Joint Optimization of Energy Efficiency and Interference for Green WLANs

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Abstract. In the past years, the issues of energy efficiency and interference are becoming increasingly serious in wireless local area network (WLAN) since lots of access points (AP) are deployed densely to provide high-speed users access. However, current works focus on solving the two issues separately and the influence of each other is rarely considered. To address these problems, we propose a joint optimization scheme of energy efficiency and interference to reduce energy consumption and interference together without sacrificing users' traffic demands. Firstly, based on energy consumption measurement of AP and network interference analysis, we establish energy efficiency and interference models respectively. Then, the weighting method is introduced to build the joint optimization to quantify the effects of user-AP association, AP switch, AP transmit power and AP channel on energy consumption and interference. Lastly, we formulate the joint optimization as an Mixed Integer Non-Linear Programming (MINLP) problem. Since the MINLP problem is NP-hard, we proposed an Joint Optimization of Energy Efficiency and Interference (JOEI) algorithm based on greedy method to simplify its computational complexity. The evaluation results show that the proposed algorithm can effectively reduce the network energy consumption while improve the capacity of WLANs.

Keywords: Energy efficiency · Interference · Joint optimization · Green WLAN

1 Introduction

As a high-speed mobile network access scheme, wireless local area network (WLAN) has been densely deployed in the enterprises, schools and other public

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areas to meet the traffic demand at peak hours [1]. However, the peak period rarely happens, and the utilization of access points (AP) during the off-peak period are reduced to low or idle, which leads to a serious energy waste [2]. Moreover, the channel overlapping in density deployment scene will cause heavy interference and degradation of user's quality of experience (QoE) [3].

Recently,the issue of energy saving and interference have been studied independently from different aspects [4]. To reduce energy wastage, researchers try to adopt switching strategies (also called 'sleep-awake') to turn off/on the low-utilization or idle APs for adapting the active capacity [1,5,6]. A green clustering algorithm was introduced to initiate a cycle of estimating user demand and performance to power on or off APs, then adjust the transmit power [1]. In reference [5], based on a centralized control framework, the actual network conditions in terms of both user density and traffic patterns are monitored and used to tune the energy consumption through a flexible energy-saving decision algorithm. Similarly, a context-aware power management framework and adaptive algorithms were proposed to dynamically configure different network elements according to user needs [6]. Actually, those existing energy-saving studies mainly focus on switching off unnecessary APs to reduce the energy consumption, but the interference between adjacent APs has not yet been considered specifically. However, according to the research [7], interference not only affects the stability of wireless network, but also increases the energy consumption of wireless systems. Therefore, to achieve more effective energy-saving and sacrifice little on users' QoE, the interference and energy consumption should be taken into account together.In work [8], the authors indicated that the interference results from the aggressive spectral reuse and high power transmission severely limits the system performance, then they use a non-cooperative game to optimize energy-efficient power for interference-limited wireless communication. However, in those works, the relationship between interference and energy consumption has not yet been quantitative analyzed accurately, which is the basis of resource scheduling and optimization in wireless system [9].

In this paper, we aim to build a quantitative optimization model which could reduce network energy consumption and interference with guaranteeing users' QoE in WLAN system. Firstly, we set experiments to quantify the influence of transmit power and throughput to energy efficiency, and analyze the relationship between interference and transmit power, establish optimization models respectively. Secondly, we introduce the weighting method to establish a joint optimization objective function, optimized energy consumption and capacity. Lastly, we put forward JOEI algorithm and verify the validity compared with three popular algorithms.

2 System Model

2.1 Network model

As shown in Fig. 1, we consider a centralized WLAN system, the reasonable and effective optimization scheme can be achieved based on the information from all wireless access points collected by controller, which can be used to operate the state of user association matrix β,AP switch on/off α,AP transmit power p and AP channel f to reduce interference and save energy.

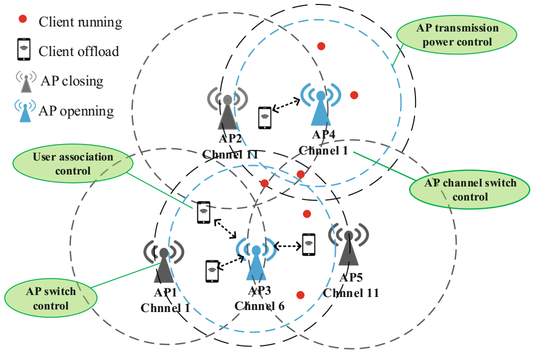

Fig. 1. The simplify scenario for energy consumption and interference joint optimization of WLAN system.

2.2 Energy Consumption Model

In order to determine the relationship among AP load, transmit power and energy consumption, we conduct an experiment with real NETGEAR WNDR 3800 WiFi devices which were deployed in common application scenario working at 2.4 GHz with 802.11 n mode, 20 MHz HT mode and random channel. As the real AP load mainly from the downlink service, we gradually change AP's downlink data transmission rate (the data from the wired side to the wireless side) and transmit power, and record AP operating power in each scene by the power tester (TECMAN-TM6). Finally, we quantitative analysis the relationship of AP load-AP transmit power-AP energy consumption according to the measurement

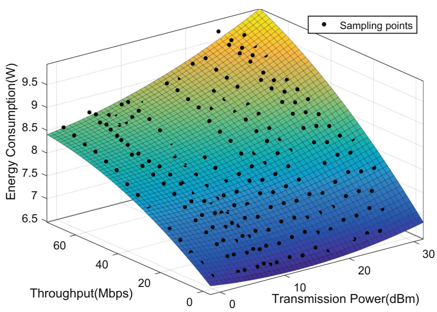

Fig. 2. Energy efficiency of AP versus throughput and transmission power.

result. The energy efficiency relation model of AP is obtained by fitting the least squares polynomial of all discrete relation data as Fig. 2.

And the relation function as follows:

$$F\left(L,p\right)=a_1+a_2*p+a_3*L+a_4*p^2+a_5*p*L+a_6*L^2 \tag{1}$$

where L represents the throughput of AP, which equals to the sum traffic requirement of all associated users with this AP, p represents the actual AP transmit power, $F(L,p)$ represents AP power consumption, and a_1-a_6 represent the fitted polynomial coefficient.

2.3 Interference Model

The interference accumulation effect between APs is described by calculating the SINR of user links [10,11]. This physical interference model considers all the links in wireless system to interfere users, which can be used to determine whether the user node meet its demands.

Assuming that $user_j$ is associated with AP_i, the SINR of the link that $user_j$ received is expressed as:

$$SINR_j^i=\frac{p_i g_{ij}}{N_0+I_j^{-i}} \tag{2}$$

where N_0 represents the system thermal noise power, p_i represents the transmit power of AP_i, and g_{ij} represents the path attenuation factor from AP_i to $user_j$,

$$g_{ij}=d_{ij}^{-r} \tag{3}$$

where d_{ij} represents the Euclidean distance between AP_i and $user_j$. r represents the attenuation coefficient, and the usual value is 2–4 [12].

I_j^{-i} represents the sum interference that $user_j$ receives from surrounding APs except for the currently associated AP_i. Furthermore, I_j^x indicates the same channel interference received by $user_j$ from the AP_x which adjacent to AP_i.

$$I_j^x=e_{ix}\Delta\left(f_i,f_x\right)p_x g_{xj} \tag{4}$$

e_{ix} represents the adjacency relationship between AP_i and AP_x. When the AP_i and AP_x have the overlapping coverage area, they are considered to be adjacent, and the value of e_{ix} is 1, otherwise 0.

$\Delta\left(f_i,f_x\right)$ represents the channel relationship between AP_i and AP_x. if f_i is equal to f_x, which means AP_x is in the same channel with AP_i, the value of $\Delta\left(f_i,f_x\right)$ is 1, otherwise 0.

It can be seen that the total interference received by $user_j$ is expressed as:

$$I_j^{-i}=\sum_{x=1}^{n} I_j^x=\sum_{x=1}^{n}\left\{e_{ix}\Delta\left(f_i,f_x\right)p_x g_{xj}\right\} \tag{5}$$

At the same time, when $user_j$ associated with AP_i, the channel capacity can be obtained according to Shannon formula.

3 The Joint Optimization of Energy Consumption and Interference

During the off-peak period, there are lots of low-utilization or idle APs,which will lead to heavy energy waste. Meanwhile, these idle APs will cause much interference to users associated with adjacent APs. Therefore, the energy consumption and interference can be reduced simultaneously through switch off idle APs. To reduce energy consumption and improve performance of system, we try to make more APs idle through users' reassociation without sacrificing users' traffic demands.

Furthermore, according to the model analysis in Sect. 2 the energy consumption and interference can be reduced simultaneously by adjusting the AP power, then improve the system capacity. Therefore, in order to reduce energy consumption with ensuring network performance, the energy consumption and the interference should be considered together. Because of the adjustment of user-AP association, AP switch, AP transmit power and AP channel have the similar influence on energy consumption and interference, these two optimization models can be combined to achieve joint optimization.

Assuming that there are n APs and m users in the WLAN system, $N = \{1, 2, \cdots, n\}$, $M = \{1, 2, \cdots, m\}$, where $AP_i \in N$, $User_j \in M$. Meanwhile, user's traffic demand is defined as vector l, where l_j represents the traffic demand of $user_j$.In order to make the energy consumption - interference joint optimization model more reasonable, we introduce a weighting factor θ, and define the joint optimization objective function as follows:

$$\begin{aligned} \Im_1 : \min_{\alpha,\beta,p,f} & \sum_{i=1}^{n} \left\{ F\left(\sum_{j=1}^{m} \beta_{ij} l_j, p_i \right) \alpha_i \right\} \\ & + \theta \sum_{i=1}^{n} \left\{ \alpha_i \sum_{j=1}^{m} \left(\beta_{ij} \sum_{x=1}^{n} e_{ix} \Delta\left(f_i, f_x\right) p_x g_{xj} \right) \right\} \end{aligned} \tag{6}$$

$$s.t.\ \alpha_i, \beta_{ij} \in \{0, 1\},$$

$$p_i \in \{0, 1, 2, \cdots, 30\}, f_i \in \{1, 6, 11\} \tag{7}$$

$$Cap_j > l_j \tag{8}$$

$$\sum_{j=1}^{m} \beta_{ij} l_j < L_{\max} \tag{9}$$

$$\beta_{ij} \le c_{ij}, c_{ij} = \begin{cases} 1 & d_{ij} < R_i \\ 0 & otherwise \end{cases} \tag{10}$$

$$\sum_{i=1}^{n} \beta_{ij} = 1 \tag{11}$$

$$\sum_{i=1}^{n} \alpha_i \beta_{ij} = 1 \tag{12}$$

The first part of objective (6) shows that the AP energy consumption model F is used to optimize the overall energy consumption of the system by adjusting user-AP association β, AP switch α and AP transmit power p. The second part of objective (6) denotes the sum of the interference received by all users is used as an indicator to assess the interference of the system.

The optimal convergence state of the joint optimization model can be dynamically controlled by setting the weight factor θ, so that WLAN service providers can change the size of θ in the algorithm according to the specific network situations and different optimization requirements, and obtain the more scientific and effective optimal solution.

The objective (6) measures the sum of energy consumption and interference. Solving problem $\Im_1$ means that the corresponding algorithm should return the optimal active AP vector α^*, the user-AP association matrix β^*, the AP transmit power vector p^* and the AP channel selection vector f^*. The constraint (7) presents the feasible domain of α_i, β_{ij}, p_i and f_i. The constraint (11) and (12) ensure that user j only can associate to one AP, and the constraint (10) ensures that only the user that within the coverage of the AP can connect to it. The constraint (9) shows that the total load of every AP is within its transmission capacity L_{max}. And the constraint (8) ensure that channel capacity between user and AP must satisfy the traffic demand of users.

From the convex function definition, we can obtain that The objective function $\Im_1$ is convex, and area bounded by the constraint functions (7)–(12) is convex.we confirm that our joint function exist an optimal solution under all of constraints. However, as we have integrated four unknown variables (i.e. user-AP association, AP switch, AP channel, AP transmit power) into the one objective function, which make it become an MINLP problem. As far as we know, solving the optimal solution of an MINLP problem is a difficult work which requires a lot of computation and time complexity. Hence, in order to solve the NP-hard problem, we propose an efficient algorithm which is based on the idea of greedy algorithm in the next section.

4 The JOEI Algorithm Based on Greedy Method

We propose an JOEI algorithm to solve the Joint Optimization of Energy consumption - Interference inspired by the idea of greedy algorithm.In energy-saving aspect, the transmit power has smaller influence than AP switch [13]. Meanwhile in interference aspect, channel selection can decrease interference more effective compared with transmit power [7]. So, in the JOEI algorithm we firstly consider transmit power as a default value to compute other three variables to reduce computational complexity. Furthermore, the optimal transmit power is obtained by solving the objective function with other three variables that have been obtained. The details of JOEI algorithm based on greedy method is given in Algorithm 1.

Algorithm 1. The JOEI algorithm

Ensure: $\alpha, \beta \in \{0, 1\}, f \in \{1, 6, 11\}, p \in \{0, 1, 2, \cdots, 30\}$.
1: **while** (1) **do**
2: Set c, l, g and e according to the network status;
3: Compute the number of adjacent APs for each AP and store them in array *ap_adjace* by ascending order;
4: **for** $i = 1$ to n by *ap_adjace* order **do**
5: Select a channel from $\{1, 6, 11\}$ as f_i which minimize the objective function $\Im_1$;
6: **end for**
7: Compute the interference value of all users under each AP_i by $\sum_{j=1}^{m} \left(\beta_{ij} \sum_{x=1}^{n} e_{ix} \Delta(f_i, f_x) p_x g_{xj} \right)$;
8: Sort interference values of all APs in descending order and store them in array *ap_interf*;
9: **for** $i = 1$ to n by *ap_interf* order **do**
10: **if** all users in AP_i can be offloaded to adjacent APs **then**
11: $k \leftarrow$ the number of users associated with APi;
12: Compute the number of users' associative APs and store them in array *user_ass* by ascending order;
13: **for** $j = 1$ to k by *user_ass* order **do**
14: Offload $user_j$ to an associative AP which minimize the objective function $\Im_1$ based on change of β;
15: **end for**
16: Turn off AP_i ,update α, β and return to step 2;
17: **end if**
18: **end for**
19: **if** all APs can't be switched off **then**
20: break;
21: **end if**
22: **end while**
23: Introduce the optimal solution of α^*, β^*, f^* to objective function $\Im_1$, compute the set of transmit power p^* as an integer programming with single-variable.

5 Performance Evaluation

In this section, we conduct experiments to validate the efficiency of JOEI algorithm compared to two classical energy-saving schemes, green-clustering algorithm [1] and cooperative energy-efficient method [14], which don't consider the influence to interference in energy-saving process. Moreover, we conduct simulations to compare the performance with another energy - interference joint study algorithm [7]. Because we take into account the more sophisticated constraints to ensure users' demands and more measures to reduce interference, our algorithm shows better performance in interference aspect, although there is a small gap in energy saving.

It is noteworthy that we solve the integer programming problem for p by the SCIP [15] optimization toolbox which uses a branch-cut-and-price method.

Meanwhile, in the experiments, we set the weight factor θ be 100 which let the part of interference in the same order of magnitude with energy consumption. More parameters are shown in the Table 1.

Table 1. Experiment parameter

Parameter	Value	Commons
r	2	Attenuation coefficient
p	[1 mW/0 dBm, 1W/30 dBm]	Limit of AP transmit power
L_{max}	70 Mbps	Limit of AP load
R	40 m	Coverage radius of AP
f_c	2.4 GHz	Carrier spectrum
N_0	10^{-13} W/−100 dBm	Thermal noise power
B	20 MHz	Bandwidth of channel

In order to get the performance of greedy algorithm, we design a set of network typologies, where 100 APs are regularly deployed and a number of users are randomly placed in a 300 m-by-300 m area. The effective coverage radius of AP is set to 40 m, the throughput demand of each user is set to a range from 2 Mbps to 4 Mbps. To simulate a real and comprehensive network condition, we change the number of users increases from 50 to 800 in steps of 50. Before the experiments, AP transmission power is initialized to 30 dBm and AP channel is set to a random value among 1, 6 and 11.

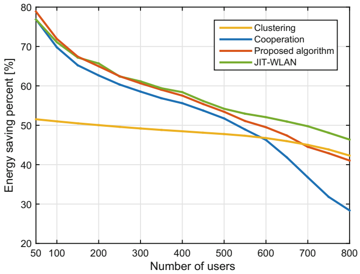

Fig. 3. Energy saving percent compared with three classical algorithm.

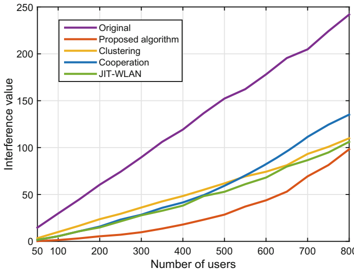

Fig. 4. Interference compared with three classical algorithm.

As shown in Fig. 3, the proposed algorithm has a better performance of energy efficiency in all types of scenes. When there are only 50 users with throughput demand, proposed algorithm obtain a high energy-saving rate close to cooperative method, which is almost 30 percent higher than clustering algorithm. As the number of users increases, the rate of energy saving reduce gradually. When the number of users increases to 800, the energy-saving rate of both proposed algorithm and clustering algorithm are decreased to 45%, but that of cooperative method is down to the percent of 30.

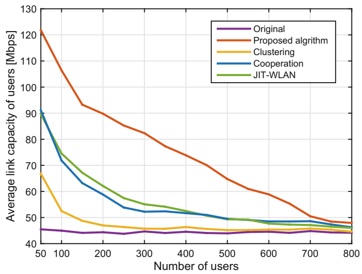

Fig. 5. Average link capacity of users compared with three classical algorithm.

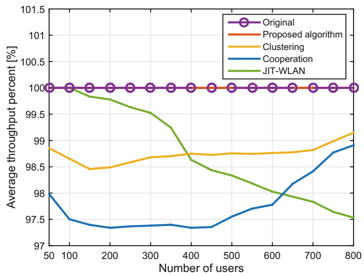

Fig. 6. Average throughput percent compared with three classical algorithm.

As shown in Fig. 4, it is the interference comparison of proposed algorithm, clustering algorithm and cooperative algorithm. The original interference represents the system's interference in the initial scenario before running algorithms. With the increase in the number of users, the initial interference is increasing. Although the two classic algorithm don't consider interference in energy-saving process, they all be helpful in reducing interference as idle APs are switch off. Obviously, Our algorithm has a better performance in all scenarios. As the channel capacity mainly affected by interference, our algorithm have the largest average link capacity of users than the original situation and other two energy-saving algorithms in Fig. 5.

As shown in Fig. 6, the average throughput percent represents the change of system throughput under different algorithms. As user throughput protection are considered in our optimal model, the average user throughput provided by JOEI algorithm is stable around the original throughput, which is 2.6% higher than that provided by the green-clustering and cooperative algorithm at most. It demonstrates that our scheme will not cause any influence on user throughput.

6 Conclusion

In this paper, we have addressed the issue of energy consumption and interference in dense WLAN. Based on real test trace, we determine the mathematical model of throughput, transmit power with energy consumption. Meanwhile, we define the interference model by analyzing the sources of interference to users in the network. We further design a joint optimization model of energy consumption and interference, which adjust user-AP association, AP switch, AP transmit power and AP channel, to reduce energy consumption as well as interference without sacrificing users' QoE. However, the solution to joint optimal is formulated as an NP-hard problem. To simplify computational complexity, an JOEI algorithm is proposed based on greedy method. The comparison experiments show that the proposed algorithm has good performance in reducing interference and ensuring user's demand with energy saving. We believe that our research will promote the development of green WLANs.

References

1. Jardosh, A.P., Papagiannaki, K., Belding, E.M., Almeroth, K.C., Iannaccone, G., Vinnakota, B.: Green WLANs. on-demand WLAN infrastructures. Mob. Netw. Appl. **14**(6), 798 (2009)
2. Jardosh, A.P., Iannaccone, G., Papagiannaki, K., Vinnakota, B.: Towards an energy-star WLAN infrastructure. In: Eighth IEEE Workshop on Mobile Computing Systems and Applications. HotMobile 2007, pp. 85–90 (2007)
3. Su, Y., Wang, Y., Zhang, Y., Liu, Y., Yuan, J.: Partially Overlapped Channel interference measurement implementation and analysis. In: Computer Communications Workshops, pp. 760–765 (2016)
4. Budzisz, L., Ganji, F., Rizzo, G., Marsan, M.A.: Dynamic resource provisioning for energy efficiency in wireless access networks: a survey and an outlook. Commun. Surv. Tutor. IEEE **16**(4), 2259–2285 (2014)
5. Debele, F.G., Meo, M., Renga, D., Ricca, M., Zhang, Y.: Designing resource-on-demand strategies for dense WLANs. IEEE J. Sel. Areas Commun. **33**(12), 24594–2509 (2015)
6. Bayer, N., Gomez, K., Sengul, C., Hugo, D.V., Gndr, S., Uzun, A.: Load-adaptive networking for energy-efficient wireless access. Comput. Commun. **72**(C), 107–115 (2015)
7. Lee, K., Kim, Y., Kim, S., Shin, J., Shin, S., Chong, S.: Just-in-time WLANs: On-demand interference-managed WLAN infrastructures. In: IEEE INFOCOM 2016 - the IEEE International Conference on Computer Communications, pp. 1–9 (2016)
8. Zeng, Y., Pathak, P.H., Mohapatra, P.: Just-in-time WLANs: A first look at 802.11ac in action: Energy efficiency and interference characterization. In: NETWORKING Conference, pp. 1–9 (2014)
9. Miao, G., Himayat, N., Li, G., Talwar, S.: Distributed interference-aware energy-efficient power optimization. IEEE Trans. Wirel. Commun. **10**(4), 1323–1333 (2011)
10. Zhou, Y., Li, X., Liu, M., Mao, X., Tang, S., Li, Z.: Throughput optimizing localized link scheduling for multihop wireless networks under physical interference model. IEEE Trans. Parallel Distrib. Syst. **25**(10), 2708–2720 (2013)
11. Gupta, P., Kumar, P.R.: The capacity of wireless networks. IEEE Trans. Inf. Theory **46**(2), 388–404 (2000)
12. Zhou, K., Jia, X., Xie, L., Chang, Y.: Channel assignment for WLAN by considering overlapping channels in SINR interference model. In: International Conference on Computing, NETWORKING and Communications, pp. 1005–1009 (2012)
13. Xu, C., Jin, W., Zhao, G., Tianfield, H., Yu, S., Qu, Y.: A novel multipath-transmission supported software defined wireless network architecture. IEEE Access **5**(99), 2111–2125 (2017)
14. Rossi, C., Casetti, C., Chiasserini, C.F., Borgiattino, C.: Cooperative energy-efficient management of federated WiFi networks. IEEE Trans. Mob. Comput. **14**(11), 2201–2215 (2015)
15. Vigerske, S., Gleixner, A.: SCIP: global optimization of mixed-integer nonlinear programs in a branch-and-cut framework. Optim. Methods Softw. **33**, 1–31 (2016)