Joint Energy Detection and Transmission Power Adjustment for FIM Problem in High Density WLANs

Yujie Wang, Qi Yang, Mao Yang(✉), Zhongjiang Yan, and Bo Li

School of Electronics and Information, Northwestern Polytechnical University, Xi'an, China
wwangyujie@mail.nwpu.edu.cn, {yangqi,yangmao,zhjyan,libo.npu}@nwpu.edu.cn

Abstract. With the rapid development of mobile internet services, the intensive deployment of wireless local area network (WLAN) is inevitable. Traditional WLAN uses carrier sense/collision avoidance (CSMA/CA) mechanism to avoid interference between links as much as possible. In the multi access points (APs) scenario, the traditional CSMA/CA may lead to the flow in the middle (FIM) problem, resulting in a sharp reduction in the throughput of the intermediate nodes and affecting the fairness of the whole network. Existing researches have shown that the FIM problem is more serious in the high density WLAN network. The existing researches on the FIM problem mainly focus on the dynamic optimization of a single parameter, the fairness and performance of the network cannot be well guaranteed. Therefore, this paper proposes a FIM oriented down link (DL) multi-parameter joint dynamic control scheme. AP as a centralized controller, regularly obtains the transmission status of the whole network, reduces the transmission opportunities of the strong AP through adaptive dynamic power and energy detection threshold control (A-DPEC) algorithm, and improves the transmission opportunities of the starvation AP, so as to achieve the performance and fair balance of the whole network. The simulation results show that the proposed scheme outperforms the comparing schemes.

Keywords: Wireless Local Area Networks · CSMA/CA · FIM · Dynamic Control

1 Introduction

With the rapid development of mobile internet services, the intensive deployment of WLAN network [1] has become inevitable. The high density deployment scenario is the main scenario faced by the next generation WLAN [2], and the intensive deployment of network will inevitably produce a variety of conflicts and interference [3,4]. Therefore, how to improve and effectively solve the problems of conflicts and interference under the high density WLAN deployment scenario has become particularly important.

D.-J. Deng et al. (Eds.): SGIoT 2022, LNICST 497, pp. 200–213, 2023.
https://doi.org/10.1007/978-3-031-31275-5_20

In high density WLAN networks, the overlapping basic service set (OBSS) [5] areas formed by overlapping multiple APs have increased significantly. Unfair competition and conflicts among OBSS users may lead to a decline in network throughput [6], which directly affects the quality of service (QoS) of users [7]. Among them, FIM problem is a typical interference problem in high density WLAN networks. It is mainly because when the network is dense, some intermediate nodes lack transmission opportunities, resulting in insufficient throughput, while their neighbor nodes obtain higher throughput, which affects the fairness of the whole network. Therefore, the core research of this paper is to improve the interference caused by FIM problem, develop appropriate solutions to improve the fairness of high density WLAN network and ensure network performance.

For FIM problem, the existing researches have the following solutions: Yin et al. [8] and Shimizu et al. [9] take the game theory as the core to ensure that different APs use different channels for information transmission, so as to improve the fairness between nodes and alleviate the FIM problem. Stojanova et al. [10] combines Markov chain to conduct theoretical analysis and simulation verification on the FIM problem. Potti et al. [11] combines genetic algorithm and gravitational search algorithm to find the optimal solution to adjust the contention window(CW) to ensure throughput and improve fairness. Fitzgerald et al. [12] improves the fairness of the whole network by classifying MAC queues and adjusting CW. Jang et al. [13] and Masri et al. [14] adopts rate control method to reduce the rate of strong nodes, increase the rate of starvation nodes, and improve the transmission opportunities of starvation nodes to improve the FIM problem. The existing researches have shown that dynamic optimization of parameters through algorithms can significantly improve the throughput of starvation nodes in high density scenarios, but there are still two problems: 1) existing algorithms for FIM problem mainly focus on the dynamic optimization of a single parameter in the network, and do not fully guarantee the performance and fairness of the network. 2) few researches have considered the adaptive dynamic adjustment of parameters from the FIM problem.

Thus, this paper proposes a dynamic management and control scheme based on tranmission power control and ED threshold adjustment. Starting from the technical root causes, combined with multi-parameter dynamic adjustment, this scheme solves and improves the FIM problem. The core idea of this scheme is that each AP regularly collects its own information and summarizes it to the centralized controller. The centralized controller makes a decision through comprehensive judgment of FIM index, and adjusts the dynamic tranmission power and ED threshold of the corresponding AP. The simulation results show that changing the node power and ED threshold dynamically can effectively solve the unfair problem between users caused by FIM problem, and improve the throughput and fairness of the whole network.

The sections of this paper are arranged as follows: Sect. 1 introduces the research background, research content and section arrangement of this paper. Section 2 briefly analyzes the FIM problem from the technical root causes and introduces the current research status of the FIM problem in detail. Section 3 introduces the joint energy detection and transmission power adjustment scheme in detail. In the Sect. 4, the performance of the proposed scheme is analyzed. Section 5 summarizes this paper.

2 FIM Problem Analysis and Related Work

2.1 FIM Problem Analysis

The FIM problem is that in high Density WLAN networks, due to the different perceptions of intermediate nodes and neighbor nodes, neighbor nodes continuously send packets to suppress intermediate node packets, so that the current node lacks transmission opportunities, resulting in the current node starvation.

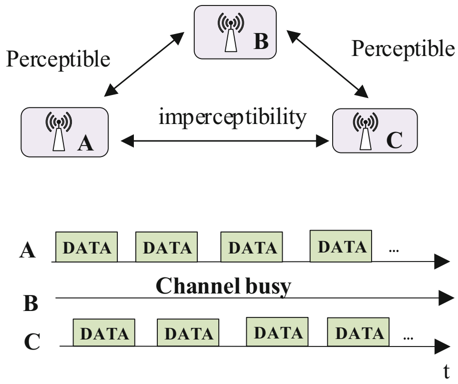


Fig. 1. FIM problem scenario

The specific scenario is shown in Fig. 1. Node A, node B and node C all use the same transmission power and clear channel assessment (CCA) threshold [15], in which node B, node A and node C can perceive, That is, the received signal strength indicator (RSSI) is greater than the ED threshold, but node A and node C cannot perceive it, that is, the RSSI is less than the CCA threshold, so node A and node C can simultaneously back off from the competitive channel to transmit data. However, for node B, if one of the neighboring nodes transmits data, node C will perceive that the channel is busy, It waits until the channel is idle. This situation causes node A and node C to preempt the channel with a high probability, and node B is difficult to preempt the channel, resulting in "starvation" of node B.

2.2 Related Work

At present, there have been many researches on FIM problem in the academic world. Figure 2 shows the existing researches structure of FIM. This section discusses the five aspects of Channel and Bandwidth selection, CW adjustment, Upper layer rate control, Power adjustment and CCA adjustment.

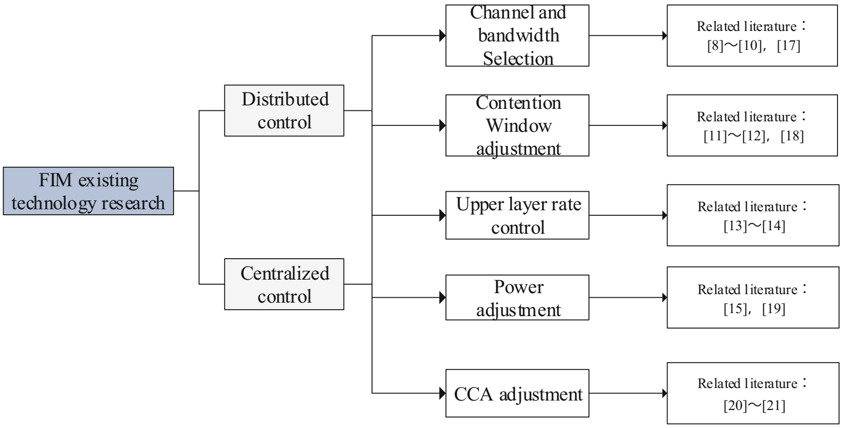


Fig. 2. Structure chart of existing technology research on FIM

(1) Channel and Bandwidth Selection
Yin et al. [8] proposes a distributed channel allocation scheme based on the idea of game theory, which mainly builds the system into a game model and uses spatial adaptive play (SAP) to find the Nash equilibrium point. In this scheme, each AP, as a decision-maker, randomly finds a channel, collects the working channels of two adjacent nodes, and randomly selects a user in each round. The selected users calculate their own benefits according to the benefit function, so as to update their channels based on the benefits. The newly updated channels make the "three-point interference unit" corresponding to the FIM problem as few as possible, so as to improve the FIM problem. Shimizu et al. [9] is still based on the idea of game theory. By designing an exact potential game (EPG), AP and STA as participants, collect channel conditions and CCA values, and calculate the gains. Participants adjust channel and spatial reuse capabilities according to the gains to alleviate node starvation. In the aspect of channel allocation, most of the existing researches are based on game theory to make decisions to obtain benefits and then optimize channel allocation. Stojanova et al. [10] proposed a Markov chain model to predict the throughput of each AP in WLAN according to the performance of the network topology of FIM problem and the throughput requirements of the AP. The model can be used for channel allocation. After the topology is given, it is concluded that large bandwidth is beneficial to throughput and small bandwidth is beneficial to fairness.

Xue et al. [17] allocates channels by setting thresholds and combining the queue conditions of nodes. It mainly calculates the weight according to the size of the queue and compares it with the set threshold. Only nodes higher than the threshold can be arranged for channels. When the queue length is reduced below the threshold, the algorithm ensures that the channel is switched in a very short time, so as to dynamically alleviate starvation nodes.

(2) CW Adjustment
Potti et al. [11] combines the hybrid genetic algorithm with the gravitational search algorithm (GSA) to adaptively adjust the CW. The population is generated through the GSA, multiple rounds of crossover, and continuous mutation to seek the optimal solution. The fitness function is determined according to the end-to-end delay. During CW adjustment, the best cwmin is selected for the node according to the fitness value of the fitness function. Fitzgerald et al. [12] divides MAC queues into control queue (CQ) and media access queue (MAQ). The main adjustment idea is that the longer the MAQ queue, the larger the CW, the shorter the MAQ queue, and the smaller the CW, so as to achieve the purpose of improving starvation nodes. Lim et al. [18] proposes a new detection technology for FIM problem, mainly through the physical energy detection mechanism implemented in WLAN to identify whether the node is in FIM state. If the node is in FIM state, it can intervene by adjusting CW within the set time to improve the channel access rate of starvation nodes.

(3) Upper Layer Rate Control
Jang et al. [13] classifies the states of a single STA, constructs a Markov model, obtains the steady-state probability, and calculates the throughput. On the basis of theoretical analysis, an upper layer rate control algorithm is proposed. The main idea is to set appropriate throughput threshold and rate threshold, reduce the speed of strong nodes through upper layer rate control, and increase the speed of starvation nodes, so as to improve the transmission opportunities of starvation nodes. Masri et al. [14] proposes an overhead free congestion control scheme (NICC), which generates no additional overhead so that nodes can inform each other of the congestion degree, and then the source node uses the enhanced additive increase multiplicative decrease (AIMD) algorithm to perform rate control. The rate control algorithm adjusts the congestion information received by the source node, The higher the degree of congestion, the greater the rate adjustment. However, the adjustment is not a blind adjustment, but is subject to the time limit set in NICC to avoid unnecessary rate adjustment, so as to alleviate FIM problem.

(4) Power Control
Mhatre et al. [15] proposed a power control algorithm based on Gibbs sampler. The core idea of the algorithm is to collect the throughput and CCA threshold values of each node, obtain the solution that minimizes the potential delay in combination with Gibbs sampler, and determine the optimal transmission power of each node. Akella et al. [19] analyzes the impact of

power adjustment on the network in detail, and adjusts each node according to the network state. If the node state is bad, it will increase the power, otherwise it will reduce the power, so as to eliminate the starvation nodes.

(5) CCA Adjustment
Li et al. [20] considers that in IEEE 802.11, when a node detects a sensing range (SR) frame on the medium, it will delay the transmission for a fixed duration, which is unfair to the node. To solve this problem, the reference proposes an enhanced carrier sensing scheme, which distinguishes based on the length of the SR frame and then carries out the corresponding delayed transmission. Zaheeruddin et al. [21] analyzes in detail the impact of CCA adjustment on network throughput. The literature proves that it is necessary to consider the MAC layer and CCA across layers to optimize the network.

The channel and bandwidth selection method can reasonably allocate the channel to some extent, but the convergence time in the game theory model is long, and the improvement effect is not obvious. The upper layer rate control method directly regulates the nodes by obtaining the network status. The control effect is obvious, but it is difficult to implement due to the design of cross layer processing. Starting from the access mechanism, the CW adjustment method can alleviate the problem of node starvation. However, due to the randomness of the selection of the CW, the effect is difficult to guarantee. The power adjustment method can improve the performance of starvation nodes, but a single power adjustment can not guarantee the performance of the whole network. For the FIM problem, there is only a single theoretical research on CCA adjustment at present, and no technical implementation has been carried out by scholars.

3 FIM Joint Multi-parameter Adjustment Scheme

This paper mainly studies the downlink FIM problem. The proposed A dynamic scheme of multi-parameter joint adjustment which is mainly divided into three parts, namely, Data statistics and collection stage, FIM problem Recognition stage and A-DPEC adjustment algorithm stage. The specific scheme is described as follows:

3.1 Data Statistics and Collection Stage

Each AP regularly statistics its own network status information and completes data collection. The set is represented by A, $A = \{t, \bar{T}, R_{rssi}\}$, which contains the channel contention time, average rate and RSSI of the previous time period. The channel contention time is expressed in t, and the calculation formula is as follows:

$$t = \frac{\sum_{j=1}^{N} t_j}{N} \tag{1}$$

where N is the total number of retreats of the current node. t_j is the duration of the j-th retreat.

The average rate is expressed as $\bar{T}$. The unit is Mbps and the calculation formula is as follows:

$$\bar{T} = \frac{rxbytes}{T_{period}} \tag{2}$$

where $rxbytes$ is the total number of bytes successfully received by the node, and T_{period} is the set time period.

After the collection, each AP is summarized to the centralized manager through the control frame. AP1, as the centralized manager, is responsible for data collection and calculation. The control frame designed in the scheme is modified based on the frame format proposed in IEEE 802.11ax draft. The specific frame structure is shown in Fig. 3. Data is filled in the user information of the control frame, in which the channel contention time accounts for 2 bits, the average rate accounts for 1 bit, and RSSI is filled according to the number of APs.

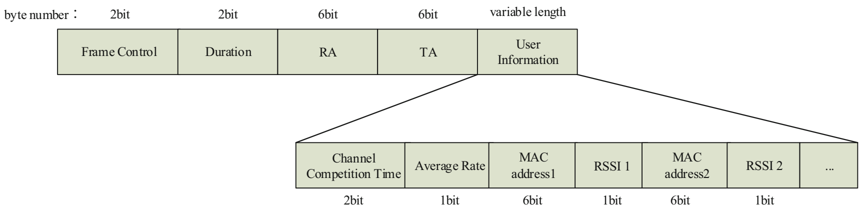


Fig. 3. Control Frame Structure

3.2 FIM Problem Recognition Stage

After obtaining the transmission information of APs. Using the average rate index and the improved Kuznets index to recognize the FIM problem nodes.

Based on the maximum average rate of the current node, $\bar{T_h}$ of 0.5 as the threshold, using $\bar{T_f}$ to represent, lower than $\bar{T_f}$ node, is judged as starvation node.

The Kuznets ratio is an index reflecting the overall income inequality. Combining RSSI and channel contention time, the improved recognitionn index formula of FIM problem based on Kuznets ratio is as follows:

$$R_i = \sum_{i=1}^{n} r_{ij} \left(t_i - t_j\right) \tag{3}$$

where i represents the i-th node. Where n represents the number of nodes.t_i and t_j are channel contention time for nodes i and j, r_{ij} Related factors for node i and node j. $r_{\mathrm{ij}} \in [0, 1]$. It represents whether the nodes need to compare. 0

represents no correlation between nodes, without comparison. 1 represents strong correlation between nodes, must be compared. r_{ij} defined as follows:

$$r_{ij} = \begin{cases} 0, R_{rssi} < C_{cca} \\ \frac{R_{rssi}+C_{cca}}{E_{ed}-C_{cca}}, C_{cca} \leq R_{rssi} \leq E_{ed} \\ 1, R_{rssi} > C_{cca} \end{cases} \tag{4}$$

where E_{ed} is the energy detection threshold, and C_{cca} is the carrier sensing threshold. Specific FIM recognition algorithm are as follows:

Algorithm 1. FIM Recognition Algorithm.

Input:

Average rate,$\bar{T_i}$;
Average rate threshold, $\bar{T_f}$;
The number of node, n;
Kuznets inex,R_i;
Minimum Kuznets index,R_l;

Output:

The states of node, n_i;

BEGIN
FOR each $i \in [1, n]$ DO
    IF ($\bar{T_i} < \bar{T_f}$) THEN
        IF ($\bar{R_i} - \bar{R_l} > \bar{R_t}$) THEN
            $n_i = 1$
        ELSE
            $n_i = 0$
        ENDIF
    ELSE
        $n_i = 0$
    ENDIF
ENDFOR
return n_i;

$\bar{R_t}$ is taken as the empirical value of 0.4. If the difference of the node is greater than $\bar{R_t}$, the node is considered to be a starvation node. Nodes meeting average rate index and Kuznets ratio index are determined as starvation nodes.

3.3 A-DPEC Adjustment Algorithm

Adaptive Dynamic Power and ED Control (A-DPEC) algorithm is based on the operation status of each AP to adaptively adjust the corresponding AP transmission power and ED threshold. T_p represents the original transmit power, E_d represents the original energy detection threshold. i represents the AP index. n_i represents the node state. If $n_i = 0$, it means that there is no FIM problem with node i. If $n_i = 1$, it means that there is FIM problem with node i. d is adjustment parameters, which value is 10.

Algorithm 2. A - DPEC Adjustment Algorithm.

Input:
The time of slot, t_i;
The time of simulation, t;
Output:
The Adjustment of power value, tp_c;
The Adjustment of Energy Detection Threshold , ed_c;

BEGIN
FOR $t = t_j, j = 1, 2...n_{slot}$ DO
  IF $n_i = 0$ THEN
    $ed_c = d \times abs(R_t - R_i)$
  the current node is saturated and the power Adjusted
    IF $tp_i > tp$ THEN
      $tp_i = tp$
  ELSE
    $tp_c = d \times abs(R_t - R_i)$
  the current node is starvation and the ED Adjusted
    IF $ed_i < ed$ THEN
      $ed_i = ed$
  ENDIF
ENDFOR
return ed_c, tp_c;
$ed_i -> ed_i - ed_c$ Update ED value
$tp_i -> tp_i + tp_c$ Update the power value

The specific steps of the algorithm are as follows:

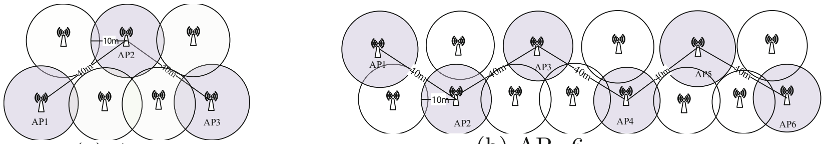
In the A-DPEC algorithm, it is proposed to adjust the parameter of starving nodes in the whole network according to the Kuznets index, which not only improves the throughput performance of nodes with high starving degree, but also ensures the throughput of other nodes. Because the algorithm is adjusted and improved according to the operation state of the whole network. In order to avoid the ED threshold and power of nodes that cannot be restored after adjustment, the check mechanism is added to the algorithm to ensure fairness.

4 Performance Evaluation

4.1 Simulation Scenario and Parameter Setting

In this paper, the protocol standard built on the basis of NS-3 [22,23] is used as the integrated system & link level simulation platformof [24,25] the next generation WLAN [22]. The cell radius is 10 m and STA nodes are randomly distributed. The specific scenario is shown in Fig. 4. Figure 4(a) is 3AP simulation scenario, and the distance between each AP and its neighbor AP is 40 m. Figure 4(b) shows the 6AP simulation scenario, and the circles with the same color are cells with the same frequency.

The simulation parameters are shown in Table 1.



(a) AP=3 (b) AP=6

Fig. 4. Simulation Scenario

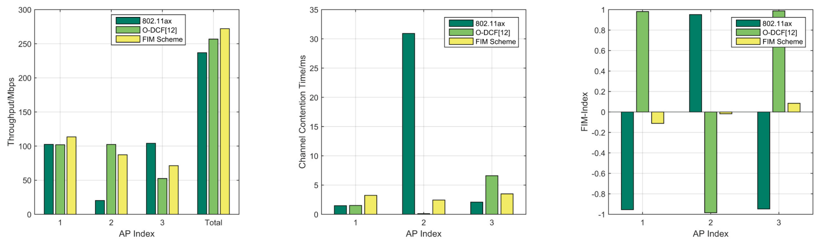
Table 1. Simulation Parameter.

Simulation Parameter	Parameter Setting
Tx Power	15 dBm
Channel bandwidth	40 MHz
RTS/CTS	open
SIFS	16us
DIFS	34us
Channel Position	36
Business Rate	1e8Mbps
Business Type	DL
MCS	9
Maximum frame aggregation length	65535
MPDU Frame Aggregation Number	21
NSS	2
CCA Threshold	–82 dBm
ED Threshold	–62 dBm

4.2 Simulation Results and Analysis

In this simulation, IEEE 802.11ax [2,20] and O-DCF scheme [12] of DL are used as comparison schemes respectively.

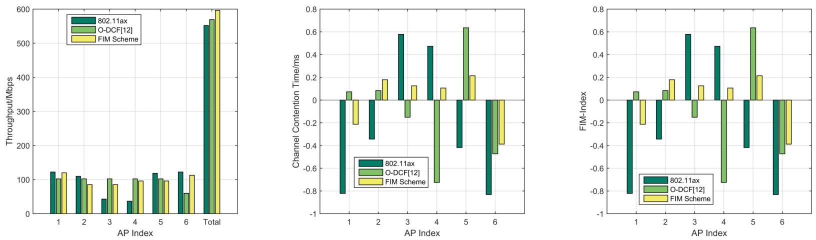
Figure 5 shows the performance comparison of 802.11ax, O-DCF scheme and FIM scheme when the number of AP is 3. When the number of AP is 3, the throughput of starvation AP is 405.23% higher than that of 802.11ax after using O-DCF scheme. The throughput of starvation AP is 330.65% higher than that of 802.11ax after using FIM scheme, and the total throughput of FIM scheme is 4.76% higher than that of O-DCF scheme. The channel contention time of starvation AP in O-DCF scheme is 250 times lower than that of 802.11 ax, and the channel contention time of starvation AP in FIM scheme is 2.8 times lower than that of 802.11 ax. The range of channel contention time of O-DCF scheme is 6.48, and the range of channel contention time of FIM scheme is 1.06. Compared with the fairness index of FIM, compared with 802.11ax and O-DCF, the gap of all node indexes of FIM scheme is smaller, and the whole network tends to be more equitable.



(a) Throughput (b) Contention Time (c) FIM-Index

Fig. 5. AP = 3 Performance comparison diagram

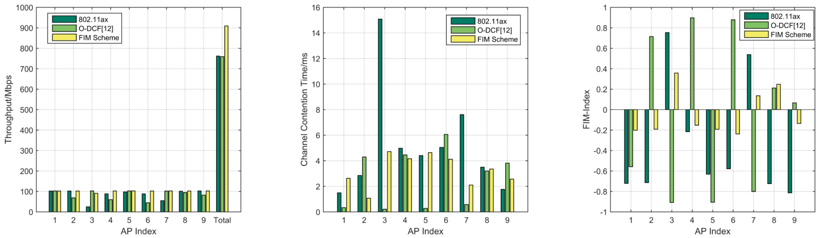
Figure 6 shows the performance comparison of 802.11ax, O-DCF scheme and FIM scheme when the AP number is 6. When the AP number is 6, the throughput of O-DCF scheme for starvation AP in 802.11ax increases by 178.9%, the throughput of FIM scheme for starvation AP increases by 162.3%, and the total throughput of FIM scheme increases by 5.9% compared with that of O-DCF scheme. The channel contention time of starvation AP in O-DCF scheme is 28 times lower than that of 802.11 ax, and the channel contention time of starvation AP in FIM scheme is 15 times lower than that of 802.11 ax. The range of channel contention time of O-DCF scheme is 4.56, and the range of channel contention time of FIM scheme is 2.59. Compared with the fairness index of FIM, compared with 802.11ax and O-DCF, the gap of all node indexes of FIM scheme is smaller, and the whole network tends to be more equitable.



(a) Throughput (b) Contention Time (c) FIM-Index

Fig. 6. AP = 6 Performance comparison diagram

Figure 7 shows the performance comparison of 802.11ax, O-DCF scheme and FIM scheme when the AP number is 9. When the AP number is 9, the throughput of O-DCF scheme increases by 314.12% compared with that of 802.11ax starvation AP, the throughput of FIM scheme increases by 268.72% compared with that of 802.11ax, the total throughput of FIM scheme increases by 19.73% compared with that of O-DCF scheme, and the total throughput of O-DCF scheme decreases by 0.35% compared with that of 802.11ax. Compared with the fairness index of FIM, compared with 802.11ax and O-DCF, the gap of all node indexes of FIM scheme is smaller, and the whole network tends to be more equitable. Compared with the channel contention time, O-DCF scheme can greatly reduce the waiting time of starvation AP in the channel and greatly improve the transmission probability of the node. Compared with the FIM scheme, the O-DCF scheme has a great effect on the performance improvement of starvation AP in FIM problem. The main reason is that the O-DCF scheme adopts the method of adjusting the CW to dynamically adjust the CW. The selection of the CW is random and the result is unstable. With the increase of the cell number, the O-DCF scheme is difficult to guarantee the whole network throughput performance.



(a) Throughput (b) Contention Time (c) FIM-Index

Fig. 7. AP = 9 Performance comparison diagram

Compared with the O-DCF scheme, the FIM scheme in this paper can not only improve the throughput of starvation AP, but also ensure that the performance of other AP in the whole network will not be greatly affected. The main reason is that the FIM dynamic control scheme continuously controls AP with a short time slot, and can flexibly adjust the access probability of AP to ensure the performance of the whole network.

5 Conclusion

In order to solve the problem of FIM in high density WLAN network and improve the fairness and performance of WLAN network, this paper proposes a scheme based on power control and ED threshold adjustment. By recognizing starvation nodes and other nodes, the ED threshold and transmission power of corresponding nodes are dynamically adjusted to weaken the ability of strong nodes and enhance the performance of weak nodes. Through simulation, it is found that the throughput of the FIM scheme is increased by 19.73% compared with that of the O-DCF scheme, and the throughput of the total throughput of the network is increased by 330.65% compared with that of the 802.11ax, which effectively improves the performance of the starvation nodes and ensures the fairness of the whole network. This design is simple and easy to implement, and has good application prospect and value in high density WLAN network.

Acknowledgement. This work was supported in part by the National Natural Science Foundations of CHINA (Grant No. 61871322, No. 61771392, and No. 61771390), and Science and Technology on Avionics Integration Laboratory and the Aeronautical Science Foundation of China (Grant No. 20185553035, and No. 201955053002).

References

1. López-Raventós, Á., Bellalta, B.: Concurrent decentralized channel allocation and access point selection using multi-armed bandits in multi BSS WLANs. Comput. Netw. (2020)
2. Qu, Q., Li, B., Yang, M., Yan, Z., Yang, A., Yu, J., et al.: Survey and Performance Evaluation of the Upcoming Next Generation WLAN Standard - IEEE 802.11ax (2018)
3. Yang, M., Li, B.: Survey and perspective on extremely high throughput (EHT) WLAN—IEEE 802.11be. Mob. Netw. Appl. **25**(2) (2020)
4. Barrachina-Munoz, S., Wilhelmi, F., Bellalta, B.: To overlap or not to overlap: enabling channel bonding in high-density WLANs. Comput. Netw. **152**, 40–53 (2018)
5. Yang, M., Li, B., Yan, Z., Yan, Y.: AP coordination and full-duplex enabled multi-band operation for the next generation WLAN: IEEE 802.11be (EHT). In: 2019 11th International Conference on Wireless Communications and Signal Processing (WCSP). IEEE (2019)
6. Zhong, Z., Kulkarni, P., Cao, F., Fan, Z., Armour, S.: Issues and challenges in dense WiFi networks. In: Wireless Communications & Mobile Computing Conference IEEE (2015)
7. Nj, M., Sahib, S., Suryana, N., Hussin, B.: RTS/CTS Framework Paradigm and WLAN Qos provisioning methods. Int. J. Adv. Comput. Sci. Appl. **8**(2) (2017)
8. Bo, Y., Kamiya, S., Yamamoto, K., Nishio, T., Abeysekera, H.: Starvation mitigation for dense WLANs through distributed channel selection: potential game approach. In: 2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC). IEEE (2017)
9. Shimizu, H., Yin, B., Yamamoto, K., Iwata, M., Abeysekera, H.: Joint channel selection and spatial reuse for starvation mitigation in IEEE 802.11ax WLANs. In: 2019 IEEE 90th Vehicular Technology Conference (VTC2019-Fall). IEEE (2019)
10. Stojanova, M., Begin, T., Busson, A.: A Markov model for performance evaluation of channel bonding in IEEE 802.11, p. 102449 (2021)
11. Potti, B., Subramanyam, M.V., Prasad, K.S.: Hybrid Genetic Optimization to Mitigate Starvation in Wireless Mesh Networks (2015)
12. Fitzgerald, E., Körner, U., Landfeldt, B.: An analytic model for throughput optimal distributed coordination function (TO-DCF). Telecommun. Syst. **66**(2), 197–215 (2017). https://doi.org/10.1007/s11235-017-0275-6
13. Jang, H., Yun, S.Y., Shin, J., Yi, Y.: Game theoretic perspective of optimal CSMA. IEEE Trans. Wirel. Commun. 1 (2018)
14. Masri, A.E., Sardouk, A., Khoukhi, L., Hafid, A., Gaiti, D.: Neighborhood-aware and overhead-free congestion control for IEEE 802.11 wireless mesh networks. Wirel. Commun. IEEE Trans. **13**(10), 5878–5892 (2014)
15. Mhatre, V.P., Papagiannaki, K., Baccelli, F.: Interference mitigation through power control in high density 802.11 WLANs. In: IEEE Infocom-IEEE International Conference on Computer Communications. IEEE (2007)

16. Iwai, K., Ohnuma, T., Shigeno, H., Tanaka, Y.: Improving of fairness by dynamic sensitivity control and transmission power control with access point cooperation in dense WLAN. In: 2019 16th IEEE Annual Consumer Communications & Networking Conference (CCNC). IEEE (2019)
17. Xue, D., Ekici, E.: On reducing delay and temporal starvation of queue-length-based CSMA algorithms. In: Communication, Control, and Computing (Allerton), 2012 50th Annual Allerton Conference on IEEE (2012)
18. Lim, Y.S., Choi, J., Kim, C.K.: Practical application of physical energy detection to recognize starvation in 802.11 wireless networks. In: 2009 International Conference on Information Networking IEEE (2009)
19. Akella, A., Judd, G., Seshan, S., Steenkiste, P.: Self-management in chaotic wireless deployments. Wirel. Netw. **13**(6), 737–755 (2007)
20. Li, Z., Nandi, S., Gupta, A.K.: Improving fairness in IEEE 802.11 using enhanced carrier sensing. IEE Proc. Commun. **151**(5), 467–472 (2004)
21. Mahajan, P.: Optimized handoff algorithm for heterogeneous networks. IETE Tech. Rev. **3** (2020)
22. Wilhelmi, F., Muoz, S.B., Cano, C., Selinis, I., Bellalta, B.: Spatial reuse in IEEE 802.11ax WLANs. Comput. Commun. **170**(1) (2021)
23. Lin, W., Bo, L., Mao, Y., Qiao, Q., Bo, Y.: Integrated link-system level simulation platform for the next generation WLAN - IEEE 802.11ax. In: Global Communications Conference IEEE (2017)
24. Zhang, K.: The Research and Simulation of Channel Modeling and Interference Abstraction for the Next Generation WLAN (2020)
25. Cai, X.W.: Research and Implementation of MAC Technology and Integrated Simulation Platform for the Next Generation WLAN (2020)