3. Convergence of the algorithm versus iteration index with different ρ.

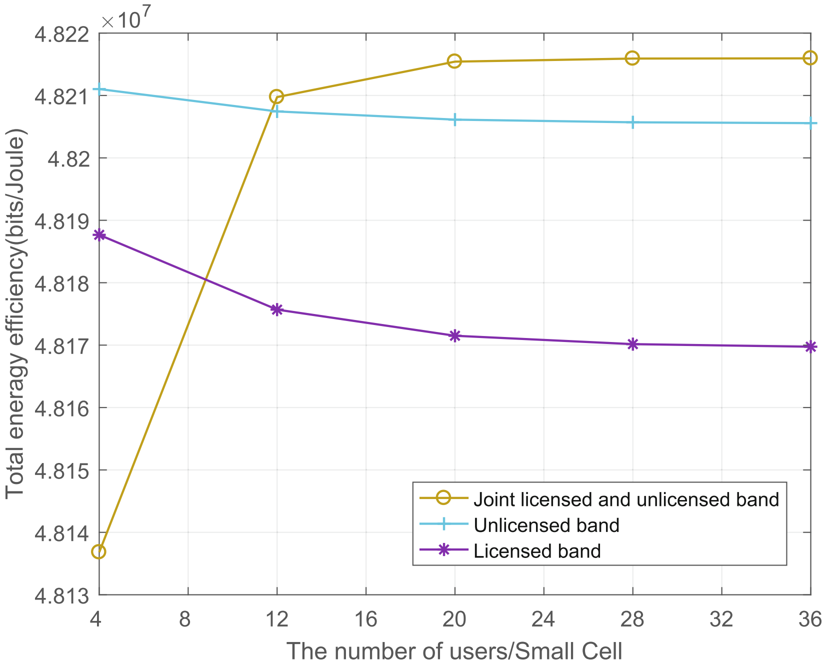

Fig. 4. The effect of SBS small users on total energy efficiency.

In Fig. 2, the total EE versus the number of iteration with different size QoS demands is illustrated. As shown in Fig. 2, the smaller the QoS requirement is, the faster the curve converges under the same number of iterations. In addition, we can find that after multiple iterations, the curve value with small QoS requirement is outperform than the QoS requirement. The change in QoS requirements does not affect the convergence iterations of the proposed algorithm.

In Fig. 3, we want to verify the action of Lagrangian parameter ρ on the curve tendency rate. Through observation, we can see that the parameter ρ has a significant influence on the tendency speed of the proposed algorithm. The larger the ρ value, the faster the convergence speed. The smaller the ρ value, the more iterations are needed. It can be seen that the selection of the parameter ρ value is directly related to the performance of the algorithm. This effect will be more obvious in the scenario where large-scale small cells and WiFi systems coexist.

Figure 4 shows the effect of SBS small users on total energy efficiency. For ease of comparison, the system EE in the licensed band scenario and the system energy efficiency in the unlicensed band scenario are also listed. From Fig. 4, we can see that when the number of users per SBS reaches a threshold, the total EE of the system is higher than that of the other two scenarios in joint licensed frequency band and unlicensed frequency band. Due to the greater bandwidth, the total EE of the network in the unlicensed band scenario is always higher than the unlicensed band scenario.

5 Conclusion

In this paper, the energy efficiency (EE) in small cells with WiFi unlicensed band sharing is investigated. We have developed a system model based on which the optimization system energy efficiency function is formulated into a convex optimization problem, the constraints such as QoS requirements and maximum transmit power are considered. Then we propose a radio resource scheduling scheme based on ADMM algorithm. The effectiveness and optimal solution of the method are shown by simulation results.

Acknowledgment. This work is supported by the National Natural Science Foundation of China (61822104, 61771044), the Young Elite Scientist Sponsorship Program by CAST (2016QNRC001), the Research Foundation of Ministry of Education of China & China Mobile (MCM20170108), Beijing Natural Science Foundation (L172025, L172049), and the Fundamental Research Funds for the Central Universities (FRF-GF-17-A6, RC1631). The corresponding author is Haijun Zhang.

References

1. Zhang, H., Chu, X., Guo, W., Wang, S.: Coexistence of Wi-Fi and heterogeneous small cell networks sharing unlicensed spectrum. IEEE Commun. Mag. **53**(3), 158–164 (2015)
2. Hwang, I., Song, B., Soliman, S.S.: A holistic view on hyper-dense heterogeneous and small cell networks. IEEE Commun. Mag. **51**(6), 20–27 (2013)
3. Hajmohammad, S., Elbiaze, H.: Unlicensed spectrum splitting between femtocell and Wi-Fi. In: IEEE International Conference on Communications (ICC), pp. 1883–88, June 2013
4. Zhang, R., Wang, M., Cai, L.X., Zheng, Z., Shen, X., Xie, L.-L.: LTE-unlicensed: the future of spectrum aggregation for cellular networks. IEEE Wirel. Commun. **22**(3), 150–159 (2015)
5. Small Cell Forum: Integrated femto-WiFi (IFW) networks. Whitepaper at smallcellforum.org, February 2012
6. Zhang, Y., Wang, H.M., Zheng, T.X., Yang, Q.: Energy-efficient transmission design in non-orthogonal multiple access. IEEE Trans. Veh. Technol. **PP**(99), 1 (2016)
7. Fang, F., Zhang, H., Cheng, J., Leung, V.C.M.: Energy-efficient resource allocation for downlink non-orthogonal multiple access network. IEEE Trans. Commun. **64**(9), 3722–3732 (2016)
8. Dong, Y., Zhang, H., Hossain, M.J., Cheng, J., Leung, V.C.M.: Energy efficient resource allocation for OFDMA full duplex distributed antenna systems with energy recycling. In: 2015 IEEE Global Communications Conference (GLOBECOM), San Diego, CA, pp. 1-6 (2015)
9. Mollanoori, M., Ghaderi, M.: Uplink scheduling in wireless networks with successive interference cancellation. IEEE Trans. Mob. Comput. **13**(5), 1132–1144 (2014)
10. Zhang, H., Huang, S., Jiang, C., Long, K., Leung, V.C.M., Poor, H.V.: Energy efficient user association and power allocation in millimeter-wave-based ultra dense networks with energy harvesting base stations. IEEE J. Sel. Areas Commun. **35**(9), 1936–1947 (2017)
11. Eckstein, J.: Augmented Lagrangian and alternating direction methods for convex optimization: a tutorial and some illustrative computational results. Rutgers University, Piscataway, NJ, USA, Technical report, December 2012
12. Yu, Y., Peng, M., Li, J., Cheng, A., Wang, C.: Resource allocation optimization for hybrid access mode in heterogeneous networks. In: IEEE Wireless Communications and Networking Conference (WCNC), pp. 1243–1248, March 2015
13. Liang, C., Yu, F.R., Yao, H., Han, Z.: Virtual resource allocation in information-centric wireless networks with virtualization. IEEE Trans. Veh. Technol. **65**(12), 9902–9914 (2016)
14. Liu, F., Erkip, E., Beluri, M., Yang, R., Bala, E.: Dual-band femtocell traffic balancing over licensed and unlicensed bands. In: Proceedings of the IEEE ICC, Ottawa, ON, Canada, pp. 6809–6814, 10–15 June 2012
15. Liu, F., Bala, E., Erkip, E., Beluri, M.C., Yang, R.: Small-cell traffic balancing over licensed and unlicensedbands. IEEE Trans. Veh. Technol. **64**(12), 5850–5865 (2015)