Research Article

Energy-Efficient User Association with Congestion Avoidance and Migration Constraint in Green WLANs

Wenjia Wu, Junzhou Luo, Kai Dong, Ming Yang, and Zhen Ling

School of Computer Science and Engineering, Southeast University, Nanjing 211189, China

Correspondence should be addressed to Wenjia Wu; wjwu@seu.edu.cn

Received 12 February 2018; Accepted 13 May 2018; Published 28 June 2018

Academic Editor: Xiaobing Wu

Green wireless local area networks (WLANs) have captured the interests of academia and industry recently, because they save energy by scheduling an access point (AP) on/off according to traffic demands. However, it is very challenging to determine user association in a green WLAN while simultaneously considering several other factors, such as avoiding AP congestion and user migration constraints. Here, we study the energy-efficient user association with congestion avoidance and migration constraint (EACM). First, we formulate the EACM problem as an integer linear programming (ILP) model, to minimize APs' overall energy consumption within a time interval while satisfying the following constraints: traffic demand, AP utilization threshold, and maximum number of demand node (DN) migrations allowed. Then, we propose an efficient migration-constrained user reassociation algorithm, consisting of two steps. The first step removes k AP-DN associations to eliminate AP congestion and turn off as many idle APs as possible. The second step reassociates these k DNs according to an energy efficiency strategy. Finally, we perform simulation experiments that validate our algorithm's effectiveness and efficiency.

1. Introduction

The IEEE 802.11-based wireless local area network (WLAN) is one of the most popular, widely used wireless access technologies in fog computing [1, 2]. WLANs are especially popular for campuses, enterprise environments, and public hotspots, serving a large number of users while satisfying their continuously growing traffic demands. Network operators usually deploy thousands of access points (APs) to achieve full coverag[illegible]ovide enough capacity. Although each AP only consumes a little energy, the overall network's energy consumption is significant due to the large-scale deployment. Escalating energy consumption increases greenhouse gas emissions and becomes a threat to environment protection and sustainable development. Moreover, it leads to higher energy costs, which is a critical component of network operational expenditures. Because the APs in a WLAN are overprovisioned with respect to peak traffic demands, but only handle peak traffic for small portions of time, energy is wasted when network traffic is low [3]. Thus, it is unnecessary to keep all resources active, which is why many researchers have pursued energy efficiency in the resource allocation and proposed many green scheduling strategies [4–6], and thus the concept of green WLANs is proposed [7–10]. In green WLANs, APs are scheduled on/off according to time-varying traffic demands, thereby saving energy.

User association is an important issue in WLAN research, and it aims to determine AP selection for each user and optimize APs' resource allocation. Most existing studies focus on performance optimization—such as load balancing, user fairness, and user qua [illegible]

there is an energy-saving mechanism that dynamically turns APs on/off to adapt to users' resource demands [7]. Related to green WLANs, there are only a few recent works on user association. These works focus on improving energy efficiency by optimizing user association.

Kumazoe et al. [19] propose a user reassociation scheme where an AP migrates its associated users to another AP and then switches its status to sleep when the AP finds that its utilization is lower than the predefined threshold. Wang et al. [20] consider user association in a heterogeneous network with hybrid energy supplies, where energy saving is subject to the constraints of a user data rate requirement, transmission power budget, and so forth. They formulate the energy cost saving optimization problem and present both centralized and distributed solutions.

Chen et al. [21] propose an AP energy-saving mechanism using SDN, aiming to reduce the amount of idle APs while satisfying QoS requirements. In the mechanism, the user association problem is formulated as an ILP model. Lee et al. [22] present a centralized management mechanism to improve energy efficiency and avoid interference without sacrificing users demands, and jointly optimize the AP on/off scheduling, channel assignment, and user association.

As discussed above, several energy-efficient user association solutions have been proposed in the past. However, to the best of our knowledge, no prior work exists that deals with the issues of AP congestion and user migration in the context of energy-saving optimization in WLANs. Hence, here we study the user association problem in green WLANs, which aims to achieve energy efficiency with AP congestion avoidance and user migration constraints.

3. System Model and Problem Formulation

3.1. System Model. Our IEEE 802.11-based multirate WLAN consists of multiple APs. The set of APs is denoted by A, and we use m to denote their number, i.e., $A = \{a_1, a_2, \dots, a_m\}$. Because users are on the go and their traffic demands are dynamic in WLANs, we represent the distribution of user traffic demands by discrete points (that is DNs) that are the center of an area aggregating the traffic demands of several users [23]. Thus, AP-user associations can be represented by AP-DN associations. We use U to denote the set of DNs, and the number of DNs is represented by n—that is, $U = \{u_1, u_2, \dots, u_n\}$. As shown in Figure 2, the AP-DN associations can be modeled as a directed graph $G(A \cup U, E)$, where E is the set of potential association relations between DNs and APs.

Because multimedia content and dowoads of mobile applications dominate the traffic demand, downlink traffic is much larger than uplink traffic, and thus we focus on dowlik trc (from the APs to DNs). For a DN $u_j \in U$, we assume that its traffic demand is a costant fo a certain time interval T, and the constant is denoted by r_j.

We assume that neighboring APs do not interfere with each other through allocating nonoverlapping channels. For the transmissio between $a_i \in A$ and $u \in U$, its available trasmission rate is denoted by c_{ij}. We exploit the PHY multirate capability and enable each device to select the best transmission rate according to the received signal noise ratio (SNR), which we obtain by

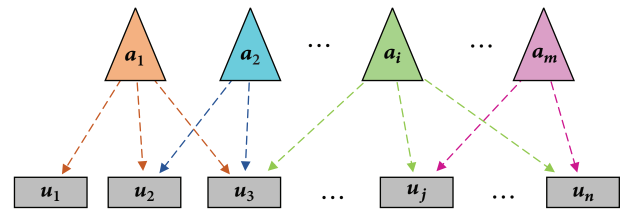


Figure 2: AP-DN association model.

$$SNR_{ij} = p_i - PL\left(d_{ij}\right) - N \tag{1}$$

where $SNR_{i,j}$ represents the SNR of signals that are transmitted from AP a_i and received at DN u_j; p_i is the transmit power of AP a_i; d_{ij} is the distance between AP a_i and DN u_j, and $PL(d_{ij})$ denotes the propagation path loss; N is the background noise power.

To characterize energy consumption of APs correctly, we use a fine-grained power model where we ascribe the power consumed by AP a_i to the following two elements [24, 25]:

(i) The baseline power (denoted by b_i) is a constant, which quantifies power consumption when the AP neither sends nor receives traffic after it is powered on.

(ii) The traffic-related power, a variable part, is generated by the wireless interface and relevant components. Because we only consider downlink traffic in this paper, the traffic-related power pertains to AP transmitting wireless signals, and thus it positively correlates with AP transmit power and AP utilization. AP utilization is defined by the fraction of time during which the AP transmits traffic.

For $a_i \in A$, we define AP power as follows:

$$P_i = b_i + \eta_i p_i \sum_{j \in U(a_i)} \frac{r_j}{c_{ij}} \tag{2}$$

where the power of AP a_i is denoted by P_i, $U(a_i)$ represents the set of DNs that are associated with AP a_i, and η_i is an efficiency factor that accounts for the AP's electrical model.

The notations and their definitions are summarized in Table 1.

3.2. Problem Formulation. In this section, we formulate the energy-efficient user association as an optimization problem based on an ILP model. Specifically, we not only consider energy optimization in the context of user association, but also take AP congestion avoidance and user migration constraints into account. We therefore define the problem as follows.

Definition 1 (EACM). Given the network $G(A \cup U, E)$, the current traffic demands of DNs (i.e.,$\{r_j \mid u_j \in U\}$), and the

Table 1: Notations.

Symbol	Definition
A	The set of access points (APs)
U	The set of demand nodes (DNs)
E	The set of potential association relations
m	The number of APs
n	The number of DNs
a_i	An AP
u_j	Am DN
r_j	The traffic demand of DN u_j
T	Time interval
c_{ij}	The available transmission rate between AP a_i and DN u_j
SNR_{ij}	The received SNR at DN u_j when signal is from AP a_j
P_i	The power of AP a_i
b_i	The baseline power of AP a_i
p_i	The transmit power of AP a_i
η_i	The efficiency factor of AP a_i
d_{ij}	The distance between AP a_i and DN u_j
$PL(d_{ij})$	The propagation path loss
N	The background noise power
$U(a_i)$	The set of DNs that are associated with AP a_i
β_{ij}	The coverage indicator between AP a_i and DN u_j
φ	The threshold of AP utilization
$\alpha(j)$	The previous association indicator
k	The maximum allowed number of migrations

previous AP-DN associations, the problem is to minimize the overall energy consumption of the APs in the current time interval through optimizing the AP-DN associations; while the traffic demands of the DNs are satisfied, the utilization of each AP is limited by a threshold, and DN migrations are also constrained.

To formulate the ILP model, we define the following sets of binary variables:

(i) x_i, which is set to 1 if AP a_i is turned on, or 0 otherwise.

(ii) $y_{i,j}$, which is set to 1 if DN u_j is associated with AP a_i, or 0 otherwise.

For each $a_i \in A$ and $u_j \in U$, we also define a coverage indicator to denote whether DN u_j is in the coverage range of AP a_i; that is,

$$\beta_{i,j} = \begin{cases} 1 & c_{i,j} > 0 \\ 0 & c_{i,j} = 0. \end{cases} \tag{3}$$

In addition, let $\alpha(j)$ be the previous association indicator that represents the AP-DN association in the previous time interval for DN u_j.

The objective is to minimize the overall energy consumption of the APs in the current time interval, as described by

$$\min T \sum_{i \in A} \left(b_i x_i + \eta_i p_i \sum_{j \in U} \frac{r_j y_{ij}}{c_{ij}} \right). \tag{4}$$

The minimization is subject to the following constraints:

$$y_{ij} \le \beta_{ij} x_i \quad \forall i \in A,\ j \in U \tag{5}$$

$$\sum_{i \in A} y_{ij} = 1 \quad \forall j \in U \tag{6}$$

$$\sum_{j \in U_i} \frac{r_j y_{ij}}{c_{ij}} \le \varphi x_i \quad \forall i \in A \tag{7}$$

$$\sum_{j \in U} y_{\alpha(j) j} \ge n - k \tag{8}$$

$$x_i \in \{0, 1\} \quad \forall i \in A \tag{9}$$

$$y_{ij} \in \{0, 1\} \quad \forall i \in A,\ j \in U. \tag{10}$$

In the aforementioned formulation, the constraint (5) states that no DN is associated with powered-off APs and an AP does not provide services for DNs beyond its coverage range. The constraint (6) imposes that each DN must be associated with an AP only. The constraint (7) ensures that each AP can satisfy the traffic demands of its associated DNs, and its AP utilization is limited by the coefficient φ. The constraint (8) denotes the allowed maximum number of migrations that cannot be exceeded. Finally, the constraints (9) and (10) define the binary of the variables.

The EACM problem is NP-hard, because it includes as a special case the set-covering problem, known to be NP-hard [26]. Although the schemes that solve the ILP model directly can find the optimal solution or at least bound it, they are impractical for a relatively large-scale scenario, because of computational complexity and memory limitations [27]. Thus, the better alternative here is to design a heuristic algorithm to solve the EACM problem efficiently.

4. MURA

In this section, we propose MURA, our efficient two-step algorithm to solve the EACM problem. The basic idea is to migrate at most k DNs from their original APs to neighboring APs, while considering energy saving and congestion avoidance. We solve this in two steps. In Step 1, we select k DNs that are associated with heavily loaded or idle APs and remove them from the current associations. In Step 2, we reassociate the removed DNs according to the energy efficiency strategy.

4.1. Step 1: DN Removal. In this step, we need to determine which k DNs to remove from the current associations. As described in Algorithm 1, we first initialize the set of APs that are turned on (A_on), the utilization of each AP (P_Util), the number of associated DNs for each AP (AP_UNum), the set of current AP-DN associations (UA_fxd), the set

Input: $A, U, E, UA\_pre\ k, \varphi, \{r_j \mid u_j \in U\}$, $\{c_{ij} \mid a_i \in A, u_j \in U\}$
Output: UA_fxd, U_rmv
(1) Initialize A_on // Set of APs that are turned on
(2) Initialize AP_Util // AP utilization
(3) Initialize AP_UNum // Number of associated DNs for each AP
(4) $UA\_fxd \leftarrow UA\_pre$ // Set of fixed AP-DN associations
(5) $U\_rmv \leftarrow \emptyset$
(6) $rm\_cnt \leftarrow k$ // Limitation of DN removal
(7) **while** *true* **do**
(8) $a_q \leftarrow \arg\max_{a_i \in A} AP\_Util(a_i)$ // Find the AP with the maximum utilization
(9) **if** $AP\_Util(a_q) > \varphi$ **then**
(10) **if** $rm\_cnt = 0$ **then**
(11) **return** *null*, *null* // Failure of AP congestion avoidance
(12) **else**
(13) $U\_a \leftarrow \{u \mid (a_q, u_j) \in UA\_fxd, \forall u_j \in U\}$
(14) Select a proper DN u_p from U_a
(15) Remove (a_q, u_p) from UA_fxd
(16) $U\_rmv \leftarrow U\_rmv \cup \{u_p\}$
(17) Update $AP\_Util(a_q)$, $AP\_UNum(a_q)$
(18) $rm\_cnt = rm\_cnt - 1$
(19) **else**
(20) **if** $rm\_cnt = 0$ **then return** UA_fxd, U_rmv
(21)
(22) **else** break
(23)
(24) **while** *true* **do**
(25) $a\_q \leftarrow \arg\min_{a_i \in A\_on} AP\_UNum(a_i)$
(26) $U\_a \leftarrow \{u_j \mid (a_q, u_j) \in UA\_fxd, \forall u_j \in U\}$
(27) **foreach** $u_j \in U\_a$ **do**
(28) Remove (a_q, u_j) from UA_fxd
(29) $rm\_cnt = rm\_cnt - 1$
(30) **if** $rm\_cnt = 0$ **then return** UA_fxd, U_rmv
(31)
(32) $A\_on = A\_on \setminus \{a_q\}$ // Turn off as many APs as possible

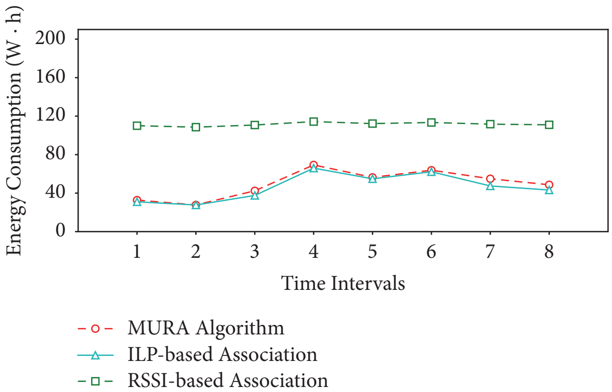
Algorithm 1: DN removal.

of removed DNs (U_rmv), and the required number of DN removals (rm_cnt). Then, we remove DNs from the current associations, successively considering AP congestion avoidance and energy saving. Specifically, we divide the process of DN removal into two parts. In the first part (lines (7) to (23)), we iteratively remove DNs to address the issue

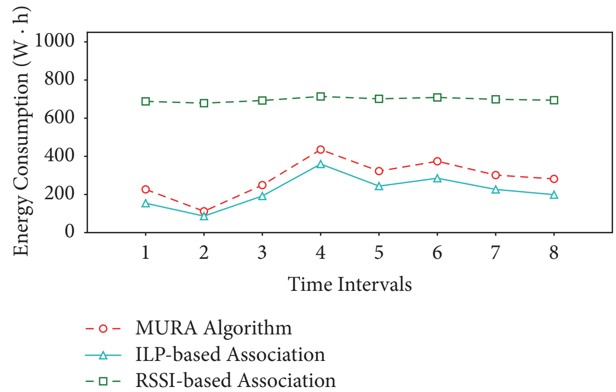
$n + |U\_a|$). Because $m < n$ and $|U\_a| < n$, the time complexity of this step is $O((m + k)n)$.

In the second step, again the initialization completes within $O(mn)$, and the sorting of U_rmv can be accomplished in $O(k \lg k)$. DN reassociation iterates at most k times. For each iteration (lines (5) to (20)), the time complexity is $O(m)$. Because $k < n$, the time complexity of this step is $O(mn + k \lg k)$.

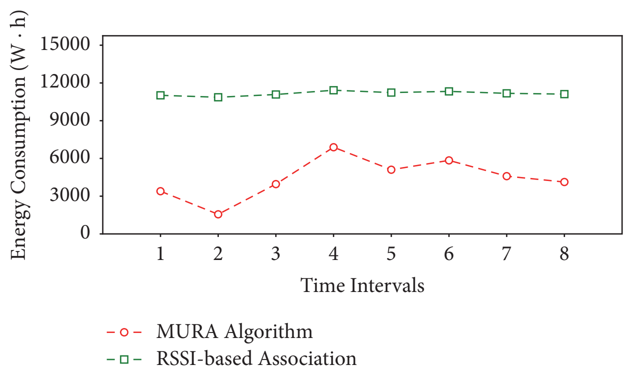
Therefore, as discussed, the time complexity of the MU[illegible]



(a) Small scenarios



(b) Medium scenarios



(c) Large scenarios

Figure 3: Validation of energy efficiency.

Table 5: Execution Time.

Time intervals	Execution time (Sec.)								
	Small scenarios			Medium scenarios			Large scenarios		
	MURA	ILP-based	RSSI-based	MURA	ILP-based	RSSI-based	MURA	ILP-based	RSSI-based
1	0.0013	0.0086	0.0005	0.0057	0.4928	0.0017	0.2718	-	0.0176
2	0.0004	0.0068	0.0002	0.0015	0.0235	0.0009	0.0524	-	0.0127
3	0.0008	0.0099	0.0003	0.0051	0.7347	0.0013	0.3151	-	0.0193
4	0.0008	0.0124	0.0003	0.0052	0.5227	0.0016	0.4825	-	0.0306
5	0.0007	0.0120	0.0004	0.0042	3.8941	0.0014	0.2137	-	0.0239
6	0.0008	0.0137	0.0003	0.0051	6.8822	0.0015	0.4613	-	0.0276
7	0.0007	0.0128	0.0003	0.0043	2.6668	0.0013	0.2814	-	0.0219
8	0.0008	0.0122	0.0003	0.0045	1.0751	0.0012	0.3111	-	0.0202

Figure 3 shows the performance of the MURA algorithm, the ILP-based association scheme, and the RSSI-based association scheme. From this figure, we can see that the MURA algorithm achieves significant energy savings comparing to the RSSI-based association scheme. Also, there is only a small gap in performance between our solution and the optimal solutions obtained by the ILP-based association scheme, which validates the near optimality of our algorithm. When the network scenarios become large, the ILP model cannot be solved by Gurobi directly, but our algorithm provides solutions within an acceptable time, as shown in Table 5. Moreover, the curves of our algorithm in Figure 3 show that an interval's energy consumption is proportional to the traffic demand, and energy consumption greatly diminishes when traffic demand is low.

5.4. Varying the Maximum Allowed Number of Migrations. Here, we evaluate the performance of the MURA algorithm, while varying the maximum allowed number of migrations (the parameter k). We perform simulations on large-scale

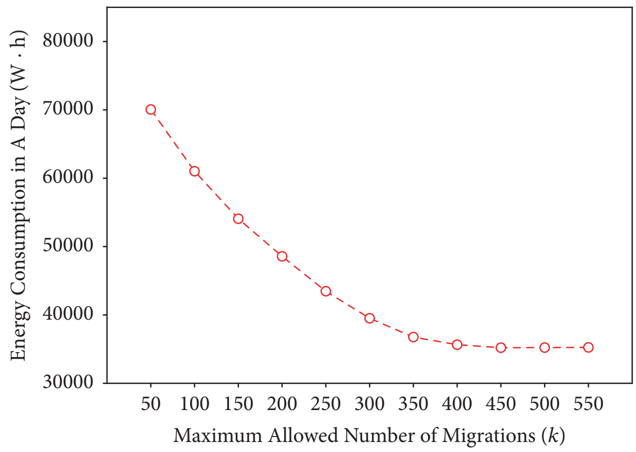


FIGURE 4: Energy consumption varying parameter k.

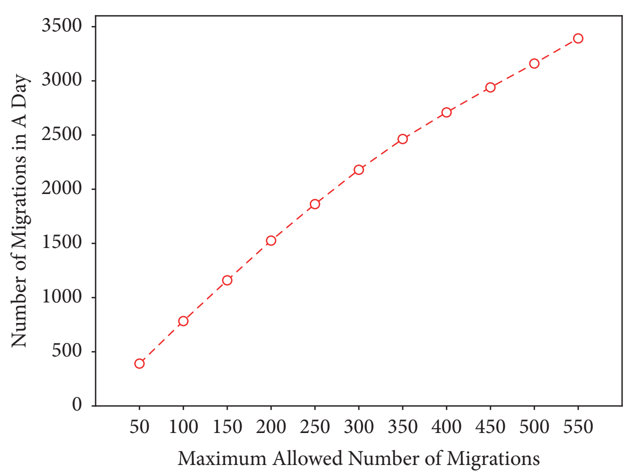


FIGURE 5: DN migrations varying parameter k.

scenarios and set the AP utilization threshold (φ) to be 0.8. For the AP power model, we again set the baseline power (b_i) to be 9 W and the efficiency factor (η_i

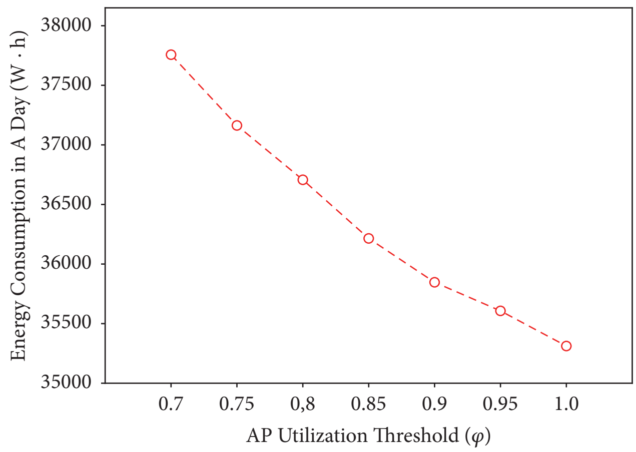


Figure 6: Energy consumption varying parameter φ.

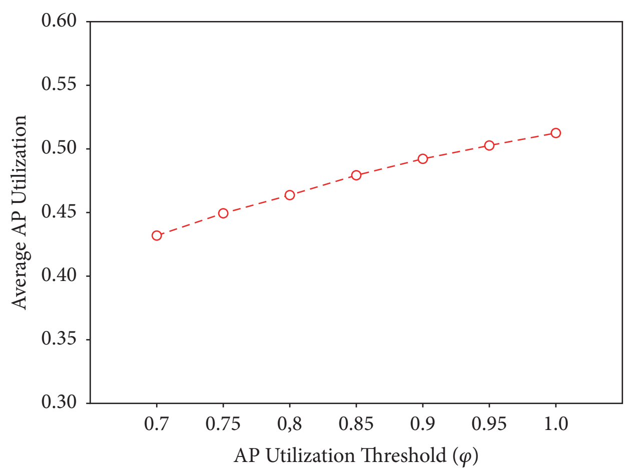


Figure 7: Average AP utilization varying parameter φ.

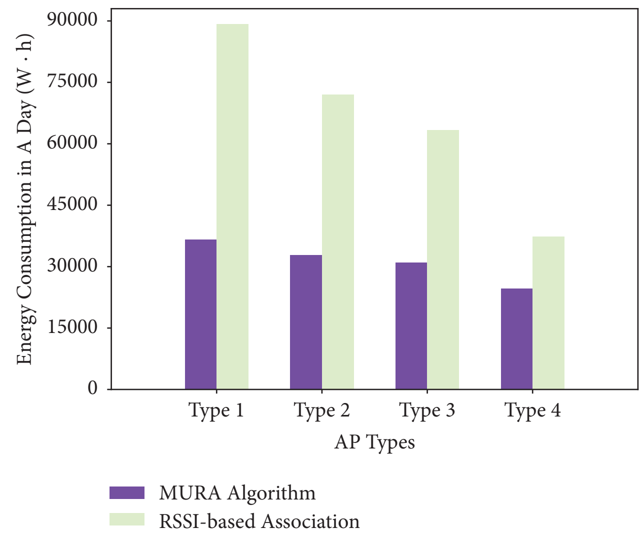


Figure 8: Energy consumption varying AP types.

6. Conclusion

We investigated the energy-efficient user association in green WLANs while considering AP congestion avoidance and user migration constraints. First, we formulated the EACM problem as an ILP model, to minimize APs' overall energy consumption in a current time interval under the constraints of traffic demand, the AP utilization threshold, and the maximum number of migrations allowed. Then, we proposed MURA, a two-step algorithm that efficiently solves the problem. Finally, we conducted simulation experiments to evaluate the performance of our proposed algorithm. The results demonstrate that MURA effectively saves energy—beyond that, the algorithm can obtain the tradeoff between energy efficiency, congestion avoidance, and migration cost.

In the future, we plan to measure traffic patterns in real-world scenarios through crowdsourcing and propose a data-driven user association algorithm that applies well to a real network.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by National Key R&D Program of China 2017YFB1003000, National Natural Science Foundation of China under Grants no. 61632008, no. 61572130, no. 61502100, no. 61602111, no. 61532013, and no. 61320106007, Jiangsu Provincial Natural Science Foundation of China under Grants no. BK20150637 and no. BK20150628, Jiangsu Provincial Key Laboratory of Network and Information Security under Grant no. BM2003201, and Key Laboratory of Computer Network and Information Integration of Ministry of Education of China under Grant no. 93K-9.

References

[1] P. Hu, S. Dhelim, H. Ning, and T. Qiu, "Survey on fog computing: architecture, key technologies, applications and open issues," *Journal of Network and Computer Applications*, vol. 98, pp. 27–42, 2017.

[2] B. Bellalta, L. Bononi, R. Bruno, and A. Kassler, "Next generation IEEE 802.11 Wireless Local Area Networks: Current status, future directions and open challenges," *Computer Communications*, vol. 75, pp. 1–25, 2016.

[3] M. Afanasyev, T. Chen, G. M. Voelker, and A. C. Snoeren, "Usage patterns in an urban WiFi network," *IEEE/ACM Transactions on Networking*, vol. 18, no. 5, pp. 1359–1372, 2010.

[4] Ł. Budzisz, F. Ganji, G. Rizzo et al., "Dynamic resource provisioning for energy efficiency in wireless access networks:

A survey and an outlook," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 4, pp. 2259–2285, 2014.

[5] X. Xu, W. Dou, X. Zhang, and J. Chen, "EnReal: An Energy-Aware Resource Allocation Method for Scientific Workflow Executions in Cloud Environment," *IEEE Transactions on Cloud Computing*, vol. 4, no. 2, pp. 166–179, 2016.

[6] X. Xu, X. Zhang, M. Khan, W. Dou, S. Xue, and S. Yu, "A balanced virtual machine scheduling method for energy-performance trade-offs in cyber-physical cloud systems," *Future Generation Computer Systems*, 2017.

[7] A. P. Jardosh, K. Papagiannaki, E. M. Belding, K. C. Almeroth, G. Iannaccone, and B. Vinnakota, "Green WLANs: on-demand WLAN infrastructures," *Mobile Networks and Applications*, vol. 14, no. 6, pp. 798–814, 2009.

[8] P. Serrano, A. De La Oliva, P. Patras, V. Mancuso, and A. Banchs, "Greening wireless communications: Status and future directions," *Computer Communications*, vol. 35, no. 14, pp. 1651–1661, 2012.

[9] F. Ganji, Ł. Budzisz, F. G. Debele et al., "Greening campus WLANs: Energy-relevant usage and mobility patterns," *Computer Networks*, vol. 78, pp. 164–181, 2015.

[10] V. Sivaraman, J. Matthews, C. Russell, S. T. Ali, and A. Vishwanath, "Greening residential Wi-Fi networks under centralized control," *IEEE Transactions on Mobile Computing*, vol. 14, no. 3, pp. 552–564, 2015.

[11] Y. Bejerano, S. Han, and L. E. Li, "Fairness and load balancing in wireless LANs using association control," in *Proceedings of the 10th Annual International Conference on Mobile Computing and Networking*, pp. 315–329, ACM, Philadelphia, PA, USA, September 2004.

[12] W. Li, S. Wang, Y. Cui et al., "AP association for proportional fairness in multirate WLANs," *IEEE/ACM Transactions on Networking*, vol. 22, no. 1, pp. 191–202, 2014.

[13] D. Gong and Y. Yang, "On-line AP association algorithms for 802.11n WLANs with heterogeneous clients," *Institute of Electrical and Electronics Engineers. Transactions on Computers*, vol. 63, no. 11, pp. 2772–2786, 2014.

[14] J. Yu and W.-C. Wong, "Optimal association in wireless mesh networks," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 5, pp. 2084–2096, 2015.

[15] W. Wong, A. Thakur, and S. G. Chan, "An approximation algorithm for AP association under user migration cost constraint," in *Proceedings of the IEEE INFOCOM 2016 - IEEE Conference on Computer Communications*, pp. 1–9, San Francisco, CA, USA, April 2016.

[16] A. Raschella, F. Bouhafs, M. Seyedebrahimi, M. Mackay, and Q. Shi, "Quality of service oriented access point selection framework for large Wi-Fi networks," *IEEE Transactions on Network and Service Management*, vol. 14, no. 2, pp. 441–455, 2017.

[17] J. Chen, B. Liu, H. Zhou, Q. Yu, L. Gui, and X. S. Shen, "QoS-Driven Efficient Client Association in High-Density Software-Defined WLAN," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 8, pp. 7372–7383, 2017.

[18] H. Kim, W. Lee, M. Bae, and H. Kim, "Wi-Fi Seeker: A link and Load Aware AP Selection Algorithm," *IEEE Transactions on Mobile Computing*, vol. 16, no. 8, pp. 2366–2378, 2017.

[19] K. Kumazoe, D. Nobayashi, Y. Fukuda, T. Ikenaga, and K. Abe, "Multiple station aggregation procedure for radio-on-demand WLANs," in *Proceedings of the 2012 7th International Conference on Broadband, Wireless Computing, Communication and Applications, BWCCA 2012*, pp. 156–161, Victoria, Canada, November 2012.

[20] B. Wang, Q. Kong, and L. T. Yang, "Context-aware user association for energy cost saving in a green heterogeneous network with hybrid energy supplies," *Mobile Networks and Applications*, vol. 20, no. 6, pp. 802–816, 2015.

[21] Y. Chen, Y. Shen, and L. Wang, "Achieving energy saving with QoS guarantee for WLAN using SDN," in *Proceedings of the ICC 2016 - 2016 IEEE International Conference on Communications*, pp. 1–7, Kuala Lumpur, Malaysia, May 2016.

[22] K. Lee, Y. Kim, S. Kim, J. Shin, S. Shin, and S. Chong, "Just-in-time WLANs: On-demand interference-managed WLAN infrastructures," in *Proceedings of the IEEE INFOCOM 2016 - IEEE Conference on Computer Communications*, pp. 1–9, San Francisco, CA, USA, April 2016.

[23] K. Tutschku, "Demand-based radio network planning of cellular mobile communication systems," in *Proceedings of the IEEE INFOCOM'98 Conference on Computer Communications Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies Gateway to the 21st Century*, pp. 1054–1061, San Francisco, CA, USA, 1998.

[24] A. Garcia-Saavedra, P. Serrano, A. Banchs, and G. Bianchi, "Energy consumption anatomy of 802.11 devices and its implication on modeling and design," in *Proceedings of the 8th ACM International Conference on Emerging Networking EXperiments and Technologies, CoNEXT 2012*, pp. 169–180, fra, December 2012.

[25] R. G. Garroppo, G. Nencioni, G. Procissi, and L. Tavanti, "The impact of the access point power model on the energy-efficient management of infrastructured wireless LANs," *Computer Networks*, vol. 94, pp. 99–111, 2016.

[26] V. Chvatal, "A greedy heuristic for the set-covering problem," *Mathematics of Operations Research*, vol. 4, no. 3, pp. 233–235, 1979.

[27] M. Rim, A. Mujumdar, R. Jain, and R. DeLeone, "Optimal and Heuristic Algorithms for Solving the Binding Problem," *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, vol. 2, no. 2, pp. 211–225, 1994.

[28] Y. Bejerano and S.-J. Han, "Cell breathing techniques for load balancing in wireless LANs," *IEEE Transactions on Mobile Computing*, vol. 8, no. 6, pp. 735–749, 2009.

[29] MCS index - 802.11n and 802.11ac,2015, https://www.wlanpros.com/resources/mcs-index-802-11ac-vht-chart/.

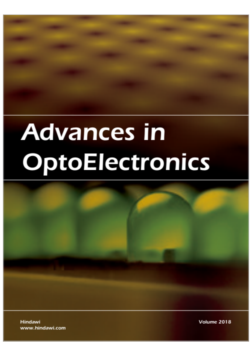
[30] MCS value achieved by clients at various signal to noise ratio levels (SNR), 2015, https://www.wlanpros.com/resources/revolution-wifi-mcs-to-snr-single-page/.

[31] A. Capone, F. Malandra, and B. Sansò, "Energy savings in Wireless Mesh Networks in a time-variable context," *Mobile Networks and Applications*, vol. 17, no. 2, pp. 298–311, 2012.


Adva ces i
Civil E gi eeri g


Jour al of
Ro otics

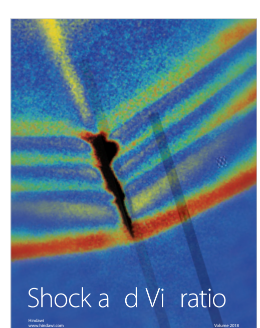

Journal of
Electrical and Computer Engineering


Advances in
OptoElectronics


VLSI Design


International Journal of
Aerospace Engineering


Active a d Passive
Electro ic Compo e ts


Shock a d Vi ratio


Adva ces i
Acoustics a d Vi ratio