



An Investigation of Knowledge-Based Software Defined Networking Framework for Automation of Wireless Network Resource Management

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ABSTRACT

Wireless networks represent a significant portion of digital society, employing the packet-switched distributed architecture. Techniques such as deep learning-based traffic classification, reinforcement learning, mobile agents, and the identification of elephant and mice flows have been utilized to handle various network functions, such as traffic identification, routing strategies, and spectrum allocation. Software-defined Networks (SDN) have played a crucial role in addressing the challenges encountered in conventional network management. However, owing to the dynamic nature of networks and the high volume of network traffic, software-defined network architecture is insufficient to ensure optimal system performance in network environments. Hence, this research proposes a framework for integrating analytics and knowledge representation within a software-defined networking architecture, aiming to automatically optimize, diagnose, and troubleshoot wireless networks. A systematic literature review and qualitative comparative analysis were used to investigate knowledge-based Software-Defined Networking (SDN) architectural frameworks in the literature. The findings indicate the proposed framework outperformed other knowledge-based SDN frameworks in network functions and knowledge integration.

INTRODUCTION

Modern telecommunications systems are undergoing a transformative evolution driven by an increase in the demand for digital services and applications. Software-defined networking (SDN) represents a networking architecture that integrates network programmability into centralized management and decouples the control plane from the data plane enabling management from a centralized point referred to as the controller (Cargelio *et al.*, 2018). Traditional network management approaches are often static and rule-based, and struggle to adapt to the dynamic and heterogeneous nature of contemporary networking environments. Hence, there is a need for innovative

solutions that harness the power of data-driven and adaptive technologies (Rahman, 2009; Wijesekra and Gunawardena, 2023).

This study introduces the concept of leveraging knowledge-based systems in the automation of network resource management in SDN as a solution to address the challenges of network resource management within Software-Defined Networks. By utilizing knowledge-based systems in the SDN architecture, network operators and administrators can benefit from real-time analytics and machine learning to make informed decisions in network management, aligning perfectly with the

principles of SDN (Atanda *et al.*, 2023). This allows the network's behaviour to be controlled programmatically and intelligently on a per-application basis. The significance of knowledge-based software-defined networks lies in their ability to enhance decision-making and information sharing (Okediran and Oguntoye 2023). In recent times, the resources shared by networks are scarce and costly. Therefore, this necessitates the need for optimal allocation of network resources.

Software Defined Networking

SDN is a type of programmable network that is managed by a software program. It differs from the conventional network architecture by separating the control plane and data plane logically and centrally as depicted in Figure 1. The control plane, which behaves like an instructor, makes all forwarding decisions based on topology and manages different controllers and planes. The data plane, on the other hand, forwards packets based on data-forwarding tables. The architecture of SDN includes an application layer (management plane) that manages networking services and applications, a control layer (control plane) that makes forwarding decisions, an infrastructure layer (data plane) that forwards packets, and northbound and southbound interfaces that facilitate communication between the layers. SDN is a promising solution for managing wireless networks due to its programmable nature and ability to utilize software-oriented application interfaces to coordinate network operations, thereby improving the overall network experience.

Wireless Network Resource Management

Wireless Network resource management comprises parameters such as bandwidth, QoS, and spectrum allocation (Ashtari *et al.*, 2022). These parameters were obtained from the data plane of the SDN and processed using machine-learning algorithms. The

output is stored as knowledge for the automation of network operation tasks. The concept of integrating knowledge with SDN for wireless network resource management is implemented in network monitoring, spectrum allocation, bandwidth management, and Quality of Service (QoS).

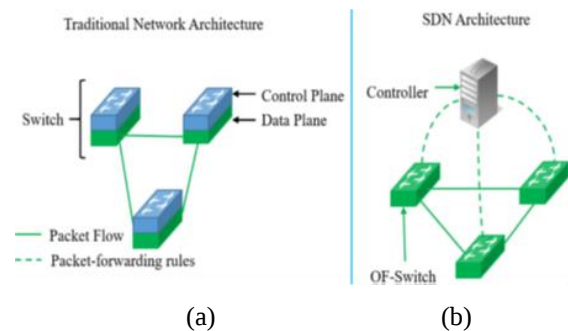


Figure 1(a): Conventional network (b): Software-defined network architecture (Source: Ashtari *et al.*, 2022)

Network Monitoring

Monitoring provides a view of the network status and illustrates network behaviour, which is a basis for further management operations such as traffic engineering, quality of service (QoS), and anomaly detection. Network monitoring involves measurement, aggregation, and preprocessing of network traffic data (Abolade *et al.*, 2022). A range of studies have explored the use of knowledge-based approaches in wireless network monitoring. Redondi and Cesana (2018) performed passive WiFi probes on wireless sensor network node devices for network monitoring. Machine learning algorithms such as Naïve Bayes, Decision Tree, and Support Vector Machine were used to profile network users and devices to provision quality-of-service. The results showed that decision tree algorithms recorded the highest accuracy.

Aumayr *et al.* (2019) used a knowledge graph-based semi-dynamic approach to determine incident resolution in a wireless network. Experimental results demonstrated that the

knowledge-based approach outperformed the traditional approach to network monitoring. Krinkin et al. (2020) proposed a knowledge graph method for integrating semantic data from various elements of telecommunications systems. The proposed method was effectively used to monitor the network bandwidth of an IP flow. The experimental results demonstrated the effectiveness of the knowledge graph approach in monitoring network conditions. Mehmood *et al.* (2023) used knowledge graphs to model the intention of users based on domain-specific service requests. The results indicated that the technique was efficient in monitoring network conditions and modeling user requirements. The drawback of the approaches used is that they are overly dependent on the manual construction of knowledge graphs and do not leverage machine learning techniques for knowledge integration.

Spectrum Allocation

Spectrum allocation in wireless networks is a critical network function given the inefficiency of current allocation methods contributing to perceived shortage and dynamic spectrum allocation. This involves adaptively dividing the available spectrum based on factors such as potential interference and traffic load, which has been proposed as a solution. Spectrum-sharing techniques, such as opportunistic access to licensed spectrum, have also been explored (Kaniezhil, 2012; Adetunji et al., 2018). Zhang *et al.* (2020) used the Particle Swarm Optimization technique for spectrum allocation in cellular networks. The results demonstrated that the approach can be used for spectrum allocation optimization. Neznik (2020) focused on channel allocation methods to improve service quality and decrease interference. The results indicated that utilizing Game Theory and Fuzzy Logic in the Smart Method. Shin *et al.* (2021) proposed a machine learning-based

spectrum-sharing method among multiple mobile network operators to address resource scarcity and demonstrated improved network performance in experimental results. Ahmed *et al.* (2021) used a Support Vector Machine and spectrum sensing to detect vacant frequency bands for spectrum allocation in a wireless network. The SVM approach recorded a high accuracy indicating optimal allocation of radio spectrum.

Rony *et al.* (2021) used an intelligent machine learning-based access-aware dynamic spectrum allocation strategy for a 5G network. The experimental results showed that the dynamic approach outperformed traditional spectrum allocation strategies. Experimental results indicated that the strategy outperformed conventional approaches in allocation accuracy and utilization. Wang *et al.* (2021) allocated the spectrum band for different network flows dynamically based on QoS policies for different active network functionalities. The results showed a high spectrum utilization.

The studies reviewed utilized various knowledge graph and machine learning optimization techniques, however, the knowledge graph could be further utilized to provide semantic context thereby boosting the spectrum allocation approaches.

Bandwidth management

Bandwidth management in Knowledge-Based Software-Defined Networking involves the dynamic allocation and optimization of network bandwidth based on real-time network conditions (Wijesekara and Gunawardena, 2023). Research on knowledge-based wireless network bandwidth management has explored various approaches. Chen (2007) proposed a method that combines frequency allocation, transmit power control, and load balancing, using site-specific knowledge to optimize network performance. Experimental

results showed the scheme's efficacy in allocating bandwidth. Kumar (2013) addressed the challenge of bandwidth management in wireless mesh networks, proposing a method that includes connection admission control and bandwidth reservation based on average data rate. The experimental results showed that the approach efficiently reduced the bandwidth requirements. Kim (2014) introduced a learning-based bandwidth management scheme, using a market-sharing game model and self-adaptability for network dynamics. Results indicated that the approach outperformed the conventional technique of inefficient bandwidth allocation.

Awad (2016) used an approach that involves intelligent clustering techniques for dynamic bandwidth allocation. The optimal online bandwidth allocation based on the data extracted from the lecture timetable was fed to the wireless network control nodes, allowing them to adapt to their environment. The technique outperformed conventional approaches. Mei et al. (2020) used Long Short-Term Memory (LSTM) for real-time bandwidth prediction to improve the Quality of Experience. The experimental results showed that the technique outperformed the traditional techniques in terms of bandwidth predictions. Labonne *et al.* (2020) proposed a novel framework for predicting network traffic flows' bandwidth. The evaluation results showed that the Random Forest algorithm outperformed the other models. The studies reviewed demonstrated varying degrees of success in the optimization of network bandwidth utilizing real-time network conditions, however, the approaches used are limited to their respective network environments. A unified framework that performs context-aware bandwidth management

The future of wireless technology requires improved communication systems. The QoS determines the performance of the network within the ambit of its resources. Maintaining the quality of service amid colossal traffic data remains a challenging research issue (Salama *et al.*, 2017). The use of knowledge-based systems to enhance the quality-of-service classification has been explored by several researchers. Machine learning methods such as supervised, unsupervised, and reinforcement learning have been utilized in this regard. Salama (2017) compared Fuzzy c-means clustering and unsupervised neural networks for their abilities to differentiate between Good, Average, and Poor QoS for voice-over IP traffic. The results indicated that the approach accurately categorized Internet traffic into QoS classes. Salama (2019) used a Bayesian and Probabilistic Neural Network approach for QoS classification of VoIP packets based on delay, jitter, and percentage packet loss ratio. The results demonstrated the effectiveness of the technique used in fine-grained QoS classification.

Gheisari (2020) developed an algorithm for optimizing QoS in peer-to-peer wireless mesh networks, which effectively prevented undue delays and distributed network load. The experimental results indicated an improvement in the approach over conventional QoS classification. Azamuddin (2020) presented a QoS management system for a local area network, using traffic policy techniques to address network congestion and achieve stable performance. The experimental results demonstrated that the method is efficient. These studies collectively demonstrated the potential of knowledge graphs in enhancing QoS in wireless networks.

Quality of Service (QoS)

Knowledge-Based Wireless Network Resource Management SDN (KBWNRM-SDN) Framework

In this study, a knowledge plane was integrated into the traditional SDN architecture. The architecture consists of the knowledge paradigm consisting of knowledge graphs, data monitoring, and the control plane and the data plane. The framework is illustrated in Figure 2

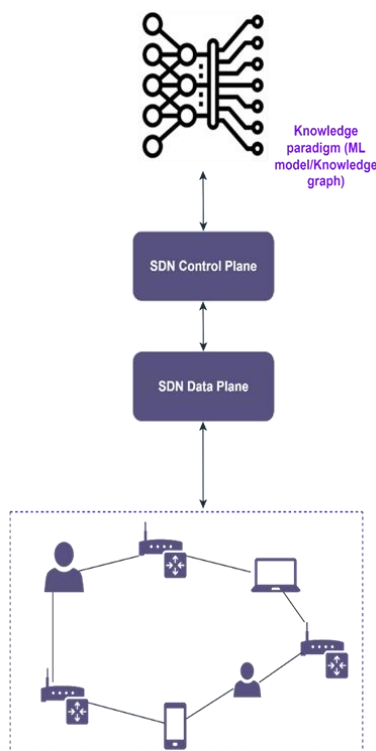


Figure 2: Knowledge-based Software Defined Networking Architecture Framework

The knowledge-based SDN framework operates by integrating these components to enable the control plane to make informed decisions about network behaviour and performance. The framework is adaptable and combines functionalities such as network monitoring, spectrum allocation, quality-of-service, and bandwidth management tasks. An overview of the framework is presented thus:

- a) **Data Collection:** data collection is implemented by the SDN Data Plane component of the SDN

framework collects data from various sources within the network, including network devices, traffic patterns, and user behaviour. This data is transmitted from the control plane.

- b) **Data Analysis:** The knowledge paradigm analyses the collected data to identify patterns, trends, and correlations that can inform decisions about network behaviour and performance.
- c) **Decision-Making:** The SDN controller uses predictive models to make informed decisions about network resource allocation, traffic management, and security. These decisions are based on the analysis of real-time data and the predictive models of future network behaviour.
- d) **Action:** The SDN controller implements the decisions made by the predictive models in the knowledge paradigm by sending commands to the network devices to adjust resource allocation, traffic flow, and security settings.

METHODOLOGY

A systematic literature review and weighted scoring technique were used to investigate the knowledge-based software-defined networking (SDN) frameworks in the literature. The systematic literature review entailed comprehensive electronic database searches across IEEE Xplore, ACM Digital Library, and ScienceDirect, utilizing targeted keywords including "knowledge-based SDN", "network architecture", and "intelligent networking" to identify relevant peer-reviewed publications from 2016 to 2024. After a thorough review of the search results from the databases, 12 frameworks were selected for the analysis. Table 1 shows the breakdown of the architectures from various databases.

Table 1: Publications breakdown

Database	Publications
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ScienceDirect	3
IEEE Xplore	4
ACM Digital	5

. The weighted scoring method is a technique that combines qualitative and quantitative measures for operational decision-making and allows the consideration of multiple criteria (Ragin, 2014; El-Khalyly *et al.*, 2020; Ouchra and Belangour, 2021).

It consists of the following steps:

- i. Selection of features to be considered
- ii. Selection of criteria to be used to evaluate features
- iii. Assignment of weights to criteria
- iv. Assignment of individual scores to each feature

The selection criteria used to evaluate the frameworks comprises criteria such as architectural features, network functionality, and knowledge representation, enabling nuanced evaluation of framework capabilities in current SDN architectural approaches. The scoring criteria used for the frameworks are outlined below:

1. Network Function (Weight 0.3)
 - Routing
 - Bandwidth management
 - Spectrum allocation
2. Knowledge Integration (Weight 0.4)
 - Learning mechanisms
 - Inference capabilities
 - Real-time adaptability

Each sub-criteria for each of the categories is given a score of 0.1. The knowledge integration is assigned the highest weight of 0.4 to reflect its significance to the scoring criteria, in line with the Weighted Score Model, the total score for a given framework ranges from 0 to 1.

RESULTS AND DISCUSSION

The comparative analysis carried out revealed significant differences in the knowledge-based SDN frameworks across the three selection criteria. The evaluation indicates that the frameworks exhibit significant differences in knowledge integration. The framework by Struhar *et al.* (2019) scored the highest across all selection criteria especially remarkable is its performance in knowledge integration. The framework by Quieroz *et al.* (2019) and Al-Jawad *et al.* (2021) showed strong performance in network monitoring and bandwidth management. Mehraban and Yadav (2024), Bahnasse *et al.* (2018) and Tengari *et al.* (2018) have limited knowledge integration and rather narrowly focus on power consumption monitoring, QoS provisioning, and power consumption monitoring, hence their relatively low scores. The proposed framework in this study yielded the highest score of all the frameworks reviewed due to its approach to combining a myriad of knowledge representation techniques. Table 2 illustrates the findings from the analysis of the frameworks.

Overall, these findings demonstrate the diverse architectural approaches and network functions offered by knowledge-based SDN frameworks. The reviewed frameworks highlight the complementary nature of network functions and offer the potential for combining their strengths. In this regard, the framework presented in this study integrates key network functions such as bandwidth management, QoS provisioning, network monitoring, and spectrum allocation concurrently.

CONCLUSION AND RECOMMENDATIONS

The study presents a framework that integrates a knowledge paradigm into the framework of Software Defined Networking to manage multiple functionalities of wireless network resources. By reducing the requirement of manual intervention by human operators in managing network resources,

due to the complexity of modern wireless presented will be useful for organizing and

Author	Framework	Network Function	Knowledge Integration	Score
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networks. Additionally, it centralizes the management of resources in wireless networks. The comparative analysis of the proposed framework with the existing knowledge-based SDN framework demonstrates that the framework

representing complex network data, relationships, and semantics, thereby enabling the network to understand, adapt, and optimize its performance in response to diverse application requirements.

Shu et al. (2016)	TESDN	QoS, IP Management	Data Analytics, Sensor networks	Heuristics	0.4
Bahnasse et al. (2018)	DSDNSM	QoS Traffic routing, Bandwidth allocation	Heuristics for QoS requirements		0.5
Chen et al. (2018)	MPLSTE-SDN	QoS provisioning Traffic prediction	Data Analytics monitoring	Network	0.4
Lin and Shih (2018)	RSM-SDN	Radio spectrum monitoring, Bandwidth control	Data Analytics		0.5
Tangari et al. (2018)	DSDNSM	Traffic monitoring Distributed resource management	Data Analytics		0.3
Queiroz et al. (2019)	BDA-SDN	Network bandwidth utilization monitoring	Fine-grained traffic monitoring Bandwidth monitoring		0.5
Struhar et al. (2019)	DTR-SDN	Network virtualization, Dynamic bandwidth allocation			0.6
Hu et al. (2020)	DTR-SDN	Traffic routing	Deep reinforcement learning, Data monitoring and analytics		0.4
Al-Jawad et al. (2021)	RLFM-SDN	Traffic routing, QoS provisioning	Bandwidth monitoring Deep reinforcement learning		0.5
Kamboj and Pal (2021)	PBF-QOS	Quality of Service	Heuristics Routing		0.4
Nsaif et al. (2021)	PCM-SDN	Traffic routing Power consumption	Heuristics Integer programming model		0.4
Mehraban and Yadav (2024)	HO-SDN	Traffic Engineering, Quality of Service	Traffic Prediction Data Analytics		0.4
Author et al. (2025)	KBWNRM-SDN	Spectrum allocation, Bandwidth management, QoS, Network monitoring	Data Analytics Machine learning models, Knowledge representation (Knowledge graphs)		0.8

Table 2: Comparative analysis of frameworks

The framework enhances the decision-making capabilities of the control plane in Software Defined Networking and improves the capacity to optimize, diagnose, and troubleshoot wireless networks, ultimately leading to enhanced network performance. Future studies could conduct experiments.

Based on the findings from this study, the following recommendations are suggested:

- Knowledge-embedded SDN frameworks that are capable of handling multiple network functions simultaneously
- The use of graph-based techniques to model network functions as they are inherently better at capturing complex relationships between nodes in wireless networks.
- Review of existing approaches that have been used to integrate knowledge into software-defined networking domains
- Design of a knowledge-based software-defined wireless network resource management framework.
- Comparative analysis of the proposed framework with existing SDN frameworks in literature.

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