Wi-fi 7(IEEE 802.11be) For Next Generation Dense Wireless Network

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***Abstract*: Wi-Fi 7, introduced by the IEEE 802.11be standard, is intended to support high-speed and low-latency communication in crowded wireless networks. When a large number of linked devices at congested area, then wireless networks experience interference, traffic congestion, and delay. Wi-Fi 7 announces several new features to improve network performance. These features are Multi-Link Operation (MLO), Target Wake Time (TWT), and Dynamic Channel Puncturing. The above feature increase throughput, reduce latency and power consumption, and help the wireless network operate more efficiently. Traditional Wi-Fi networks mostly use rule-based method that do not adapt rapidly to dynamic traffic and interference fluctuations.**

This paper gives the idea about a unified ML framework that aims to improve network efficiency in dense Wi-Fi 7 scenarios. In my understanding, a machine learning-driven optimization framework enhances Wi-Fi 7 performance mainly because it can use MLO links at the same time and use TWT and the dynamic channel puncturing feature. These features also improve the parameter of ML-based Wi-Fi 7.

***Index Terms*- Wi-Fi 7 (IEEE 802.11be), Machine Learning, Multi-Link Operation (MLO), Target Wake Time (TWT), Dynamic Channel Puncturing.**

I. Introduction

A. Background

The demand for wireless devices is increasing day by day, and users need high-speed internet with low delay [29]. Crowded places where multiple users need strong and reliable connectivity [1]. Wi-Fi 7 uses techniques such as channel puncturing, TWT, and MLO to help reduce traffic jam in network, increase speed, and improve efficiency [8] [9] [14] [15]. But in rule-based Wi-Fi 7, faces problem, like interference and heavy traffic, still exist [4]. ML methods can help improve network performance in a heavy network.

B. Motivation

In crowded places where multiple users work together, Wi-Fi networks face problems such as slow speed, delay, interference, and high energy use [3] [4]. The IEEE 802.11be introduces new features like MLO, TWT, and dynamic channel puncturing to improve performance and overcome the problem, but fixed methods cannot adjust well and cannot make better decisions when network conditions change [6] [23]. So, this study focuses on using machine learning (ML) to improve Wi-Fi 7 performance in dense network.

C. Contributions

We works on rule-based Wi-Fi 7, and analyzes the problems that are faced in recent Wi-Fi 7, and compares different methods used to best link selection reduce delay, and save energy. Also work on how ML-based Wi-Fi 7 overcomes the problem. This study we also find out the research gaps, groups existing methods, and suggests ideas for future improvements.

II. Literature Survey

A. Overview of Wi-Fi 7 Technologies

Wi-Fi 7 uses powerful features such as MLO, TWT, and dynamic channel puncturing; these features also increase speed and reduce delay [14] [24]. But problems like interference and resource management still remain [4] [11]. This study gives ideas about machine learning that overcome the problems of rule-based Wi-Fi 7[28] [33]. In this study we integrate the feature of Wi-Fi 7 with ML that will improve the performance of Wi-Fi 7

B. Multi-Link Operation (MLO) Optimization

We study this work in MLO which uses multiple bands that is 2.4, 5, and 6 GHz at the same time, which increases its speed and decrease delay [1] [31]. But in a crowded network, fixed link selection does not work well [20] [23]. It suggests that using reinforcement learning choose better links selection that improve the performance of wi-fi7.

C. Predictive Target Wake Time (TWT) Scheduling

In this study we analyze that fixed rule-based Wi-Fi 7 use of TWT helps devices decide when to sleep and wake up, saving energy [7] [6]. But in the case of dense networks, fixed timing can cause traffic problems [11]. In this study we suggest that if we use a GRU model to predict network traffic, setting better wake-up times will also improve the performance of Wi-Fi 7[5] [26]

D. Intelligent Dynamic Channel Puncturing

Rule-based wi-fi7 use feature Dynamic Channel Puncturing that helps devices to choose only the clean parts of a channel without interference [4] [22]. Rule based methods react late because they use fixed limits [33]. This study compared the rule-based techniques with machine learning approaches that can understand the changing network condition and take a decision smartly [10] [28] In this ML based approaches reduce the interference and increase the efficiency

E. ML-Based Unified Framework

This paper suggests one combined ML system for IEEE 802.11be. In this, reinforcement learning improves MLO, which helps to choose better link selection; GRU improves TWT; and ML chooses the best channels, which enhance the ML-based Wi-Fi 7 performance [2] [5] [19]

III. Classification of Existing Works

Classification Based on Technique

1. Rule-Based Methods: We study that this rule-based Wi-Fi 7 use static rules such as set link selection and fixed TWT timing. They are easy but cannot handle changing conditions and cannot work properly in crowded network [23] [6] [20].

2. Optimization-Based Techniques: In this study, we see that existing work on optimization-based methods uses mathematical formulas to improve performance. This method is more complex. This method is also slow for real-time use [3] [21].

3. Machine Learning Methods: We analyze ML methods learn from data and adjust automatically. This method is the advancement of pervious methods. They work better in changing conditions in a crowded environment but need more processing power [25] [29]

Classification Based on methods;

1. Threshold-Based Method: Threshold-based method decisions are complete using static limits. This is a simple rule-based method that takes decisions from predefined limits, for example, shifting channels when interference is high [4].

2. Mathematical Methods: According to the previous study we understand that the Mathematical methods form math-based representations of the Wi-Fi 7 system [3] and this method empoys equations to increase speed and reduce interference. This method is more accurate but requires more calculation, and this thing makes this method complex. [12].

3. Deep Learning Methods: Deep learning methods use advanced models to predict network behavior and improve the performance of Wi-Fi 7 in heavy traffic of networks [5] [27].

4. Reinforcement Learning Method: In this study we analyze that the reinforcement learning method learns from environment conditions and improves its feature over time. They are helpful for batter link selection and managing resources in busy traffic network [2] [30] [17].

Classification Based on Application

1. Adaptive MLO: We investigate how ML-based wi-fi7 helps to automatically select the optimum link instead of using preset rules, enhancing performance and minimizing delay in congested networks [2] [21].

2. Predictive TWT: ML predicts future activity that schedules sleep and wake times, saving energy. It is also reduced network congestion. [26] [6].

3. Dynamic Channel Puncturing: We understand in this study that ML helps to detect interference patterns and select better channels. Dynamic channel puncturing selects a clean sub-channel automatically. This is to improve throughput and efficient spectrum use. [18] [4] [32].

4. AI-Based Resource Management:

Combines intelligent systems using ML methods that are used to manage bandwidth allocation, user scheduling, and power control. In simple words, ML models become Wi-Fi 7 more intelligent. This method takes better decisions than a fixed rule-based method [11] [17].

IV. Comparative Analysis

Authors and Year	Major Contributions	Identified Limitations	Research Gap
Chen et al. (2023) [5]	Studied spectrum utilization techniques for IEEE 802.11be networks	Mostly theoretical evaluation without intelligent adaptation	Need for AI-based spectrum management framework for Wi-Fi 7 in dense networks
Zhang et al. (2023) [30]	Proposed channel allocation methods for high-density wireless environments	Used heuristic and static allocation strategies	Lack of ML-driven adaptive channel allocation for Wi-Fi 7 networks
Kim et al. (2023) [13]	Analyzed latency reduction techniques in next-generation WLAN systems	Focused on protocol improvements without predictive models	Need for AI-based latency-aware traffic management in Wi-Fi 7
Li et al. (2023) [15]	Evaluated high-capacity transmission capabilities of IEEE 802.11be	Limited intelligent resource scheduling mechanisms	Need for ML-based resource scheduling framework for Wi-Fi 7
Singh et al. (2023) [23]	Investigated congestion problems in crowded wireless networks	Limited predictive analysis of traffic behavior	Need for AI-based congestion prediction and management in Wi-Fi 7 environments
Ahmed et al. (2023) [1]	Studied network reliability in dense WLAN deployments	Mainly simulation-based performance evaluation	Need for intelligent reliability-aware AI models for Wi-Fi 7 networks
Gupta et al. (2023) [8]	Analyzed techniques to improve network throughput	Throughput optimization studied separately from other metrics	Need for AI models that jointly manage latency, bandwidth, and reliability in Wi-Fi 7
Brown et al. (2023) [4]	Studied traffic prioritization strategies in dense wireless systems	Lack of adaptive and intelligent prioritization mechanisms	Need for AI-based dynamic traffic prioritization in Wi-Fi 7
Patel et al. (2024) [19]	Investigated multi-band communication advantages in Wi-Fi 7	Limited adaptive traffic distribution across multiple bands	Need for ML-based multi-band traffic balancing in Wi-Fi 7 networks
Rodriguez et al. (2024) [21]	Studied interference mitigation techniques in dense WLANs	Reactive interference control methods used	Need for proactive AI-based interference prediction for Wi-Fi 7
Hassan et al. (2024) [9]	Explored energy-efficient communication in dense WLAN environments	Energy management considered independently	Need for integrated AI-based energy and traffic management framework
Park et al. (2024) [18]	Proposed improved scheduling mechanisms for next-generation WLANs	No adaptive learning-based scheduling models	Need for reinforcement learning-based scheduling in Wi-Fi 7 networks
Lopez et al. (2024) [16]	Investigated multi-user communication strategies in Wi-Fi 7	Limited coordination among multiple users	Need for AI-based multi-user coordination and access control
Tanaka et al. (2024) [25]	Studied channel utilization efficiency in Wi-Fi 7 systems	Static optimization methods applied	Need for intelligent AI-based channel utilization techniques
Kumar et al. (2024) [14]	Investigated scalable network management solutions for WLANs	Lack of unified intelligent control framework	Need for a unified AI-based framework for managing multiple Wi-Fi 7 features in dense networks

Table 1 Comparative Analysis of recent wi-fi

V. OPEN CHALLENGES AND FUTURE DIRECTIONS

In IEEE 802.11be networks, it is hard to handle changing interference and heavy traffic in crowded places. It is also difficult to manage MLO, TWT, and channel puncturing together. Machine learning can help, but it needs high processing power.

Future Directions: In this study we understand that in the future, we should design simple and lightweight ML models that use less power. This ML-based wi-fi 7 overcomes the performance issues that are occurring in traditional wi-fi 7. This method works smartly in crowded network.

VI. CONCLUSION

This paper explains different methods to improve IEEE 802.11be in crowded areas. In this study we compare rule-based methods and machine learning methods for features such as MLO, TWT, and channel puncturing and this comparation shows that rule-based methods work using a fixed method, while ML methods work by learning from data and past network behavior. We understand from this study, Machine learning-based intelligent control systems give better performance than rule-based methods.

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REFERENCES

[1] Ahmed, S., Khan, M., and Ali, R., "Network reliability in dense WLAN deployments," *IEEE Access*, vol. 11, pp. 45678–45690, 2023.
[2] Bellalta, B., "IEEE 802.11ax: High-efficiency WLANs," *IEEE Wireless Communications*, vol. 23, no. 1, pp. 38–46, 2016.
[3] Bianchi, G., "Performance analysis of the IEEE 802.11 distributed coordination function," *IEEE Journal on Selected Areas in Communications*, vol. 18, no. 3, pp. 535–547, 2000.
[4] Brown, T., Wilson, J., and Clark, P., "Traffic prioritization in dense wireless systems," *IEEE Transactions on Wireless Communications*, vol. 22, no. 5, pp. 3456–3468, 2023.
[5] Chen, L., Zhang, Y., and Xu, H., "Spectrum utilization techniques for IEEE 802.11be networks," *IEEE Communications Magazine*, vol. 61, no. 6, pp. 72–78, 2023.
[6] Cisco Systems, "Cisco Annual Internet Report (2018–2023)," *Cisco White Paper*, 2020.
[7] Duffy, K., O'Connor, D., and Murphy, S., "Performance analysis of Multi-Link Operation (MLO) in IEEE 802.11be networks," *IEEE Transactions on Network and Service Management*, vol. 20, no. 3, pp. 2101–2115, 2023.
[8] Gupta, R., Sharma, V., and Mehta, A., "Improving network throughput in dense WLANs," *IEEE Systems Journal*, vol. 17, no. 4, pp. 5890–5901, 2023.
[9] Hassan, M., Ibrahim, A., and Saleh, K., "Energy-efficient communication in dense WLAN environments," *IEEE Internet of Things Journal*, vol. 11, no. 2, pp. 1450–1462, 2024.
[10] IEEE Standard Association, "IEEE Std 802.11be™-2024: Enhancements for Extremely High Throughput (EHT)," *IEEE*, 2024.
[11] Jiang, W., and Mao, S., "Deep reinforcement learning for resource allocation in wireless networks," *IEEE Network*, vol. 33, no. 4, pp. 44–51, 2019.
[12] Kim, B., Park, S., and Park, H., "Data Division Transmission Method with Performance Analysis in Wi-Fi 7 Multi-Link Operation," *IEICE Transactions on Communications*, vol. E107-B, no. 2, pp. 1–10, 2024.
[13] Kim, J., Lee, S., and Park, H., "Latency reduction techniques in next-generation WLAN systems," *IEEE Transactions on Mobile Computing*, vol. 22, no. 7, pp. 4123–4135, 2023.
[14] Kumar, P., Singh, R., and Verma, N., "Scalable network management solutions for WLANs," *IEEE Access*, vol. 12, pp. 22345–22360, 2024.
[15] Li, X., Wang, Q., and Chen, Z., "High-capacity transmission in IEEE 802.11be," *IEEE Wireless Communications Letters*, vol. 12, no. 4, pp. 678–682, 2023.
[16] Lopez, D., Garcia, M., and Torres, J., "Multi-user communication strategies in Wi-Fi 7," *IEEE Communications Letters*, vol. 28, no. 3, pp. 512–516, 2024.
[17] Mao, S., and Nebel, J., "Machine learning for wireless communications: A survey," *IEEE Communications Surveys & Tutorials*, vol. 22, no. 4, pp. 3032–3061, 2020.
[18] Park, S., Choi, Y., and Kim, D., "Scheduling mechanisms for next-generation WLANs," *IEEE Transactions on Vehicular Technology*, vol. 73, no. 1, pp. 890–902, 2024.
[19] Patel, A., Shah, K., and Desai, R., "Multi-band communication in Wi-Fi 7 networks," *IEEE Access*, vol. 12, pp. 33456–33470, 2024.
[20] Qiao, D., Choi, S., and Shin, K. G., "Goodput analysis and link adaptation for IEEE 802.11a wireless LANs," *IEEE Transactions on Mobile Computing*, vol. 1, no. 4, pp. 278–292, 2002.
[21] Rodriguez, J., Martinez, L., and Perez, F., "Interference mitigation in dense WLANs," *IEEE Transactions on Communications*, vol. 72, no. 2, pp. 998–1010, 2024.
[22] Saad, W., Bennis, M., and Chen, M., "A vision of 6G wireless systems," *IEEE Network*, vol. 34, no. 3, pp. 134–142, 2020.
[23] Singh, A., Kaur, P., and Singh, G., "Congestion problems in dense wireless networks," *IEEE Access*, vol. 11, pp. 56789–56802, 2023.
[24] Sun, Y., Peng, M., Zhou, Y., Huang, Y., and Mao, S., "Application of machine learning in wireless networks," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 4, pp. 3072–3108, 2019.

[25] Tanaka, Y., Suzuki, T., and Yamamoto, K., "Channel utilization efficiency in Wi-Fi 7 systems," *IEEE Transactions on Wireless Communications*, vol. 23, no. 2, pp. 1345–1357, 2024.
[26] Wang, C., Zhang, H., and Li, Y., "AI-based optimization for next-generation WLANs," *IEEE Access*, vol. 10, pp. 112233–112245, 2022.
[27] Xiao, Y., "IEEE 802.11 performance enhancements and limitations," *IEEE Network*, vol. 18, no. 6, pp. 14–20, 2004.
[28] Xu, X., and Saad, W., "Reinforcement learning in wireless networks," *IEEE Wireless Communications*, vol. 25, no. 6, pp. 44–51, 2018.
[29] Yang, P., Cao, Z., and Liu, X., "Interference-aware resource allocation in dense wireless networks," *IEEE Transactions on Communications*, vol. 68, no. 3, pp. 1796–1808, 2020.
[30] Zhang, H., Liu, X., and Zhao, W., "Channel allocation methods in high-density wireless environments," *IEEE Transactions on Network Science and Engineering*, vol. 10, no. 4, pp. 2765–2778, 2023.
[31] Zhang, J., and Letaief, K. B., "Multi-link operation in next-generation WLANs," *IEEE Wireless Communications*, vol. 30, no. 1, pp. 12–19, 2023.
[32] Zhao, N., Chen, Y., and Ding, Z., "Deep learning in wireless communications," *IEEE Wireless Communications*, vol. 26, no. 2, pp. 93–99, 2019.
[33] Zhou, Z., Chen, X., Li, E., Zeng, L., Luo, K., and Zhang, J., "Edge intelligence for IoT," *Proceedings of the IEEE*, vol. 107, no. 8, pp. 1738–1762, 2019.