QoS-Guaranteed AP Selection Algorithm in Dense IEEE 802.11 WLANs

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Abstract. IEEE 802.11 wireless local area network (WLAN) is a popular connectivity method because of its convenient deployment, low cost and flexibility. Due to the limited coverage of single access point (AP), multiple APs are often arranged in current WLANs to meet the coverage requirement. In such dense WLANs, the actual situation is that every wireless station (WS) has different quality of service (QoS) requirements for the actual acquired throughput. Thus, this paper proposed a QoS-Guaranteed AP selection algorithm to increase the overall QoS of WSs for the actual acquired throughput. The proposed algorithm relies on a centralized framework and considers the diverse QoS requirements. According to these concrete requirements, the proposed algorithm can distribute WSs to APs fairly and achieve the near-optimal access of AP based on the game theory. Finally, the numerical simulation results verify that the proposed algorithm can effectively improve the overall QoS of WSs.

Keywords: AP selection algorithm · QoS-Guaranteed · Dense IEEE 802.11 WLANs · Game theory

1 Introduction

IEEE 802.11 wireless local area networks (WLANs) have been widely deployed as wireless infrastructures, which can provide data access services in home, corporate and public environments.

Due to the limited coverage of a single access point (AP), multiple APs are often arranged in WLAN to meet the coverage requirement. In such dense WLANs, every wireless station (WS) has different quality of service (QoS) requirements for the actual acquired throughput according to its own situation. The QoS of a WS is strongly influenced by which AP it associates with. Thus, for each WS, how to select a suitable AP to obtain satisfactory service is very important.

The conventional AP selection strategy for WS is to associate with the AP with the highest received signal strength indication (RSSI), which has been proved to be not effective in dense WLANs. Because location distribution of WSs is usually quite unevenly around APs [1], and this simple strategy might lead to bad performance and load imbalance [2].

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Existing AP selection can be classified as distributed or centralized strategies. In the case of distributed strategies, the WSs gather some metrics from APs and then choose the best AP based on these metrics. The authors in [3] presented a distributed strategy based on game theory to maximize the overall network throughput. The authors in [4] presented a classification of works and introduced a distributed strategy, which addressed quality of experience (QoE) enhancement.

In the case of centralized strategies, the decision on the selection of the best AP is performed by a controller. The controller has an overall view of the managed network. For centralized strategies, the authors in [5, 6] used SDN-based platforms to implement centralized approaches to address AP selection for WSs. The authors in [7] proposed a cloud-based access node selection approach using a potential game.

However, the traditional works did not consider the different QoS requirements of WSs and cannot distribute WSs to APs fairly. In order to increase the overall QoS of WSs instead of individual QoS of WS, a QoS-Guaranteed AP selection algorithm is proposed for dense WLANs in this paper. In the proposed algorithm, the different QoS requirements of WSs and the distance between WSs and APs are considered, and a new performance metric are proposed to evaluate the QoS of WS. In addition, based on the fair evaluation, the centralized framework and two-tier approximation game theory are adopted to manage the network to increase the overall QoS. The numerical simulation results show the effectiveness of the proposed algorithm.

2 System Model

2.1 Network Model

As shown in Fig. 1, this paper considers a centralized dense IEEE 802.11 WLAN. The network has one access point controller (AC), M APs and N ($N > M$) WSs. The AC is used to manage all APs and has an overall view of the managed network. Let $\mathbb{M} = \{1, 2,\ldots, M\}$ and $\mathbb{N} = \{1, 2,\ldots, N\}$ denote the sets of APs and WSs, respectively. Assume that neighboring APs operate at different (non-overlapping) frequency channels, so that there is no interference among them.

The network transmission protocol adopts IEEE 802.11b. IEEE 802.11b is a multi-rate protocol and the supported transmission rates are 11 Mbps, 5.5 Mbps, 2 Mbps and 1 Mbps. The transmission rates are determined by channel conditions. The MAC layer protocol of IEEE 802.11b adopts distributed coordination function (DCF). Each WS i ($i \in \mathbb{N}$) has a QoS requirement for the actual acquired throughput r_i and thus it has to select a suitable AP to meet its r_i. Assume that each WS is in saturation mode, which means it always transmits data to AP.

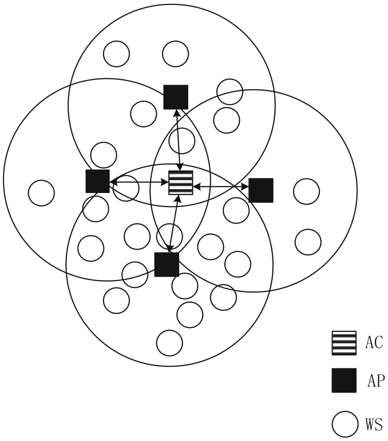

Fig. 1. A centralized dense IEEE 802.11 WLAN

2.2 Communication Model

The link capacity $c_{i,\ j}$ between WS i and AP j can be expressed as:

$$c_{i,j} = B\log_2(1 + \frac{p_i h_i}{\sigma}), \tag{1}$$

where B represents the bandwidth of the selected channel, p_i represents the transmission power of WS i, h_i represents the channel gain between WS i and AP j, and σ represents the thermal noise power.

Once $c_{i,\ j}$ is determined, the bit rate $b_{i,\ j}$ between WS i and AP j can be obtained. The $b_{i,\ j}$ is calculated by mapping $c_{i,\ j}$ to the closest but below the bit rate level provided by the orthogonal frequency division multiple access (OFDMA) modulation scheme supported by IEEE 802.11b.

When multiple WSs associate with the same AP and transmit data to the AP through the DCF provided by the MAC protocol of the IEEE multi-rate protocol at the same time, the performance anomaly occurs. And the high-rate WS will be dragged down by the low-rate WS, so that the actual acquired throughput of the high-rate WS will be greatly reduced.

The Fig. 2 illustrates a performance anomaly scenario. There are two IEEE 802.11b APs and five WSs. WS_4 has two choices, AP_1 or AP_2. The Table 1 shows that if WS_4 selects AP_2, the achievable throughput of WS_5 is dragged down by WS_4, from 7.73 Mbps to 0.81 Mbps. It can also be seen that if WS_4 selects AP_1, it can have a better throughput 1.96 Mbps, although AP_1 is more crowded than AP_2. AP_1 is also a better choice from the perspective of total throughput 15.57 Mbps. The achievable throughputs in Table 1 are calculated based on the analysis of [8].

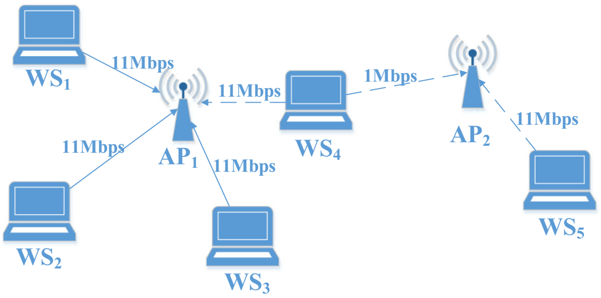

Fig. 2. Scenario illustrating performance anomaly

Table 1. Achievable throughputs based on the choice of WS_4

Choice of WS_4	Achievable throughput (Mbps)					Total (Mbps)
	WS_1	WS_2	WS_3	WS_4	WS_5	
AP_1	1.96	1.96	1.96	1.96	7.73	15.57
AP_2	2.66	2.66	2.66	0.81	0.81	9.60

3 Problem Formulation

In IEEE 802.11b environment, $X_{i,\,j}$ represents the obtained throughput after WS i selecting AP j and can be expressed as:

$$X_{i,j} = U_{i,j} \times \frac{\mathrm{s_d}}{b_{i,j} T_{i,j}} \times b_{i,j}, \tag{2}$$

where $U_{i,\,j}$ is the fraction of time that WS i is able to access the medium of AP j, $\mathrm{s_d}$ is the length (in bits) of the data frame and its value is 12272, $T_{i,\,j}$ is the overall transmission time (counting protocol overhead, transmission time, and the time spent in contention procedure) for a single frame sent by WS i and $b_{i,\,j}$ is the bit rate between WS i and AP j.

Let $\mathbb{W}_j$ denote all the WS sets (WS $i \in \mathbb{W}_j$) of AP j. K represents the number of WS in $\mathbb{W}_j$. The $T_{i,j}$ can be expressed as:

$$T_{i,j}(K) = t_{\mathrm{tr}} + t_{\mathrm{ov}} + t_{\mathrm{cont}}(K), \tag{3}$$

where t_{tr} represents the frame transmission time, t_{ov} represents constant overhead and t_{cont} represents the time spent in the competition.

The t_{tr} can be expressed as:

$$t_{\mathrm{tr}} = \frac{s_d}{b_{i,j}}, \tag{4}$$

The t_{ov} varies according to the bit rate used by WS. If it transmits at 1, 2, 5.5 or 11 Mbps, then the t_{ov} = 541, 305, 271, 262 μs respectively. (these parameters are for 802.11b).

The t_{cont} can be written as:

$$t_{cont}(K) \simeq SLOT \times \frac{1 + P_c(K)}{2K} \times \frac{CW_{min}}{2}, \tag{5}$$

where the value of *SLOT* is 20 μs, the congestion window *CW* varies between CW_{min} = 31 and CW_{max} = 1023. $P_c(K)$ is the proportion of collisions of each data packet successfully acknowledged at the MAC layer ($0 \leq P_c(K) < 1$). The $P_c(K)$ can be expressed as:

$$P_c(K) = 1 - (1 - \frac{1}{CW_{min}})^{K-1}, \tag{6}$$

The $U_{i,j}$ can be expressed as:

$$U_{i,j} = \frac{T_{i,\,j}}{\left(\sum_{WS\ k \in W_j} T_{k,j}\right) + P_c(K) \times t_{jam} \times K}, \tag{7}$$

where t_{jam} represents the average time spent in a collision.

The duration of the collision depends on the type of WS collision (slow or fast) involved. Thus, the t_{jam} can be obtained by considering all possible WS pairs between at different rates, that is as follows:

$$t_{jam} = P_1 T_{1,j} + P_2 T_{2,j} + P_3 T_{3,j} + P_4 T_{4,j}, \tag{8}$$

where $T_{1,\,j}$, $T_{2,\,j}$, $T_{3,\,j}$, and $T_{4,\,j}$ represent the overall transmission time of a single frame for WS with transmission rates of 1, 2, 5.5 and 11 Mbps, respectively. P_1, P_2, P_3 and P_4 represent the probability of having a packet sent at the slow transmission rates of 1, 2, 5.5, and 11 Mbps, respectively.

P_1, P_2, P_3 and P_4 can be computed as the ratio between the number of WS pairs that contain the slow host and the total number of pairs that can be formed in the set of all WSs. They can be calculated as below formulas:

$$P_1 = \frac{K_1(K_1 - 1) + 2K_1(K_2 + K_3 + K_4)}{K(K - 1)}, \tag{9}$$

$$P_2 = \frac{K_2(K_2 - 1) + 2K_2(K_3 + K_4)}{K(K - 1)}, \tag{10}$$

$$P_3 = \frac{K_3(K_3 - 1) + 2K_3K_4}{K(K - 1)}, \tag{11}$$

$$P_4 = \frac{K_4(K_4 - 1)}{K(K - 1)}, \tag{12}$$

where K_1 is the number of WS with a bit rate of 1 Mbps in $\mathbb{W}_j$, K_2 is the number of WS with a bit rate of 2 Mbps, K_3 is the number of WS with a bit rate of 5.5 Mbps, K_4 is the number of WS with a bit rate of 11 Mbps.

Each WS i has a QoS requirement for the actual acquired throughput r_i. Define $Q_{i,j}$ as the QoS of WS i to the selected AP j for the actual acquired throughput, and can be expressed as:

$$Q_{i,j} = \begin{cases} \frac{X_{i,j}}{r_i}, & \frac{X_{i,j}}{r_i} < 1 \\ 1, & \frac{X_{i,j}}{r_i} \geq 1 \end{cases}, \tag{13}$$

Each WS i needs to select the appropriate AP in the WLAN for data transmission. Let $\lambda_{i,j} \in \{0,1\}$ denote the selection decision between the WS i and the AP j, i.e. $\lambda_{i,j} = 1$ means that the WS i decides to associate with AP j, otherwise $\lambda_{i,j} = 0$.

Based on this, the problem of maximizing the overall QoS for the actual acquired throughput can be described as follows:

$$\max_{\lambda_{i,j}} \sum_{i=1}^{N} \sum_{j=1}^{M} Q_{i,j} \lambda_{i,j}, \tag{14}$$

4 QoS-Guaranteed AP Selection Algorithm

Game theory has been widely used as an efficient method to address the decision-making problems among multiple game players [9]. In order to maximize the overall QoS for the actual acquired throughput, we adopt a two-tier approximation algorithm called QoS-Guaranteed AP selection algorithm (QASA). In the proposed algorithm, we regard WSs as the rational game players. The outer layer adopts a stochastic game to find an overall optimal AP selection decision profile for all the WSs, and the inner layer adopts a greedy approximation method to find a locally optimal AP selection decision of WS i for its r_i.

Let $\mathbb{A} = (A_1, A_2, ..., A_{i\text{-}1}, A_i, A_{i+1}, ..., A_N)$ denote the AP selection decision profile of all WSs. Also, let $\mathbb{A}_{\text{-}i} = (A_1, A_2, ..., A_{i\text{-}1}, A_{i+1}, ..., A_N)$ denote the AP selection decision profile of all WSs except WS i. A_i denotes the AP selection decision of WS i. $\mathbb{A}$ can be also denoted as $(A_i, \mathbb{A}_{\text{-}i})$. Given the AP selection decision profile of other WSs $\mathbb{A}_{\text{-}i}$,, WS i would like to choose a locally optimal AP selection decision A_i^* to meet its r_i. WS i adopts A_i^*, which can maximize its Q_i, i.e.,

$$Q_i\left(A_i^*, \mathbb{A}_{-i}\right) \geq Q_i\left(A_i, \mathbb{A}_{-i}\right), \forall\, i \in \mathbb{N}, \tag{15}$$

Furthermore, we can formulate our problem of maximizing the overall QoS AP selection as a strategic game as

$$\Gamma = (\mathbb{N}, \{\overline{\mathbb{A}}_i\}_{i \in \mathbb{N}}, \{Q_i(A_i, \mathbb{A}_{-i})\}_{i \in \mathbb{N}}), \tag{16}$$

where $\mathbb{N}$ is the set of game players, $\overline{\mathbb{A}_i} = \{1,\cdots,M\}$ is the set of strategies for game player WS *i*, and $Q_i(A_i, \mathbb{A}_{-i})$ is the revenue function to be maximized by player WS *i*.

In QASA, each WS first calculates their locally optimal AP selection decision profile in coming time slot and then computes the overall QoS based on this decision profile. If the overall QoS is increased, save this WS to the contention set. Then for any WS in contention set, only one WS whose decision profile has the highest overall QoS wins the update opportunity and other WSs keep unchanged in this time slot. Then update the current decision profile with decision profile of this winner WS.

According to the Nash equilibrium existence theorem, our multi-user AP selection game is a finite player game, in which each WS can choose a pure strategy from a finite set of AP selection strategies, and thus it has a Nash equilibrium [10]. That is, after a finite number of time slots, the algorithm converges when no WS needs to update its AP selection decision profile, and the near-optimal decision profile for all the WSs are obtained [11]. The pseudo code is as follows:

Algorithm QoS-Guaranteed AP selection algorithm(QASA)

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Initialize: $\mathbb{N}$, $\mathbb{M}$, $B$, the distance from WS $i$ to AP $j$ $d_{i,j}$, $p_i$, path loss exponent $\gamma$, $\sigma$, $r_i$,
    $\overline{\mathbb{A}_i}$, the initial $A_i$ is the closest AP to WS $i$, the contention set $\mathbb{C} = \varnothing$;
for each iteration $\tau$
    for all WS $i$ do
        compute the local optimal AP selection decision profile of WS $i$ $(A_i^*, \mathbb{A}_{-i})$
        in next time slot $(\tau + 1)$;
        compute $\sum_{i=1}^{N}\sum_{j=1}^{M} Q_{i,j}\lambda_{i,j}(\tau+1)$ based on $(A_i^*, \mathbb{A}_{-i})$;
        if $\sum_{i=1}^{N}\sum_{j=1}^{M} Q_{i,j}\lambda_{i,j}(\tau+1) > \sum_{i=1}^{N}\sum_{j=1}^{M} Q_{i,j}\lambda_{i,j}(\tau)$ then
            save WS $i$ to $\mathbb{C}(\tau)$;
        end if
    end for
    while $\mathbb{C}(\tau) \neq \varnothing$ do
        each WS in $\mathbb{C}(\tau)$ contends and only one WS with the biggest $\sum_{i=1}^{N}\sum_{j=1}^{M} Q_{i,j}\lambda_{i,j}$
        wins update opportunity
        $A_{\text{winner}} = A_{\text{winner}}^*$
        update $A_{\text{winner}}$ in $\mathbb{A}$;
    end while
end for
return $\mathbb{A}$ and $\sum_{i=1}^{N}\sum_{j=1}^{M} Q_{i,j}\lambda_{i,j}$
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5 Simulation Results

In this section, the scenario includes M IEEE 802.11b APs randomly distributed in an area of 200 m × 200 m with a minimum distance of 20 meters between them, and N WSs randomly distributed in this area. The bandwidth of the wireless channel B is 20 MHz. The transmit power of the WS i p_i is 10 dBm. The Gaussian thermal noise σ is −55 dBm. We assume that the path loss follows that free-space model, and the path loss exponent γ is set to 3.5. The QoS requirement r_i is randomly generated from 3 to 7 Mbps.

In order to verify our proposed algorithm, we use the exhaustive algorithm as a benchmark for comparison, as shown in Fig. 3. In the exhaustive algorithm, it first checks all possible selection decision profiles of WSs, and then chooses a globally optimal selection decision profile with an overall maximum QoS. Because the exhaustive algorithm has a large amount of computation and is not suitable for the scenario of owing many WSs and APs. Therefore, the number of AP is set to 4, and the number of WSs $N = 1, 2, \ldots, 8$. It can be found that the overall QoS of our proposed QASA is very consistent with exhaustive algorithm results. The numerical results confirm that QASA can provide a near-optimal solution to our problem.

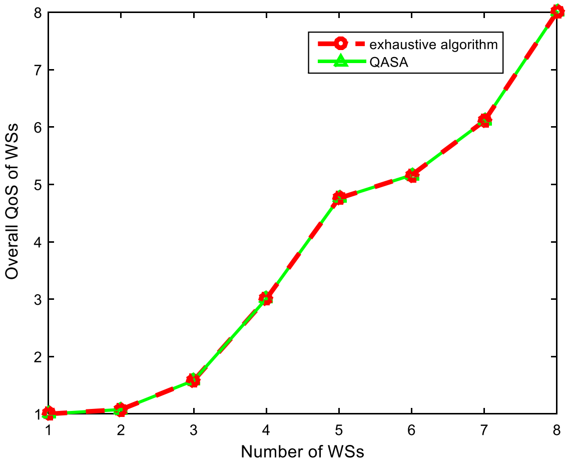

Fig. 3. Comparison between QASA and exhaustive algorithm

In addition, we present the convergence behavior of QASA under different WS numbers, which are $N = 30$, 50 respectively. The number of AP is set to 8. From Fig. 4, one can be seen that the overall QoS of WSs gradually increases as the number of iterations increases. After a finite number of iterations, the QASA converges to a certain value. In addition, when $N = 30$, the number of iteration to reach equilibrium is 22, and when $N = 50$, the number of iteration is 48. It indicates that the more WSs exist, the more iterations are needed.

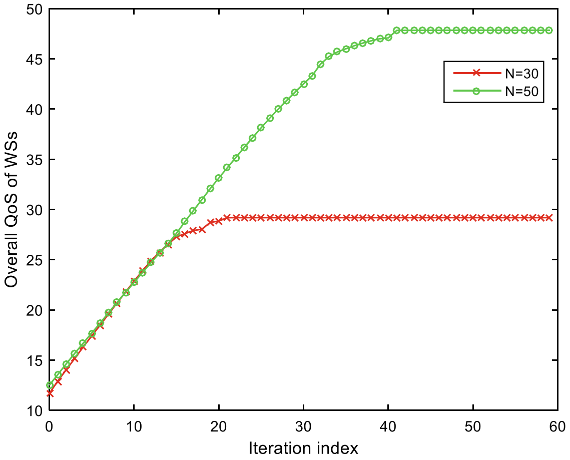

Fig. 4. Iteration comparison of QASA with different number of WSs

In order to verify the performance of our proposed QASA, we compare our QASA with the RSSI algorithm and the maximizing total network throughput algorithm (MTNT) [3]. At this simulation, the number of APs is set to 10. The comparison results are shown in Fig. 5. It can be seen from the simulation results that our QASA can increase the overall QoS by 160% and 10% compared to the RSSI algorithm and MTNT, when the number of WS is 50. In RSSI algorithm, all WSs make decisions alone, and might lead to bad performance and waste many resources. The MTNT does not consider the requirements of WSs and causes unfair distribution. Numerical result of Fig. 5 demonstrates our QASA has better flexibility and adaptability and can effectively improve the overall QoS of WSs.

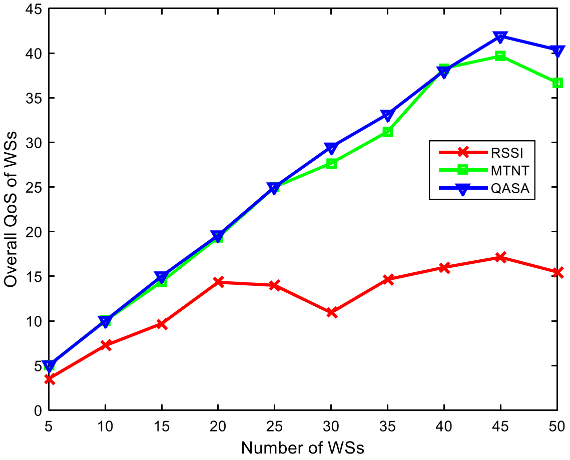

Fig. 5. Comparison results by adopting different AP selection algorithms

6 Conclusions

IEEE 802.11 WLAN is a popular connectivity method. It is important to select a suitable AP for every WS in this network. The actual situation is that every WS has different QoS requirements for the actual acquired throughput. For guaranteeing a fair distribution of the actual throughput according to the QoS requirement of WS, we propose a AP selection algorithm based on maximizing overall QoS criterion for multi-WSs and multi-APs WLAN, and utilize game theory to get the near-optimal AP selection decision. Simulations show that the QASA can effectively improve the overall QoS of WSs for the actual acquired throughput.

In the future work, we will pay attention to predict the movement of WSs and make decisions based on that. Moreover, we will investigate more metrics to define QoS, such as delay and jitter.

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