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Wireless Fidelity (Wi-Fi) Traffic Analysis: A Systematic Review

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ABSTRACT

In the era of pervasive connectivity, Wireless Fidelity networks have become essential to modern communication systems, facilitating seamless wireless internet access and data transmission across miscellaneous devices. As the adoption of Wireless Fidelity technology continues, the complexity of monitoring and optimizing these networks also increases. This systematic review aims to enhance the existing knowledge on Wireless Fidelity traffic analysis tools by conducting a rigorous assessment of current tools, their functionalities, and areas of expertise. The study adopts the pre-recording systematic reviews and meta-analysis method and a total of thirty-three articles were carefully extracted and analyzed using the chosen search technique. These articles were classified into two main categories: machine learning techniques and other techniques. The outcomes of the review can be divided into distinct parts. Firstly, between 2018 and 2022, there were no studies conducted in Malaysia regarding Wireless Fidelity traffic analysis tools. Secondly, machine learning techniques were found to be particularly effective in extracting valuable insights related to user preferences, content consumption habits, and prevailing service usage trends. As a result, the future work should focus on proposing a new model for an intelligent Wi-Fi traffic analysis tool based on machine learning techniques, to be implemented and validated in real environments.

1. Introduction

Wireless Fidelity (Wi-Fi) networks have evolved into the core of contemporary communication systems in the age of pervasive connectivity, providing smooth wireless access to the internet and enabling data transmission across a wide range of devices. The complexity of monitoring and optimizing these networks rises along with the continued use of Wi-Fi technology. Researchers and network managers have created a wide variety of Wi-Fi traffic analysis tools to solve the issues brought on by the growing volume of Wi-Fi traffic [1]. The Wireless Fidelity (Wi-Fi), which offers ubiquitous and practical wireless access in a variety of locations including homes, offices, and public areas, has evolved into a crucial part of our contemporary technology landscape. Data traffic passing through Wi-Fi networks has increased as a result of their growing use and importance. As a result,

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studying Wi-Fi traffic has become an important topic of research, providing information on user behavior, network performance, and security flaws [1].

The Wi-Fi traffic analysis tools serve as critical instruments for understanding the dynamics of data flows within wireless networks. These tools employ various techniques, such as packet capturing, protocol analysis, and data visualization, to monitor and dissect the Wi-Fi traffic patterns. By capturing and analyzing the network packets in real-time, these tools offer valuable insights into network performance, bandwidth utilization, and Quality of Service (QoS) metrics, enabling efficient network management and optimization [2]. Moreover, the Wi-Fi traffic analysis tools have proven instrumental in understanding user behavior and usage patterns. By analyzing traffic data, these tools can extract valuable information on user preferences, content consumption habits, and service usage trends. This knowledge is invaluable for service providers and businesses seeking to enhance user experience, tailor services, and optimize content delivery [3].

Despite the numerous advantages provided by Wi-Fi traffic analysis technologies, difficulties still exist in their efficient deployment and use. Wi-Fi protocols and technology are rapidly changing, creating a constant need for tool compatibility and adaption. Additionally, the prevalence of encrypted traffic creates major barriers to thorough traffic analysis, necessitating creative approaches and solutions to deal with these encryption problems [4].

The research gap in the context of Wi-Fi traffic analysis tools lies in the need for innovative solutions to ensure their ongoing compatibility and effectiveness amidst the rapid evolution of Wi-Fi technology and protocols. Simultaneously, the challenge of decrypting and analyzing encrypted traffic represents a critical research problem, demanding creative approaches that allow for meaningful insights to be gleaned while respecting privacy and security concerns. These research gaps and problems collectively underscore the imperative to enhance Wi-Fi traffic analysis tools for improved adaptability and the ability to address the complexities posed by encryption, ultimately enabling the provision of crucial insights into network performance, user behavior, and content delivery optimization.

Hence, this systematic review aims to contribute to the body of knowledge surrounding the Wi-Fi traffic analysis tools by conducting a meticulous assessment of existing tools, their functionalities, and the areas they excel in. By identifying strengths and limitations, as well as potential gaps in the current toolset, this review seeks to inform researchers, practitioners, and network administrators about the state-of-the-art in the Wi-Fi traffic analysis tools. Ultimately, the insights gleaned from this review can guide future research efforts, foster advancements in the field, and enhance the efficiency and efficacy of the Wi-Fi traffic analysis in both academic and practical domains.

The rest of the paper is structured as follows. Section 2 discuss the analysis of Wireless Fidelity (Wi-Fi) traffic using machine learning. Section 3 presents detail methodology of this work. Section 4 elaborates the findings before Section 5 concludes the study and includes recommendations for further work.

2. Wireless Fidelity (Wi-Fi) Traffic Analysis using Machine Learning

Wireless Fidelity (Wi-Fi) traffic analysis using machine learning involves applying Artificial Intelligent techniques to analyze data traffic in Wi-Fi networks. This approach helps in understanding network behavior, optimizing performance, and enhancing security. Machine learning algorithms can detect patterns and anomalies in network traffic, predict bandwidth needs, and identify potential security breaches. By processing vast amounts of network data, these algorithms provide insights for better network management, improve user experience by optimizing traffic flow, and enable proactive security measures to protect against cyber threats. The use of machine learning in Wi-Fi traffic analysis represents a significant advancement in managing and securing wireless networks.

There have been several notable recent developments in this field. For example, a study in [5] presents DeepWiTraffic, a cutting-edge Traffic Monitoring System (TMS). This system uses just two Wi-Fi transceivers to function, and it is affordable, portable, and non-intrusive. It performs vehicle detection and classification by leveraging the unique Wi-Fi Channel State Information (CSI) of passing cars. Using machine learning, DeepWiTraffic analyses CSI amplitude and phase data for spatial and temporal connections, classifying cars into five different categories. DeepWiTraffic's effectiveness is validated by a sizable corpus of CSI data, which is supported by ground-truth video data from a two-lane rural roadway. DeepWiTraffic boasts an excellent 99.4% detection accuracy and 91.1% classification accuracy, outperforming many modern non-intrusive TMSs (IEEE).

Another significant study [6], delves into network traffic analysis, with a focus on anomaly and attack detection. This research underscores the challenges in mathematical modeling due to the diversity of traffic patterns and the intricate nature of network attacks. The study counters these challenges using data-driven modeling and computational intelligence. It employs graph-based modeling, utilizing the Granular Computing Approach for Labelled Graphs (GRALG) approach, which leverages feature information granulation and genetic optimization. This approach enables the classifier to recognize complex network traffic patterns and anomalies effectively, achieving notable performance in both accuracy and complexity.

In conclusion, machine learning in Wi-Fi traffic analysis signifies a major leap towards smarter, more secure, and efficient wireless networks. These evolving techniques are essential for tackling the increasing complexity and demands in wireless communication systems, leading to more effective and user-centric network management solutions.

3. Methodology

The key goal of this research is to examine and thoroughly explore Wi-Fi traffic analysis in two approaches: (1) machine learning techniques and (2) other techniques. The section that follows evaluates and synthesizes scientific literature in order to identify, choose, and evaluate the importance of Wi-Fi traffic analysis studies. Lastly, this research will recommend future works that related to the abovementioned problems in this article. Finally, this research will offer further study as a solution to the problems that are recognized in this article. In this study, a systematic literature review is conducted using the pre-recording systematic reviews and meta-analysis (PRISMA) method [7]. Identification, screening, eligibility, and data abstraction are the four main sub-sections that are discussed.

3.1 Identification

There are three stages involve in this systematic that were used to choose many relevant papers related to this study. The first phase involved identifying the keywords by looking for related, linked relationships using thesaurus, dictionaries, encyclopedias, and previous research. Following the selection of all pertinent keywords, search strings were developed for the databases Scopus and Mendeley (see Table 1). The current study project was able to successfully obtain 96 articles from the selected databases.

Table 1
The search strings

Scopus	TITLE-ABS-KEY ("wireless fidelity" AND traffic AND analys*) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022)) AND (LIMIT-TO (SRCTYPE , "j"))
Mendeley	"wireless fidelity" AND traffic AND analys*

3.2 Screening

Duplicate papers were removed from consideration during the initial screening. The research's first step resulted in the rejection of 51 publications, while the study's second stage used the experts' diverse inclusion and exclusion criteria to screen 7 publications. It was the first criterion applied because literatures; research articles and conference proceedings were the primary source of this research and there were several other were omitted from the most recent research. The publications were also restricted to works published in English and was created with the last two years from year 2018 to 2022.

3.3 Eligibility

A comprehensive set of 38 articles was compiled for the third step, known as eligibility assessment. During this phase, thorough scrutiny was applied to the titles and key content of each article to ascertain their alignment with the inclusion criteria and relevance to the objectives of the current study. After this rigorous evaluation, five publications were excluded from consideration due to their lack of adherence to pure scientific principles and insufficient support from empirical data. Ultimately, a total of 33 selected items were included for the subsequent review, as shown in Table 2.

Table 2
The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2022 - 2018	< 2018
Literature type	Journal (only research articles)	Journal (book chapter)
Publication stage	Final	In Press

3.4 Data Abstraction and Analysis

To investigate and synthesize various research methodologies (quantitative, qualitative, and mixed methods) in this study, the evaluation approach encompassed a comprehensive analysis. Identification of pertinent subjects and subtopics was the aim of the expert study. The theme's development began with the data gathering phase. As displayed in Figure 1, 33 articles were carefully examined for pertinent to the subjects of the present investigation. The impact of the Wi-Fi traffic analysis was then evaluated by the authors as they established and identified key groupings in the second stage.

The two main areas that resulted from the process were machine learning techniques and other techniques. After that, the authors continued each established subject and any further themes, conceptions, or ideas. Throughout the data analysis process, a detailed log was maintained to record various analyses, opinions, enigmas, and pertinent thoughts related to interpreting the data. The authors then scrutinized the results to identify any inconsistencies in the theme development process. Finally, the derived themes were refined to ensure their coherence and uniformity.

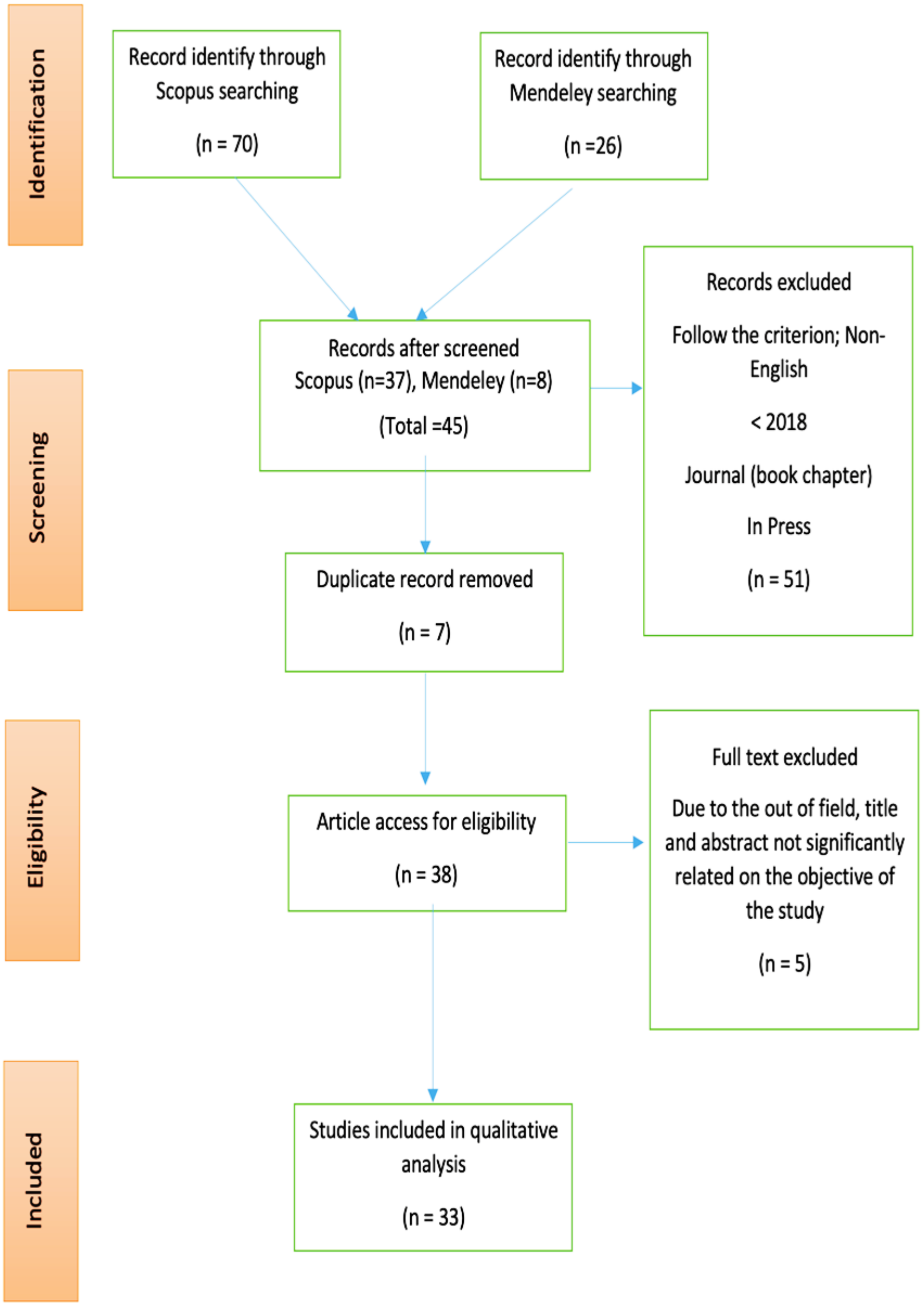

Fig. 1. Flow diagram of the proposed searching study

4. Results

Wi-Fi traffic analysis tools have demonstrated their significance in comprehending user behavior and usage patterns. Through meticulous examination of traffic data, these tools possess the capability to extract valuable information pertaining to user preferences, content consumption habits, and prevailing trends in service usage. Using the designated search technique, a total of thirty-three articles were retrieved and subjected to analysis. This section has studied different variants of the techniques involve in developing and designing Wi-Fi traffic analysis tools and consequently, the techniques can be characterized into two main categories namely machine learning techniques and alternative techniques as shown in Table 3 and Table 4.

Table 3
Summary of machine learning techniques

No.	Reference	Methodology	Results
1	[3]	An algorithm using fuzzy logic technique.	The proposed algorithm showed competent to be used in this environment.
2	[4]	A method to classify attacks on Wi-Fi utilizing Convolutional Neural Network model.	99.73% of F1 score. 0.24% of false positive rate.
3	[8]	A model applying two learning patterns.	62.4% of average throughput that was better than previous algorithm.
4	[9]	A framework implementing marked Poisson point process (MPPP) and Markov chain model.	The proposed framework showed competent to be used in this setting.
5	[10]	A model that employing Graph-based Temporal Convolutional Network (GTCN) technique.	The model exhibited increase of 3.2 to 10.2 percent.
6	[11]	A method that executing in real-time integrating semi supervised Possibilistic Fuzzy C-Means clustering algorithm.	The proposed method could provide accurate and real-time information.
7	[12]	An approach incorporating of machine learning algorithms in identifying and analyzing cellular providers.	0.75 of F1 score. 0.84 of AUC-ROC.
8	[13]	A novel four state semi-Markov model.	Almost 4% increase in power savings. 58% of decrease in resource usage.
9	[14]	A traffic monitoring system using a machine learning technique.	99.4% of average detection accuracy. 91.1% of average classification accuracy.
10	[15]	A Graph-based modeling.	The proposed model indicated proficient in identifying network traffic patterns.
11	[16]	A framework utilizing machine learning algorithms.	82% and 78% of overall accuracy for gender and education level

The research works in Table 3, spanning references [3] through [16], collectively represent significant advancements in the field of wireless networks. The study in [3] introduces a fuzzy logic-based algorithm for session transfer in Wi-Fi/WiGig networks, demonstrating competence but lacking detailed context analysis. In [4], a convolutional neural network model classifies Wi-Fi network attacks with notable F1 scores, yet questions of scalability and broader applicability remain. The deep Q-network model in [8] optimizes WiFi network spatial reuse, showing throughput improvements but lacking comparison with newer algorithms. Research [9] combines marked Poisson point process and Markov chain models for LAA/Wi-Fi coexistence, with unexplored performance under varying network conditions. The study in [10] uses a graph-based temporal convolutional network for traffic prediction, with improved accuracy but untested adaptability to different mobile networks. In [11], semi-supervised clustering supports real-time traffic monitoring, yet its accuracy and reliability under diverse environmental conditions need further validation.

Work in [12] leverages machine learning for cellular network cell selection analysis, showing moderate performance with potential for improvement. The semi-Markov model in [13] aims at power savings in DRX over LAA-LTE-A networks, showing significant improvements but not tested in high-density scenarios. Deep learning for traffic monitoring in [14] achieves high accuracy, but scalability and performance in varied conditions require clarification. Research in [15] employs graph-based techniques for network traffic analysis, proficient but lacking in diverse traffic type evaluation. Finally, the framework in [16] uses machine learning for demographic inference from Wi-Fi traffic metadata, raising substantial ethical and privacy concerns despite its accuracy. Each work contributes uniquely but also highlights areas needing improvement, particularly in scalability, adaptability, and comprehensive performance evaluation under diverse conditions.

Table 4 encompasses diverse research works in wireless networks and communication technologies, each employing innovative methodologies and yielding significant results. For instance, research [17] explores a novel data offloading method using virtual banks and movement prediction, showing effective improvement in data offloading. Another study [18] integrates blockchain technology to enhance the coexistence of heterogeneous networks, indicating notable effectiveness. The smart home systems in [19] are advanced through an intelligent signature extraction scheme, achieving an impressive 86.2% accuracy. Further, an analytical model in [20] provides insights into flow-level performance in heterogeneous wireless networks, with specific attention to policies and traffic intensities. In [21], queue theory is analyzed for Wi-Fi applications, offering detailed end-to-end packet delay metrics for different services. Techniques to lower spectrum consumption in Wi-Red are evaluated in [22], showing potential reductions in spectrum usage. Smart home pattern modeling is innovatively addressed in [23], where a high percentage of events and user activities are accurately identified.

Table 4
Summary of alternative techniques

No.	Reference	Methodology	Results
1	[17]	A prediction method applying an opportunistic network.	The proposed method could improve data offloading effectively.
2	[18]	A blockchain-enhanced scheme.	The proposed scheme indicated effectiveness.
3	[19]	An intelligent method.	86.2% accuracy.
4	[20]	A flexible and accurate model.	The model specified perceptions on policies and different traffic intensities.
5	[21]	An analysis on a theory.	171.717 ms and 0.977 ms of end-to-end packet delay and packet delay variation for VoIP. 32.495 ms and 7.207 ms on videotape conferencing.
6	[22]	Post-Analysis techniques.	The proposed techniques able to reduce the spectrum consumption.
7	[23]	A smart home architecture is designed.	95% of 343 events were identified. 100% accuracy users were tracked.

Table 4. Continued
Summary of alternative techniques

No.	Reference	Methodology	Results
8	[24]	An authentication scheme.	The scheme effectively able to certificate and signature verification cost.
9	[25]	An algorithm is proposed.	The proposed algorithm able to enhance the throughput of the system.
10	[26]	A video broadcasting scheme.	The presented scheme capable to confirm a high quality of service.
11	[27]	A device selection approach.	For network emulation experiments, the achieved performance improvement reached up to 32.66% and in hardware experimentation, the observed enhancement went as high as 50%.
12	[28]	An original system.	The system effectively able to enhance on radio map updating and localization accuracy.
13	[29]	A methodology implementing segmented shifter.	The methodology capable to validate low-traffic users.
14	[30]	A new coordination architecture.	10× gains of the architecture.
15	[31]	A Stackelberg game is employed.	The approach effectively employed.
16	[32]	An analytical model to analyze the dual path packets offloading scheme in realistic LTE-WiFi HetNets scenario.	The offloading experiment results verified the accuracy of the proposed model.
17	[33]	A mathematical framework.	The analysis concluded that the rate accomplished by devices is principally controlled by the initial window size.
18	[34]	A framework.	The analysis and results able to support the proposed framework.
19	[35]	A novel architecture.	The architecture exhibited meaningful performance enhancements.
20	[36]	A secure and lightweight protocol.	The proposed protocol can be simply incorporated into the devices.
21	[37]	A novel system.	88% energy efficiency improvement.
22	[38]	An indoor automated navigation system.	The system exhibited accuracy and feasibility of the theory.

The study in [24] proposes efficient privacy-preserving authentication schemes for vehicular networks, significantly reducing certificate and signature verification costs. A Q-learning based algorithm in [25] enhances LTE-U and Wi-Fi coexistence, improving system throughput. Situation-aware video broadcasting over train-trackside WiFi networks is explored in [26], ensuring high-quality service. Research in [27] examines client-centric access device selection in Beyond 5G IoT networks, showing substantial performance improvements in both network emulation and hardware experiments. In [28], a novel system for WiFi radio map adaptation and indoor positioning is presented, enhancing localization accuracy. A segmented reconfigurable cyclic shifter for 5G QC-LDPC decoders is developed in [29], validating its efficiency for low-traffic users. The work in [30] introduces a multi-timescale beamforming architecture for multi-cell networks, achieving significant gains.

In [31], a Stackelberg game-based approach is employed for motivating mobile participation in data offloading, proving to be effective. Performance analysis of a packets offloading scheme on a software-defined platform is conducted in [32], verifying the model's accuracy. The coexistence of 5G NR unlicensed and WiGig in millimeter-wave spectrum is analyzed in [33], focusing on the impact of initial window size on device rates. Network connectivity management in multi-clouds infrastructure is the focus of [34], supporting the proposed framework with thorough analysis and results. Research in [35] presents a scalable virtualization and offloading-based architecture for 5G networks, demonstrating meaningful performance enhancements. Secure device-to-device communications for 5G IoT applications are addressed in [36], with a protocol that can be easily incorporated into devices. An energy-conscious access point system for reliable IoT services in Wi-Fi networks is developed in [37], showing an 88% improvement in energy efficiency. Lastly, [38] introduces an indoor navigation system using a two-axes three-points policy and Bezier curve, exhibiting accuracy and feasibility. Each study contributes to the evolving landscape of wireless communication, highlighting advancements and challenges in areas such as data offloading, network coexistence, smart systems, performance optimization, and security protocols.

This section has studied different variants of the techniques involve in developing and designing Wi-Fi traffic analysis tools. Wi-Fi signals are more prevalent than ever because to the proliferation of Wi-Fi-capable gadgets logging onto wireless networks. Consequently, approaches or techniques targeted at using connection data for a variety of objectives have emerged because of the widespread use of these signals. As shown in Table 3 and 4, the techniques have been categorized as machine learning techniques and alternative techniques.

Machine learning has proven its adaptableness and usefulness by being used in a wide range of sectors, including security, image processing, atmospheric research, traffic management, and many more have indicated the promising prospects for its future trajectory. Furthermore, machine learning algorithms have exhibited flexibility and efficiency especially for copious volumes of data stemming from a diverse source [39]. Additionally, machine learning algorithms have the capacity to generalize and adapt to diverse contexts, contingent upon the sufficiency of representative training data for the specific task at hand [40]. Hence, machine learning algorithms have proven to be efficient and effective to be implemented as techniques in developing and designing Wi-Fi traffic analysis tools.

5. Discussion and Conclusions

The primary objective of this systematic review is to enrich the body of knowledge concerning Wi-Fi traffic analysis tools through a rigorous evaluation of their existing functionalities and areas of expertise. The outcomes of this review based on Table 3 and 4 can be categorized into two distinct parts. The first part, between 2018 to 2022, there is no studies are carried out in Malaysia environment regarding the Wi-Fi traffic analysis tools. Therefore, there is a big opportunity for researchers to design and develop Wi-Fi traffic analysis tools and test them in any suitable environment in Malaysia.

For the second part, based on Table 3, machine learning techniques have the ability to extract invaluable information pertaining to user preferences, content consumption habits, and prevailing trends in service usage. Over the recent years, the confluence of Wi-Fi and machine learning algorithm have engendered a proliferation of diverse applications, thereby spawning various distinct research niches.

As machine learning techniques or algorithms such as TOPSIS, Weight Sum Method and deep learning have proven to be efficient to produce a solid result, so, for the future work, the next step is to propose a new model on providing an intelligent Wi-Fi traffic analysis tool based on a machine learning technique in real environment specifically in Malaysia.

As the conclusion, this systematic review seeks to provide a comprehensive overview of the manifold applications of machine learning techniques applied to Wi-Fi connection data specifically in developing an analysis tool.

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