Heliyon 10 (2024) e29965

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

Software defined wireless sensor load balancing routing for internet of things applications: Review of approaches

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ARTICLE INFO

Keywords:
SDWN
SDIoT
Load balancing
Routing
IoT application

ABSTRACT

The proliferation of the Internet of Things (IoT) devices has led to a surge in Internet traffic characterized by variabilities in Quality of Service (QoS) demands. Managing these devices and traffic effectively proves challenging, particularly within conventional IoT network architectures lacking centralized management. However, the advent of Software-Defined Networking (SDN) presents intriguing opportunities for network management, capable of addressing challenges in traditional IoT architectures. SDN's ability to provide centralized network management through a programmable controller, separate from data forwarding elements, has led researchers to incorporate SDN features with IoT (SDIoT) and Wireless Sensor Networks (SDWSN) ecosystems. However, despite the SDN support, these networks encounter challenges related to load-imbalance routing issues, as the SDN controller may be constrained while certain access points serving end users become overloaded. In response to these challenges, various load-balancing routing solutions have been proposed, each with distinct objectives. However, a comprehensive study that classifies and analyzes these solutions based on their weaknesses and postmortem challenges is currently lacking. This paper fills this gap by providing an in-depth classification of existing solutions. The study categorizes the problems addressed by different schemes and summarizes their findings. Furthermore, it discusses the shortcomings of current studies, and postmortem challenges associated with integrating SDN with IoT, and suggests future research directions.

1. Introduction

The Internet of Things (IoT) is an emerging global innovation operating over Internet and enables the exchange of goods and services. It is undergoing continuous development and refinement as its technology is being explored and refined. A prior study reported that the number of connected Internet of Things (IoT) devices is predicted to reach 83 billion by 2024 [1]. Traditionally, these

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https://doi.org/10.1016/j.heliyon.2024.e29965
Received 21 January 2024; Received in revised form 13 April 2024; Accepted 18 April 2024
Available online 19 April 2024
2405-8440/

devices are programmed with complex rules (routing topologies) using the vendor's proprietary interface, which is very hard to modify in real time [2]. Besides, the constrained nature of the devices affects their programmability with multiple rules to provide optimal network services. As such, traditional networks cannot adopt adequate policies to meet the application-specific requirements of IoT in real-time. As a result, a new network architecture is required to manage the explosion of IoT and meet their application's Quality of Service (QoS) demands. Software Defined Networking (SDN) was introduced to overcome the challenges of the traditional network [3]. It's programmable network emerged to separate the network control logic from data forwarding elements. This way, forwarding devices were relieved from the control function and focused on forwarding traffic flows based on the decision made by the control logic. This has made network management easier and more flexible, speeding up network innovation. The automated reconfiguration of the SDN is foreseen as a key and critical enabler for several emerging technologies, including IoT [4]. The SDN paradigm has evolved over the years and has already been applied in early wireless technology, which prefigured the IoT and sensor networks [5]. Wireless environments are rapidly increasing daily due to their facile connectivity anywhere. IoT devices are wirelessly connected to the Internet, serving various applications commonly found in health care, smart learning, homes, and transport [6]. Although, the SDN centralized network control has revolutionized the network architecture, especially for dynamic single and multi-path routing and energy efficiency. Different from traditional distributed networks, some new paradigms, Software Defined Internet of Things (SDIoT) and Software Defined Wireless Sensor Networks (SDWSN) are proposed to adapt in real-time for better network management and service provisioning. Access Point (AP) is deployed in SDIoT and SDWSN to provide services to end users, resulting in high variable AP densities and uneven load distribution among the AP and SDN Controller [7].

Some efforts were made to balance the load among AP. The existing method can be classified as a client and centralized-based [7,8]. Most existing studies focus on the former Approach; in this method, wireless stations learn AP load and make association decisions independently. The method is simple; however, it can not make precise decisions for evenly distributing the load due to the lack of a global network view. Centralized-based systems show better load-balancing decisions due to their centralized network knowledge and automatic adjustment of the coverage area of specific AP [9]. Several studies [10–12] leverage the centralized-based method to balance the load among AP efficiently. However, they incorporate unnecessary association and disassociation decisions for the AP, which overload the controller. In addition, the association decision is mostly based on a single metric, which may not always be optimal. Composite metrics may perform better; unfortunately, they were not adequately considered. This may have non-trivial consequences, especially for traffic flows that complicate QoS demand. Traffic flows exhibit different variabilities with different QoS requirements, especially in wireless environments. The nature of the health care environment generates various Traffic that complicates QoS requirements; physiological data requires a different QoS to transmit without data loss and delay. The traffic heterogeneity in Ref. [13] is classified as emergency (high-priority Traffic) and delay-sensitive (critical Traffic) packets. In this regard, optimized routing is required to meet the QoS demands efficiently. Some routing schemes in wireless environments have been proposed over the years. The existing routing algorithms are widely used as static and dynamic to obtain the NSI [3], and different solutions have been introduced over the years based on the latter and former with different objectives. However, most schemes have not sufficiently balanced the network load and resources during routing, affecting network resources. Optimized load-balancing routing is necessary for optimal network resource usage.

Several studies were introduced to balance the load among SDN resources. Ref. [14] presents a systematic review of load-balancing approaches. The authors classified the exisiting approaches into two; traditional approach and those based on artificial intelligence. Similarly [15], presents various load balancing schemes in SDN, including SDN controller, switch, links, and load balancer. Load balancing for IoT application was presented in Ref. [16]. The paper in Ref. [17] surveyed SDN architecture while focusing on load balancing. The study discussed load balancing approach based on artificial intelligence and synthesize the weakness of various solutions, including employed algorithms, a problem addressed, strengths and weaknesses of the problems, and finally, point out potential research direction. However, Refs. [14,15,17] have not covered load balancing routing with IoT applications in SDWSN. The Wireless IoT domain evolved into SDWN-based IoT (SDWN-IoT), playing significant role in future technology. The work in Ref. [18] discussed wireless networks' challenges and design requirements. The paper survey related works on network management due to the heterogeneous nature of nodes in wireless networks. In contrast, the survey in Ref. [19] explored SDWN-IoT and SDWSN-IoT concerning the role of Traffic Engineering in the former and latter. In particular, the paper discusses flow management and analyze fault tolerance. Topology update was touch up and traffic flows was analyzed in SDWN-IoT and SDWSN-IoT. However, load balancing and QoS routing were not covered in the paper. The work in Ref. [20] presents managing smart technologies, including IoT, for Routing and security. The paper explores routing solutions for SDWBAN and SDIoT. However, wireless and load-balancing aspect was not discussed in the paper. The wide adoption of IoT and its application required integration with various wireless technology for optimal performance. The paper in Ref. [21] presents an Optimized load balancing for effective network flow management, reducing network congestion in SDWN. The research brings out the issues posed by current the solutions, examining several ways to integrate SDN with other technologies to address issues like security. The study further discussed installation problems and wireless network coverage was analyzed. Energy-constrained resources remain a crucial issue that affects device performance in wireless networks during routing due to the proliferation of sensor technology. Ref. [22] presented the survey to explore related solutions in SDWSN aimed at reducing energy consumption. A review of algorithms in SDN routing for IOT Security was presented in Ref. [23]. Emphasis was given to optimization solutions for routing and security in IoT. Unfortunately, load balancing and wireless aspects were not covered. Other related surveys focus on [24] exploring security concerns while integrating SDN with blockchain to facilitate greater security and network performance for IoT applications. The paper discussed various security frameworks in SDIoT and their potential advantages. The weaknesses were highlighted, and possible research directions were pointed out. While researchers are better with time, the aforementioned related review papers have not adequately covered load balancing routing in SDIoT, SDWSN, and SDWN while pointing out their weaknesses and highlighting possible postmortem challenges while integrating with SDN. As such, a notable gap exists in their coverage because many Wireless IoT domains are transitioning into SDWN-based IoT to benefit from the SDN features.

Consequently, the need to investigate load-balancing routing within this context becomes increasingly apparent. Furthermore, the unique challenges posed by dynamic network conditions in SDWSN, driven by wireless technologies and sensors, differentiate it from conventional SDN architectures. Addressing this gap is crucial, as load-balancing routing challenges within SDWSN take on a new dimension in the context of IoT applications. Unlike existing works, this study aims to fill this void, contributing to the broader understanding of the issue and addressing the specific challenges posed by the evolving landscape of SDWSN-based IoT. By bridging this gap, the study aims to provide essential insights, future work recommendations, and additional perspectives on load balancing routing within SDIoT applications and SDWSN, enriching the literature and advancing the understanding of load balancing within this dynamic context. This served as motivation for the current study. To this end, this study focussed on load-balancing approaches, considering SDWN, SDIoT, and SDWSN. The study identifies challenges and provides insights for future research. The comparison of related surveys is presented in Table 1.

1.1. Paper contribution

This review paper studies various load-balancing routing approaches in SDIoT and SDWSN. The scope of the paper revolves around integrating emerging technologies with SDN. The paper provides the following contributions.

1. The study designed a taxonomy to classify the load-balancing routing approaches into four (4): mathematical optimization-based, Context-Aware, Nature-inspired, and artificial intelligence-based approaches.
2. The study discusses the background challenges that need to be considered when designing a solution for load-balancing routing for IoT applications. Analysis and summary of the existing study were discussed.
3. Analyses the postmortem challenges of integrating software-defined networking with other emerging technologies.
4. We provide a thorough analysis and synthesize the existing studies while highlighting their weaknesses.
5. The study outlines potential challenges and identifies some unanswered research challenges that need further investigation.

The paper organization is as follows: The background and challenges of the study was presented in Section 2. The study discussed why SDNs are in the IoT ecosystem in Section 3. The research methodology was presented in Section 4. The Classification of Software-Defined Wireless Network Load Balancing Routing Approaches extensively discusses various solutions and their weakness in Section 5. The summary of load-balancing routing approach proposals is also presented in Section 6. Section 7 analyzed and discussed some postmortem challenges and Future work. The paper was concluded at Section 8.

2. Background and challenges

The proliferation of IoT devices has led to significant traffic flow generation, and load balancing among various devices is become challenging, affecting network performance. The evolving network traffic variabilities and lack of centralize network structure are among the issues, causing non optimal load balancing. These challenges motivate researchers to investigate various concerns, including load balancing and routing challenges. Some of these challenges include the following.

Table 1
Comparison of previous related surveys with their technical contribution.

Reference	Survey Scope	SDWN	Routing	Load Balancing	SDIoT	SDWSN
Musa et al. [14],	Present systematic load balancing review focused on using artificial intelligence and conventional techniques.	✓	X	✓	X	X
Semong Et al. [15],	Discussed various load-balancing solutions concerning different SDN components.	✓	X	✓	X	X
Alhilali Et al. [17],	Surveyed AI-based load balancing solutions	✓	X	✓	X	X
Kobo et al. [18],	Present challenges and design requirements for wireless networks. It discussed related works and analyzed their weakness.	✓	X	X	✓	✓
Kumar et al. [19],	Investigate and present various traffic engineering roles in SDWN-IoT and SDWSN-IoT.	✓	✓	X	✓	X
Isyaku et al [20]	The paper presents managing smart technologies with SDN. An in-depth review of Routing and security were presented.	X	✓	X	✓	X
Kumar et al. [21],	Optimized load balancing for effective network flow management	✓	✓	X	✓	✓
Ali et al. [22]	Surveyed energy-aware solutions in SDWSN	✓	✓	X	X	✓
Manocha et al. [23],	The paper presented related works on in SDWSN for energy reduction and utilization.	X	✓	X	✓	✓
Turner et al. [24],	The paper discussed various security frameworks for SDIoT.	X	✓	X	✓	X
Present paper	Present review on load balancing routing for SDWN, SDIoT, and SDWSN	✓	✓	✓	✓	✓

2.1. Heterogeneity of IoT devices

The ubiquity of devices in IoT has transformed industries and people's life with potential data-driven insight and adaptability. The IoT devices are heterogeneous in nature as such various hardware platforms were used to configure these dense devices, making it rigid and difficult to accommodate the present users demand in real time. Therefore, heterogeneity is challenging due to the diverse range of devices with varying capabilities [25]. The devices come in various shapes and sizes designed for specific tasks. Some devices come from low power supply, and others have high performance. This diversity poses serious load balancing and routing challenges between IoT applications. A seamless routing strategy for resource-rich devices might prove inadequate for resource-constrained sensors. Balancing the load across such heterogeneous devices requires carefully considering their processing power, memory, energy constraints, and communication technologies. The IoT device may have different communication standards, such as Wi-Fi, Bluetooth, Zigbee, LoRaWAN, and cellular networks [26]. These standards are used to optimize specific use cases and network conditions. Involving devices with various communication standards may require collaboration within a single network. It is essential for load balancing and routing to adopt the varying latency and data rates associated with these communication standards for efficient data transmission across devices [27]. However, centralized network architecture is lacking in the conventional IoT platform. This significantly impacts managing and maintaining these diverse devices coupled with various traffic generated by the IoT application. Scalable load-balancing routing strategies must constantly obtain global network knowledge to account for the device's mobility whenever it joins the network. This becomes even more pronounced in environments with high device mobility, such as smart transportation systems and homes [28]. As such, interoperability and compatibility issues may be unavoidable. A significant challenge is ensuring that devices from different manufacturers can seamlessly communicate and collaborate within an IoT network. It is essential for load balancing and routing strategies to account for devices with varying data formats, communication protocols, and levels of compatibility. Therefore, load balancing and routing approaches must consider these various heterogeneous challenges to foster efficient data exchange.

2.2. Real-time QoS requirement for IoT applications

The diverse application in the IoT ecosystem generates various types of traffic flows that exhibit different types of Traffic, volume, and quantity, complicating QoS demands in real-time. For example, healthcare applications require periodic monitoring in real-time for efficient data transmission and response. The IoT sensors can generate huge amounts of data; some traffic is critical, and others are emergencies [29]. Priority routing is necessary to consider these types of traffic and route them through an optimized path without hurting their QoS requirements. However, routing traffic based on their QoS demand on real time is quite challenging. The real-time requirement is quite challenging due to the heterogeneity of these traffic flows and many sensing devices generate these data with varying demands [30]. Therefore, Load balancing and routing must consider the trade-off between real-time monitoring and optimizing resource utilization for better service delivery [31]. This is a multifaceted challenge that requires innovative and adaptive load-balancing routing strategies. Navigating the complex relationships between various QoS routing metrics (delay, throughput, bandwidth, packet loss, etc) and diverse features of the IoT devices is paramount for unlocking the potential of real IoT applications.

2.3. Energy efficiency

Energy is a critical concern in IoT deployment due to limited resources. The challenges associated with energy load balancing routing awareness are multifaceted, primarily due to sensing, data transmission, and receiving [32]. Although. Data aggregation is a technique that can contribute to energy savings by reducing the number of transmissions [33]. However, determining the optimal level of aggregation is challenging. This required an efficient solution to ensure the efficiency of networking devices. The Heterogeneity of IoT devices significantly contributes to significant energy consumption. These devices vary in processing power, energy profile, and communication capabilities. Incorporating these challenges in routing decisions is quite challenging. An efficient solution is required to monitor the network devices' residual energy dynamically and compute a path with better energy efficiency. The process will require periodic monitoring and the ability to reroute when the energy level of the set of devices on the selected Path is depleting [34]. While topology changes more often, it may affect the monitoring mechanism. Unfortunately, a lack of centralized network management adds more complexity to the system. Frequent device mobility, addition, and removal may add more processing overhead. Adaptability to the system is necessary, favoring energy-efficient routes while being resilient to topology changes. It impacts the system's Quality of Service (QoS), which poses a significant challenge in energy-aware routing. IoT applications exhibit varying QoS demand. Some applications have stringent delay requirements in real-time, while others need to prioritize energy conservation [29]. Striking the right balance between the former and the latter is a non-trivial problem. Besides, the balance may have another implication on the computational complexity. The communication required for route updates can contribute to unnecessary energy consumption. It is necessary for load-balancing routing to manage this overhead efficiently. Therefore, energy-efficient load balancing routing in SDWN for IoT applications requires consideration of device heterogeneity, dynamic network changes, and diverse applications' QoS demand.

2.4. Congestion management

IoT involves the interconnection of numerous devices and sensors, each generating and transmitting data, which can lead to network congestion [35]. Wireless networks are more prone to transmission challenges. Congestion in IoT arises when the incoming traffic flows exceed the capacity of the transmission resources, which has a significant impact in the context of load-balancing routing [36]. The most common congestion includes link and node levels. The former occurs when buffer/queue overflow, such as when the packet service rate is smaller than the packet arrival rate. In contrast, the latter occurs when many active sensor nodes use the same channel simultaneously to transmit packets. The congestion is not only peculiar to the IoT ecosystem; it may also arise in SDN. Congestion can be categorized into the controller, switch flow table, and transmission link between switches and switch–controller [3]. Congestion on the controller occurs when the number of flow requests exceeds what the controller can handle in a second. A buffer overflow may occur when the number of flow rules exceeds the flow table capacity [37]. Similarly, the communication link between the switch to the controller is constrained with limited bandwidth. It is essential that routing and load balancing consider these challenges for efficient solutions, which may help improve the packet delivery ratio and congestion.

2.5. *Traffic flows management*

The significant growth of devices in modern network infrastructure has created a digital landscape of unprecedented complexity. These devices generate data with different packet size, inter-packet time, and duration [38]. Efficient traffic management has become a critical concern that spans domains ranging from healthcare, data centers, and big data to smart cities [1]. Different communication standards are adapted for these heterogeneous networks [39]. The lack of standardized data formats and protocols is considered one of the most significant challenges of traffic management in the conventional IoT architecture. IoT devices may use different communication protocols, making it difficult to analyze data from various sources [40]. The challenges lie in coordinating the movement of the data, ensuring its timely delivery, and optimizing the utilization of network resources while mitigating the risks of congestion, latency, and inefficiency. Smart health, Urban environment, big data, and many more environments are not exempted from traffic flow management [41]. Smart health and urban environments rely on interconnected sensors and devices to sense and capture data. This has necessitated intelligent traffic management to meet the QoS demand of various technologies. Balancing the demand for mobile IoT devices in both healthcare and intelligent transportation with environmental sustainability requires advanced algorithms and real-time data analyses to manage traffic flows effectively in real-time [42]. Machine learning techniques are widely used to gather, analyze, and predict Traffic flows for various purposes, including adaptive routing with flow management awareness [43]. SDN has recently been used for the dynamic configuration of network resources in real-time [44].

3. Why SDNs in IoT ecosystem and its applications

This section explores the integration of Software Defined Networking (SDN) within the Internet of Things (IoT) ecosystem and other emerging technologies, unfolding in three key areas. Firstly, the study discusses the fundamental principles of SDN, its architecture, and the components that constitute the SDN. Afterward, Empowering IoT Through SDN was discussed to lay the groundwork by elucidating the inherent benefits of SDN while highlighting the dynamic and programmable features that enhanced load balancing routing and other applications of IoT networks. The final section is focused on practical applications of SDN in various emerging

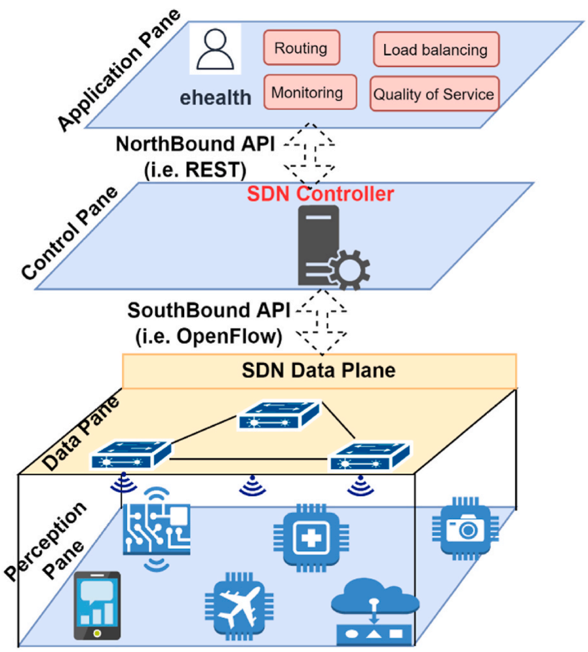

Fig. 1. SDN architecture with perception plane.

technologies, discussing how SDN is strategically deployed in various scenarios to optimize and manage resources. The following subsections detail each area.

3.1. Overview of software defined networking

Software Defined Networking (SDN) is an emerging technology that advocates the separation of network control logic from data forwarding entities. The SDN architecture consists of three plus one functional components, as shown in Fig. 1: Application, Control, Data plane, and perception plane [20]. Some of these planes operate independently, while others operate under instructions from the higher plane. The communication between each plane is through a standardized interface [45]. Network administrators leverage an open standard interface to manage the communication between the network control logic and data forwarding elements to optimize resource usage. More details of SDN can be found at [46,47].

The application plane consists of various network applications for monitoring, routing, load balancing, security, Quality of Services, and many more applications for managing network or service provisioning. These applications create rules using an Application Programming Interface (API) to handle every incoming packet in various network domains, including healthcare IoT, mobility management, and security [48]. For example, security experts may deploy some Access Control List (ACL) to allow legitimate traffic and block suspicious flows. QoS flow-aware applications can also be deployed for emergency and critical data in healthcare IoT to prioritize emergency data on top of the application layer. The communication interface between the application layer and control plane is through a Northbound Interface (NBI) [49]. Initially, REST APIs is used as the NBI, others used includes NETCONF and YANG. However, RESTful API is widely used as the NBI API. It is an architectural style for an API that uses Hypertext transport protocol requests to access and use data.

The Control Plane operate as the engine, providing fine-grained control over the network forwarding entities [50]. It receives high-level policies from the application plane, converts them to service through flow rules, and instructs the data forwarding entities to install them in their data structures to handle data traffic transfer. A single controller may efficiently manage the network business logic and network devices. However, failure to reach out the controller on real time can affect the network performance. Dynamic large-scale networks like IoT may require multiple controllers for efficient network performance. Fortunately, SDNs also support distributed controllers to meet the needs of an emerging network, including IoT environments [45]. These controllers operate in either reactive or proactive mode. The former heavily depends on the controller for any subtle changes in the network. The latter involves minimal controller intervention at the cost of more storage space in the data-forwarding elements. The control and data plane communication is usually through a southbound interface [51]. It's an interface that manages the communication between the control plane and network infrastructure through network programmability and automation. This way, network administrators can configure and manipulate the network infrastructure efficiently. There are several southbound interface protocols [49]; however, OpenFlow is the most popularly used [52]. This way, it provides three different services to the network. Firstly, devices generates control messages upon changes in network status. Secondly, the controller accumulates flow statistics produced by forwarding devices. Thirdly, packet-in messages are generated and send to controller to request how to manage new incoming flows. These three functions are essential in OpenFlow governed networks.

Data planes consist of networking devices, including routers and switches and routers connecting with each other for data transmission. These devices are released from performing any control action, focusing on forwarding traffic flows. The SDN Controller instruct these devices through flow rules on how to process incoming traffic flows. The instruction could be in reactive or proactive mode: the former required switches to consult the controller whenever new traffic flows arrive, and the latter installed flow rules in the switch Flowtable in advance. Flowtable is a logical data structure in the switches to manage traffic flows. The data structure consists of matching, action, and counter. The matching field matches against every incoming packet, while the action is taken based on the matching rules. The counter field maintains the statistical record of successfully matched packets. These traffic flows are translated into flow entries, and the data plane typically processes them using a special data plane processor [53]. However, the Flowtable is built on special high-speed memory Ternary Content Addressable Memory (TCAM). However, its constraint in space and exhibits higher power consumption [54]. Therefore, dynamic large-scale networks, including IoT, may require large storage to manage the network efficiently. The TCAM power consumption and higher IoT device energy consumption may represent another bottleneck affecting the network performance. Several solutions were proposed to address this concern [54,55].

Perception Plane consists of wireless access points, sensing devices, actuators, and other wireless and IoT devices. Wireless facilities are attached to these devices to the data plane [56]. The devices can sense and generate data from various data sources. An aggregator assimilates information produced by the sensor, typically incorporating some nodes responsible for collecting and transmitting the data over the Internet through an IoT Gateway. In addition, the aggregators may merge sensing device in local network, facilitating connectivity between wireless sensor and other node. This way, the integration of SDN features with this perception plane can provide centralize network management while speeding up innovation and enforcing new policy on the IoT realm. Notably, some research has explored the softwarization of Wireless Sensor Networks (WSNs) and IoT; there is an ongoing investigation in this domain. In addition, network complexity is another concern affecting the perception plane. It required an understanding of network infrastructure to program the network to meet emerging network demands efficiently. Standardization policy in the industry is still ongoing to address the data plane and perception plane communication interface [57].

3.2. Empowering IoT through software-defined networking

The proliferation of wireless devices and other smart technologies plays a role in realizing the concept of IoT in different forms nowadays. IoT devices are mostly wirelessly connected through the Internet, serving diverse applications without a single acceptable standard to connect every possible device sufficiently while supporting the concept of a truly connected world. Selecting the correct wireless connectivity and forming a prospective control on an IoT wireless device is quite challenging as a result of the inability of the traditional network to handle its demand. Ref. [58] reports the exponential increase in IoT devices, and the level of their data consumption only reflects how big data growth perfectly overlaps with that of IoT. Managing big data consumption and other advanced technology in a continuously expanding network leads to non-trivial concerns, especially for data collection and processing. The authors explore various big data analytics for IoT ecosystems. Their work emphasizes the significance of big data and its role in investigating big data analytic prospects for IoT systems. The work in Ref. [59] explores how IoT technology is growing enormously in healthcare systems for fitness programs and monitoring systems for better emergency services. However, the sensed data from the medical sensor must be transmitted to a path with higher link quality for efficient data delivery; otherwise, it will affect the data quality. Priority routing was presented in Ref. [29], and the authors devised a scheme to compute a path with minimal latency to forward critical sensed data on time without hurting the data QoS demand. The study reported data and device management were among the challenges in the IoT environment. The diversity, Heterogeneity, and large volume of data generated by the IoT devices motivate the research [60]. The authors survey different approaches for IoT data management, including middleware or architecture-oriented solutions and indexing structured and unstructured data through NoSQL language. Other researchers [61,62] report that the frequency of link failures in IoT networks is higher than the node failures. This way, they leverage SDN features to introduce reactive link failure on SDIoT based on TOPSIS using multi-objective decisions. Their finding shows an improvement in throughput, recovery time, and packet delivery ratio.

Conversely, the application of the IoT realm to a smart environment setting is increasing daily. Smart homes, markets, enterprises, and transport are increasingly equipped with many IoT devices. Ref. [63] presents smart air quality, water quality, and radiation pollution monitoring solutions. However, most operators of such environments lack adequate understanding of their IoT assets for proper management; IoT device functionality with optimal protection from cyber-attacks is quite challenging. The paper in Ref. [64] framework for IoT device classification using traffic characteristics obtained at the network level in a smart environment. A multi-stage machine learning-based classification algorithm was used to demonstrate its ability to identify specific IoT devices accurately. In this way, IoT devices could be adequately managed for better services. The dynamic services offered by IoT devices and the high data generated by these devices lead to significant energy consumption. Processing these data over the network required energy-aware routing. It is a critical concern because IoT devices are constrained with limited resources, including energy, memory, and transmission bandwidth, significantly impacting the lifetime and over-network performance.

Identifying a secure and energy efficient route is regarded as a multi-constraint routing due to the several factors influencing routing decisions. Ref. [63] offers a comprehensive review of routing methods with energy awareness for IoT applications, thoroughly examining diverse techniques and suggesting possibilities for future research. Because, most studies compute paths based on minimal energy consumption or distance, which may introduce routing overhead. Other researchers [65] highlight the importance of incorporating node roles, such as estimating lifetime and congestion levels at the node for the optimal Path. This way, the work in Ref. [65] proposed a routing strategy by incorporating the lifetime and congestion level of the node. Their solution offers less energy consumption with better QoS. However, load balancing aware routing was overlooked in their solution. An efficient routing solution is required to balance the load distribution among different routes. Imbalance load among the network devices may increase latency with higher packet loss and decrease packet delivery ratio, significantly impacting the system QoS. A comprehensive IoT load-balancing survey was presented in Ref. [66]. The paper categorizes load balancing into centralized and distributed computing concerning the number of physical objects employed for exchanging data. The merits and demerits of each approach were highlighted, as well as various challenges and open issues.

Researchers have tried to improve the IoT realm by addressing routing, load balancing, security, device management, and QoS provisioning. However, these solutions are not always as promising as conventional technological solutions. Service providers must investigate various options to satisfy the IoT ecosystem's current demand, sustain the onslaught of many linked devices, and remain competitive. Futuristic technologies become the base of hope, and various technologies are ready to change the course of future world connectivity, including Software-Defined Networks (SDN) [46]. The programmability nature of SDN offers many opportunities for various tasks, such as flexible network management, routing, load balancing, and security, which are key elements in the IoT ecosystem [18]. To this end, various emerging technologies can be integrated with SDN features to produce new framework, like SDIoT. The integration of SDN and wireless body network is another new innovation. Similarly, the other researchers leverage on SDN features to improve the network management in WSN ecosystems. More details of integration of SDN with other technology can be found at [20].

3.3. Application of SDN

The programmable features of SDN with flexible and efficient network management have motivated its application in several ways, including industries and sectors, for better network performance. The size of enterprise networks is typically large and grows rapidly. Similarly, data Centers and Cloud Computing environments require traffic optimization, resource allocation, and efficient management of the virtualized network for dynamic resource management. In this regard, many companies have already applied the SDN in their network to simplify service operations. SDN facilitates network virtualization, enabling the creation of multiple virtual networks on a shared physical infrastructure [67]. This is particularly useful for providers offering multi-tenant services, as it allows each tenant to have its isolated network environment, leading to more flexible and cost-effective network service deployments. SDN has also been applied to geographically distributed networks connecting data centers successfully. B4 [62] is an example of such developments, enhancing bandwidth management for efficient resource utilization.

IoT is another hot area that leverages SDN potential features for efficient device management and communication support for IoT devices. Integrating SDN with IoT provides a dynamic environment for IoT networks, which speeds up innovation. It further facilitates real-time device monitoring and data processing and enhances overall IoT ecosystem scalability [2]. The issues of diverse applications with varying bandwidth and latency requirements in 5G networks necessitated a shift from conventional networks to the SDN paradigm [68].

Other application areas include campus networks for educational institutions. It allows for centralized access control management, policy enforcement, and network segmentation, making it easier to adapt to changing user and device requirements [52]. SDN has shown rapid evolution in cellular and wireless networks. Blockchain is another technology that leverages SDN's features to provide better security and network management in IoT environments. Applying artificial intelligence to SDIoT is another promising application for data management in IoT. Table 2 summarizes some applications of SDN in various emerging technologies.

4. Research methodology

The study formulates some research questions to ensure comprehensive and unbiased coverage of the literature. These questions were used to search for related work using various keywords in different data sources. The study carefully searches and include the most related and relevant documents while excluding irrelevant and out of scope references. Thereafter, the articles were screened and evaluated to assess the quality of the manuscript. This way, it follows established guidelines and best practices for conducting systematic literature reviews, which aim to minimize bias and enhance the validity of the findings.

Research Questions and Motivation: this study considered six (6) different research questions and motivations as summarized in Table 3. These questions analyzed the fundamental research challenges and approaches proposed to address load-balancing routing in SDIoT and SDWSN.

Keywords: various keywords were used to identify and select the most relevant references. The study uses various strategies to screen in and out references based on the Boolean operator, a search string tailored to the research topic. Table 4 summarizes the selected keywords.

Searching process: the study leverages various scientific databases and repositories as shown in Table 5 to search for related works using the keyword in Table 4. The study used logical operators "AND" and "OR" to associate words. We used the searching string ([B1, S1] OR [B1,S2] OR [B1,S3] OR [B1,S4] OR [B1,S5] OR [B1,S6] OR [B1,S7]) AND ([B2, S8] OR [B2, S4] OR [B2, S3]). Many articles were screened out as a result of incompatible titles and mismatches of abstracts. Afterward, an adequate number of articles were considered based on the search results.

Inclusion and Exclusion Criteria: The inclusion and exclusion criteria to filter the most relevant papers are summarized in Table 6. The study screens articles based on title and abstract against the inclusion and exclusion criteria. Thereafter, full article texts are read and assessed against the same criteria to determine their eligibility and quality for inclusion. Fig. 2 shows the number of published articles selected for the present document per year. Similarly, Fig. 3 illustrates the articles published by reputable publishers between 2019 and 2023. The articles were categorized based on issues affecting load balancing routing and approaches based on classic mathematical optimization-based, Context-Aware, Nature-inspired, and artificial intelligence-based approaches.

4.1. Rationale of the proposed study and its intended audience

The rationale behind this study is that the Internet of Things has potentially shaped individual lives, including industrial sectors with various features. Unfortunately, the number of devices increases by the day, and the conventional network fails to manage the network efficiently due to the decentralized nature of the network architecture. Several researchers leverage the new features introduced by software-defined networking and devise various frameworks. However, there is a need to efficiently balance network resources for optimal usage with better performance. Load balancing routing in SDN-enabled IoT networks seems to receive less attention. This, in turn, leads to inefficient utilization of network resources for both the IoT ecosystem and SDN. This study found the need to elaborate more on these issues while analyzing the existing studies. Therefore, a survey is presented to classify the existing literature while synthesizing their weakness and pointing out some unanswered research questions that need further investigation.

Table 2
Application of SDN in various emerging technologies.

Reference	Area	Description
[24]	SDN with Blockchain in IoT ecosystem	SDN was integrated into blockchain technology to provide better network management in IoT environment
[69]	Software Defined Internet of things	It's a framework that integrates SDN into IoT environment for effective services provisioning and the IoT servers load balancing.
[70]	BlockChain and SDN into a cloud computing platform for the IIoT	SDN is integrated with blockchain to enhance cloud computing security for smart IIoT applications.
[71]	SDN in e-healthcare for IoT system	SDN is integrated with e-healthcare to control resources for the healthcare IoT system
[72]	SDN and Artificial Intelligence	Artificial Intelligence is applied in SDN for security detection in emerging network technology.
[20]	SDN with WBAN, Wireless, and IoT	IoT ecosystem mart technologies management based on Software Defined Networking architecture

Table 3
Research questions and motivation.

Research Questions	Motivations
RQ1: What are the main challenges in the IoT ecosystem in achieving optimal load-balancing routing?	To understand the various challenges affecting load balancing routing in IoT
RQ2: How do resource constraints affect optimal load balancing in an IoT environment?	It helps guide researchers in incorporating such resources during load-balancing routing decisions.
RQ3: How SDN can be integrated with IoT to achieve better performance	To study how SDN can be used to overcome the challenges of conventional networks for better network performance
RQ4: What are the various SDIoT and SDWSN load-balancing routing approaches	To understand and analyze the weaknesses of the existing schemes
RQ5: What are the possible postmortem challenges of integrating SDN with other emerging technologies	To understand the possible challenges that may arise after integrating SDN with other technologies
RQ6: What are the possible research trends and potential future research directions	To highlight the potential unanswered question that may require further research investigations

Table 4
List of string and keywords.

String	Batch1 (B1)	Batch2 (B2)
String1 (S1)	Internet of Things	IoT
String2 (S2)	IoT load balancing routing challenges	Internet of Things routing with resource awareness
String3 (S3)	IoT load-balancing routing	Internet of Things Optimized routing
String4 (S4)	Wireless Sensor Network Load balancing	WSN routing, load balancing
String5 (S5)	SDIoT load balancing routing	Software Defined Internet of Things optimizes load balancing
String6 (S6)	Software Defined Wireless Sensor Network routing	SDWSN load balancing routing
String7 (S7)	Software Defined Networking	SDN
String8 (S8)	IoT Application, Nature Inspire, Optimization load balancing routing	Artificial Intelligence, Context-Aware Optimization load balancing routing

Table 5
Data source and repository and URL.

Digital Library	URL
Web of Science	https://www.webofscience.com
IEEEXplore	https://ieeexplore.ieee.org/Xplore/home.jsp
Springer	https://link.springer.com/
ACM Digital library	https://www.acm.org/
Google Scholar	https://scholar.google.com/
Scopus	https://www.scopus.com

Table 6
Inclusion and exclusion criteria.

Inclusion	Exclusion
The articles are only written in the English language	Non-English language articles
The papers that focused on load-balancing routing in SDIoT and SDWSN	The papers that focused on load balancing routing on SDN without other emerging technologies
The articles that were published in indexed and reputable journals and conferences	Non-indexed journal and conference articles
The articles that cover the Application of SDN in IoT	Papers covering SDIoT for Fog and cloud computing

This study targets novice researchers and those interested in integrating software-defined networking with other emerging technologies, especially IoT and wireless sensors, to manage the network efficiently and optimize network resources through load-balancing routing.

5. Classification of software-defined wireless network load balancing routing approaches

The Software Defined Wireless Network Load-balancing Routing Approaches are classified based on technical principles as presented in Fig. 4. Most load-balancing routing approaches are divided into classic mathematical optimization-based, Context-Aware, Nature-inspired, and artificial intelligence-based approaches. In addition, several technical methods have been integrated from various studies. The study searched various scientific databases and search engines based on the established methodology discussed in the previous section. The following subsections discuss and analyze each approach.

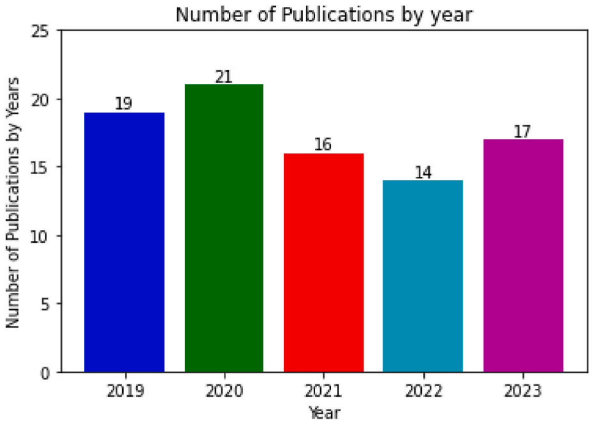

Fig. 2. Articles published by year.

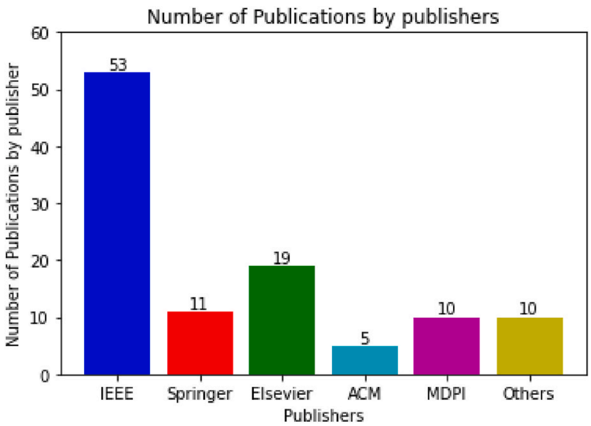

Fig. 3. Distribution of publications by publishers.

5.1. *Classic mathematical optimization-based based load balancing routing*

The growing number of IoT devices generates high traffic volumes, leading to heavy network loads and congestion. Classic mathematical optimization-based load balancing involves using mathematical models and algorithms to optimize workload distribution across resources in a network or computing environment. The goal is to achieve different objective functions, including efficient resource utilization, minimize response time, and ensure that no single resource is overly burdened. Various optimization techniques and algorithms can be applied to address load-balancing challenges, as summarized in Table 7. The work [21] proposed Optimized load balancing for effective network flow management, reducing network congestion in SDWN based on the optimization process. The authors combine two network forwarding elements manage by distributed controllers. One controller was used to manage the sensor environment while the second for wireless. This way, the packet delivery ratio was improved with better network efficiency. However, the data plane comprised different networking nodes; some were overutilized, while others were underutilized. Therefore, Ref. [21] overlooked classifying these nodes for fairness, and Ref. [73] argued that load balancing should consider two challenges: identifying the load on the device and disassociating devices from overutilized devices. The authors proposed a Fairness and Load Balancing mechanism based on Network Load Monitoring, Handoff-Delay, and Association Control. The mechanism continuously monitors the network's load to identify any disparities among the devices, allowing it to maximize their utilities while accounting for the handoff delay costs using discretized linear programming and general assignment problem theory. This way, it outperformed the conventional method with higher throughput. However, the quality of service was overlooked; flows exhibit variabilities with different conflict quality of services. The Approach overlooked the QoS demand of various flows.

Ref. [74] presents a load-balancing mechanism in a smart city. The solution leverages a monitoring mechanism to periodically monitor network resource. This way, the bandwidth demand of flows was studied, and afterward, an optimization solution was formulated to optimize the link load to route flows based on their bandwidth demand. To further improve the video transmission service of multimedia applications. The work in Ref. [76] proposed a strategy to estimate the level of congestion on network resource. The authors model the problem as bitrate adoption problem and leverage on probability to estimate the level of link congestion. The solution adjust the video bitrate periodical while keeping congestion below a threshold level. Although there was an improvement on

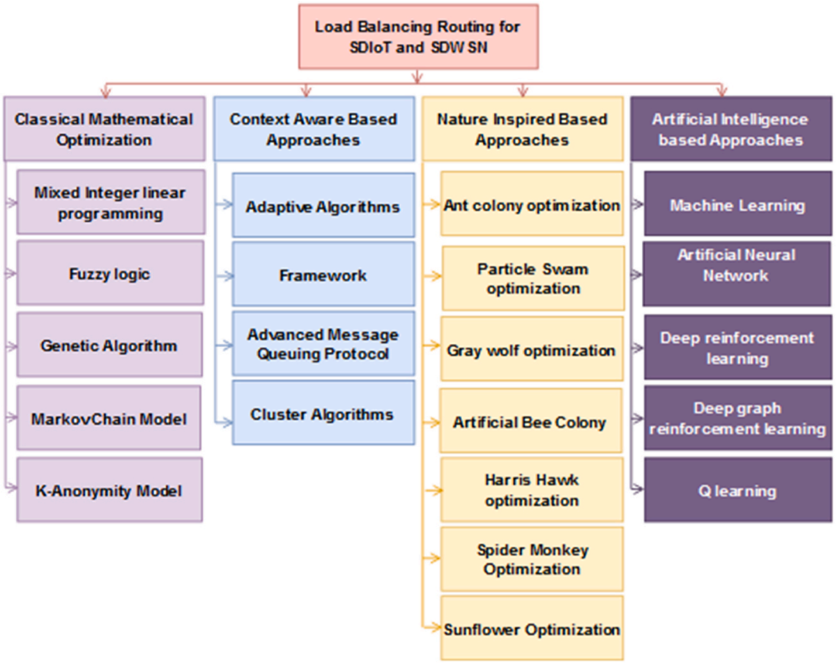

Fig. 4. Taxonomy of classification of software-defined wireless network load balancing routing approaches.

Table 7
Comparison of classic mathematical optimization-based based load balancing routing.

Reference	Problem address	Approach	Application	Strength	Remark
[21]	Network congestion	Mixed-Integer Linear Programming (Optimization)	IoT	Improve packet delivery with less network congestion	Convergence time may be higher due to MILP complexity time
[74]	Link load and Flows Quality of Services	Optimization	SDWSN in Smart City	Improved node traffic and throughput	Overlooked node load classification
[73]	Unevenly distributed load among network resource	Optimization	SDWN	It outperformed the conventional method with higher throughput	Flows quality of service was overlooked
[75]	Energy consumption	Ant Colony Optimization and Fuzzy Logic	SDWMN	Reduced energy consumption with better QoS provisioning	load balancing and admission control issues were overlooked
[76]	link congestion	Optimization	SDWMN	link utilization was improved	They overload integrating link and node load for efficient congestion management.
[77]	Dead nodes survivability	Genetic algorithm	SDWSN for IoT Application	The Approach achieved higher network lifetime and throughput	Convergence time may be higher due to MILP complexity time
[78]	Selecting a precise neighbor/device during routing	multi-criterion hysteresis optimization routing	SDIoT	Improved throughput, request delivery ratio, delay, and response time,	multicriteria computation may lead to extra processing overhead.
[79]	QoS routing among different smart devices for routing	Optimization	Software-defined Industrial Internet of Things	Improved average time delay, goodput, throughput, and download time	This may lead to computational overhead
[80]	Dynamic load balancing routing	Markov Chain and optimization problem	SDWSN for IoT Application	Improve energy consumption and system throughput	It may lead to higher computation as the network increases in size.
[81]	Striking balance between energy, reliable routing, and security levels	k-anonymity model	SDWSN	Optimized energy consumption and improve life time	it may be complex to handle massive data flow, and controller overhead is high

video transmission. However, the demand in wireless environment is beyond QoS provisioning. Energy consumption is a non-trivial concern in wireless ecosystems. Ensuring energy efficiency and maintaining QoS poses increased difficulty within wireless mesh networks.

The study described in Ref. [76] formulates a prospective routing solution that prioritizes energy efficiency and QoS to reduce energy usage while ensuring a specific QoS for multimedia based on Integer Linear Programming (ILP). This solution involves assessing the cost of individual network links through a fuzzy logic system, considering multiple metrics. The authors then employ a meta-heuristic, using the ant colony algorithm, to find an optimum solution to the problem. However, this solution fails to address load balancing and admission control issues. Moreover, it lacks network stability and reliability, particularly in scenarios involving dead nodes. An energy aware routing algorithm was proposed in Ref. [77] to improve the lifetime of network node. Both SDN and IoT ecosystem has some resource with power constraints. This way, the authors focused on controller placement problem aimed at improving network reliability and stabilize the node lifetime. Similarly in Ref. [82], the CPP was modeled as NP problem and cluster head was chosen based on its residual energy. This way, the Approach achieved higher network lifetime and throughput than benchmarking works.

Another interesting multi-criterion hysteresis optimization routing has been proposed in Ref. [78]. The study classify next neighboring IoT node based on three criteria on the basis of their consistency. This way, optimal device is included during routing decision while an optimization solution was used to identify reliable node among others. However, multicriteria computation may lead to extra processing overhead.

Other researchers leverage incorporating SDN and edge computing in IoT ecosystems to devise an optimal routing solution. Ref. [79] proposed an adaptive routing transmission architecture to improve network latency. They facilitate data exchange involving various smart devices with varying delay requirements. The proposal suggests an integrated framework that combines a global centralized software-defined network and edge computing. This Framework aims to identify the optimal routing path for data flow within the Industrial Internet of Things (IIoT), considering deadlines, traffic load balancing, and ensuring energy consumption efficiency.

Although the works in Refs. [75,75], and [77] have presented various energy-aware solutions, they have not investigated the dynamic routing in SDWSNs for IoT applications. To overcome this challenge, Ref. [80] proposes an energy aware dynamic routing algorithm. The solutions work in three phases; the first phase focuses on investigating time-varying characteristics of SDWSNs; afterward, the Markov chain is used to compute the node's state-transition probability. A dynamic link weight is devised based on link reward and cost. The link reward is associated with link energy efficiency (EE) and node, while node locations influence the link cost. The scheme leverage on adjustable coefficient to main balance on link reward and cost. Thereafter, the energy routing is modeled as optimization problem. The solution identifies the optimal relay based on energy efficiency derived from the formulated link weight. This way, energy consumption and throughput were improved.

Several researchers focused on optimizing the energy consumption of sensor nodes in wireless ecosystems. Other researchers [81] argued that there is a big challenge in balancing among energy consumption, reliability and security levels in routing due to resource limitation constraints withing the sensor nodes. To address this challenge, they introduced an energy-aware topology management and routing algorithm. The authors devised a mutation approach to suggest several paths based on composite metrics. Although, the Approach has optimized energy consumption while improving resource life time. However, the SDN controller may easily be stress as the network size increases, the processing load may also augment.

5.2. Context-aware load balancing routing approach

Context-aware load balancing routing is widely used in Software Defined Wireless sensors for various Internet of Things applications. It considers various contextual factors to distribute network traffic and other services among network resources efficiently. Context-aware load balancing goes a step further by considering additional information about the current state of the network, servers, or the application itself. A framework was presented in Ref. [83] to balance the load between IoT devices based on SDN principles. The Framework applies different management strategies in a distributed manner to distribute tasks between devices equally while accelerating data management among IoT devices. This way, average waiting time and processing performance were improved. However, IoT devices are known for complicating QoS demand. Unfortunately, the Framework overlooked those demands.

Ref. [84] proposed QoS Path Selection and Resource-association, and a QoS-based path selection scheme is proposed for adaptive load balancing to improve the network performance of SDWSN. However, the diversity of network traffic with varying loads could lead to performance bottlenecks, which could decrease transmission quality because the routes may pass through multiple hops. Ref. [85] developed load-balancing solutions to guarantee transmission quality in the wireless ecosystem. This way, links are selected based on composite metrics, signal-to-noise ratio, and probability. The link that meets the aggregated metrics value is selected for onward traffic transmission. However, there were some improvements in packet delivery ratio and throughput. However, they overlooked classes of traffic that should be treated separately and focused on improving the quality of routing links. To overcome these challenges, work in Ref. [86] presented a framework for Load balancing and QoS provisioning. The authors introduced congestion detection, load balancing, and QoS provisioning modules. The congestion detection module periodically monitors the network to obtain its load. Once the network congestion is detected, the load balancing module will be initiated to balance the load based on the path load. At the same time, QoS provision addresses the challenge of handling a mixture of QoS demands while considering best-effort user traffic without compromising the performance of non-QoS Traffic. This way, the Framework handles heavy load while satisfying the QoS demand of different flows without starving the non-QoS user traffic.

The rapid development and growth of WMNs attract ISPs to support users' coverage anywhere, anytime. However, most of the previous solutions overlooked the role of SDN in managing the architectural concerns of the WMN. Ref. [87] leverages the SDN controller to aggregate the entire topology discovery and monitor the QoS properties of extended WMN nodes. This way, topology discovery and QoS monitoring were improved for flows for complicated QoS demand. QoS requirements are essential because various applications with different demands rapidly evolve in the wireless sensor ecosystem. Providing the required QoS in a communication network is inevitable. As such, QSDN-WISE was presented in Ref. [88]. The authors added modules to enable node cluster formation and improve QoS. This way, double-cluster heads were used to mitigate the energy hole problem by distributing the energy consumption and workload among multiple cluster heads, thereby improving the overall energy efficiency and network lifetime. However, the paper does not discuss the potential impact of the proposed protocol on network latency and overhead, which are crucial factors in real-time applications. A multi-hop routing approach was presented in Ref. [89] to reduce sensor nodes' energy consumption. The authors devised three algorithms: a neighbor discovery algorithm, a status data collection algorithm, and a controller operation phase algorithm. The controller utilizes distance and residual energy as parameters to compute the routing path in their design. The SDN controller updates the routing table whenever it detects a node that has depleted its energy or fallen below the user's specified threshold. The work claimed to have improved network life time with optimal energy consumption while increasing packet delivery ratio. However, its protocol dependent and network size. Increasing the network size may augment the overhead on controller, affecting the system performance.

Ref. [90] presents energy consumption solutions and control overhead reduction techniques for prolonging the network lifetime. In their solution, Controller was used to periodically obtain the general network view. Afterward, the residual energy of paths were obtain and the path with higher residual energy is return among several paths for data transmission. Although the solution prolongs the network lifetime and minimizes control overhead while increasing the packet delivery ratio, The advantage is at the cost of longer path length leading to higher update operation. As the demand for IoT keeps growing, many smart devices may gradually generate more updated operations, leading higher packet-in messages between SDN controllers and forwarding entities. Unfortunately, frequent network monitoring may affect the performance of controller. In addition, its constraint with number of requests to handle per unit of time. These concerns have negative impact on load balancing routing as the network augment. To handle such a scenario with better load balancing, the work in Ref. [91] balance the load among controllers based on switch migration technique. The solution classified controllers as over and underutilized. This way, a multi-criterion was used to identify overloaded controller and move some switches to under load controller. The result indicates that the proposed solution reduces communication overhead with efficient load distribution.

The study in Ref. [92] noted the rigid nature of IoT architecture and proposed SDIoT load balancing framework for large scale in IoT ecosystem. The authors created a controller pools among several controllers. Afterward, they categorized the controllers as main and basic controller in the pools. Thereafter, a dynamic load balance was devised among the main controllers based on election and optimally balance the load on the basic controllers. This mechanism reduces latency and ensures message consistency among the main controllers. However, it is noteworthy that a high overhead burdens this Approach.

A comparative Table 8 was presented to summarize the related works. The summary indicates some researchers focused on balancing the load among IoT devices. Others introduced load-balancing approaches based on network resources. Energy consumption is another metric that was considered during load-balancing routing. Some scholars consider the QoS demand of different flows and route them through a path with sufficient QoS.

Table 8
Context-aware load balancing routing approach.

Reference	Problem address	Approach	Application	Strength	Remark
[83]	Load balancing among IoT devices	Adaptive load balancing	SDIoT	Improved average waiting time and processing performance	Overlooked Flows QoS demand
[84]	Network Resource Management	Adaptive load balancing	SDWSN in IoT	Reduce computation and improve resource utilization	Communication overhead
[85]	Unbalanced traffic load	LBRCQT algorithm	SDWMN	improved packet delivery and throughput while reducing delay	Overlooked traffic flow variabilities, which have an impact on QoS.
[86]	Load balancing and QoS provisioning	Load balancing Framework	SDN	Can accommodate more heavy flows than benchmarking works.	It may not be scalable to large-scale networks because of single-point failure.
[87]	Network Architecture Problem	Advanced Message Queuing Protocol	SDWMN	Improved topology discovery and QoS monitoring	Frequent topology monitoring may induce additional processing load on the controller.
[88]	Network Quality of Service	clustering algorithm	SDWSN in IoT	Improved QoS for multimedia flows	It may impact network latency and overhead, which are crucial factors in real-time applications.
[89]	Energy consumption	Energy-aware adaptive algorithm	SDWSN	Optimized energy consumption	Frequent Involvement of SDN controller can lead to extra processing load
[90]	Energy Consumption	Energy-aware algorithm	Industrial Internet of Things (IIoT)	prolongs the network lifetime and minimizes control overhead while increasing the packet delivery ratio	The advantage is at the cost of longer path length leading to higher update operation
[91]	Load balancing among multiple controllers	Load balancing Framework	SDIoT	Reduces communication overhead with efficient load distribution	The solution may not be efficient in large-scale IoT environments
[92]	Load balancing among controllers in IoT environment	load-balancing routing framework	SDIoT	Better CPU utilization with minimal response time	May suffer from high communication overhead

5.3. Nature inspire load balancing routing solution

Adopting the number of gadgets will surely increase the load of the heavy network, affecting the system performance or flows with various QoS demands. Nature-inspired algorithms are widely used for load balancing in many emerging networks, including IoT, SDN, and other wireless ecosystems, due to their ability to mimic and adapt strategies observed in natural systems. These algorithms are designed to optimize and distribute workloads efficiently, drawing inspiration from the self-organization and adaptability found in biological and ecological systems. The Ant Colony Optimization (ACO) algorithm is widely used for Load Balancing of SDN among several existing optimization algorithms. The model in Ref. [93] proposed a G-ACO SDN LB system that combines the GA's mutation, crossover, and collection operations with the ACO algorithm for an increased track search speed. Although the solution has a higher searching optimal path, round trip time, and lower packet loss rate. However, their solution may exhibit higher energy usage. The work in Ref. [94] noted the performance of cluster routing for minimizing energy. However, cluster hotspot is among the issues that affect the efficiency of cluster routing. As such, the authors introduced hybrid fork and adaptive particle swarm optimization (PSO) to optimized the energy consumption while avoiding collision and improved life time. PSO was used to calculate the cluster head while traverse path and switch between based station, as similarly introduced in Ref. [95]. However, The lack of comparative analysis with other existing protocols makes it challenging to determine the superiority of the proposed protocol in terms of energy consumption, network lifetime, and control overhead.

Similarly, in Ref. [96], a green routing algorithm was introduced utilizing meta-heuristic principles in Software-Defined wireless sensor networks. The algorithm leverages the Gray Wolf Optimization (GWO) algorithm to enhance routing decisions, considering the network's condition through factors such as average intra-cluster distance, average residual energy, cluster size, and average distance from cluster heads to the controller. It is noteworthy, however, that the algorithm operates assuming that the network is static and the nodes are homogeneous.

The scheme in Ref. [97] proposed QoS-based load balancing routing to reduce energy consumption and improve networks' lifetime. The scheme maintains load balancing between Cluster Heads while the Markov Model and the Artificial Bee Colony (MMABC) algorithm were used to find the best candidate nodes of each cluster to be turned into a Cluster head. The simulation results indicate efficient energy utilization with more alive nodes and packet delivery ratios. However, In SDWSN, the control node is responsible for forwarding the processed data to its neighboring control server. Unfortunately, the control server required more energy and operated with limited battery capacity. A Harris Hawks Optimization solution was presented in Ref. [98] to improve the energy consumption of the Control Server and placement in SDWSN. The solution results outperform the benchmarking results with better energy efficiency,

Table 9
Comparison of nature inspire load balancing routing solution.

Reference	Problem address	Approach	Application	Strength	Remark
[93]	Resource usage	Ant Colony Optimization (ACO)	SDN and IoT	Improved the processing time to select an optimal path while decreasing flows round trip time.	This may lead to higher controller overhead
[94]	Energy consumption	fork and join adaptive particle swarm optimization (FJAPSO)	SDWSN and IoT	Maximizes the network lifetime	Overlooked the energy consumption of SDN resources
[95]	energy and computational overhead hotspot problem in cluster-based routing	particle swarm optimization and artificial bee colony algorithm	Mobile-based SDWSN	Optimized energy usage and reduce processing overhead	The lack of comprehensive analyses makes it challenging to determine the superiority of the solution
[96]	Energy consumption	Gray Wolf Optimization	Software-Defined Wireless Sensor Network	The solution has improved network lifespan, residual energy, network throughput, and convergence rate.	The algorithm assumes that the network is static and the nodes are homogeneous.
[97]	Energy consumption	Markov Model (MM) and the Artificial Bee Colony (ABC)	Wireless sensor in IoT	Improved number of alive nodes and number of delivered Packets	Overlooked balancing the load on SDN resources and update operation
[98]	Control Server energy consumption and placement	Harris Hawks Optimization	SDWSN	Enhances the lifetime of the SDWSN with better load balancing	The solution may lead to extra processing overhead in the system
[99]	Optimized routing based on network resource	Genetic Mutation Based PSO (GMPSO)	IoT enabled SDWSN	Improve Control node selection and Path Optimization	It may lead to higher controller processing overhead especially in large network
[100]	Controller load balance	Spider Monkey Optimization Algorithm	SDN and IoT	improved throughput and average response time	The swapping process of moving switches from utilize to under may introduce additional overhead
[101]	Controller load balance due to an increase in the delay	Enhanced sunflower optimization (ESFO) algorithm	SDIoT	Improved latency between controllers	It may exhibit slower convergence speed in large-scale network

load balancing, and delay performance metrics. However, implementing these algorithms in the entire routing process may lead to extra processing overhead in the system, leading to inefficient resource utilization.

Implementing intricate scenarios, such as selecting and managing nodes for specific functions within low-power and lossy networks, comes with numerous challenges. Designing an efficient load-balancing routing mechanism becomes essential to minimize energy consumption during task execution and data transmission. The task of selecting optimal nodes and reducing the search space among numerous nodes is known to be NP-hard. Ref. [99] introduced a solution that prioritizes energy efficiency, utilizing particle swarm optimization (PSO) for optimal node selection. This solution is tailored for SDIoT systems functioning within heterogeneous multi-sink structures. Energy and throughput were improved; however, it may lead to high controller overhead due to a lack of fitness calculation and consideration like controller distance, Although, previous studies have made significant improvements in balancing the load among devices. However, the SDN controller offered many services to stabilize the networks. An increase in the exchange of messages between the controller and other data-forwarding elements will augment the workload on the controller. As the number of IoT devices increases, the flow processing time also augment. This is negative impact not only to controller but also the flowtable update operation, affecting performance. An efficient load-balancing approach is necessary to consider the controller component for an efficient solution. Ref. [100] presented an efficient load-balancing technique that chose the controller with the least load controller using the Spider Monkey Optimization Algorithm-based load-balancing method. The scheme estimates the load of each controller in the network. If the load reaches a threshold value, the controller is declared overloaded, and the Spider Monkey optimization algorithm (SMOA) will be activated to select an optimal controller with minimal load. Afterward, some switches will be moved to the underutilized controller. This way, throughput and average response time are improved. However, the swapping process of moving switches from overutilized to under may introduce additional overhead. The latency between the controllers is another challenging factor affecting the system performance. The messages synchronization between controllers is the most challenging factors especially in large scale network. To address this concern, the study in Ref. [101] introduced adaptive CPP based on sunflower optimization. The proposed solution outperforms other natures inspired algorithms with better latency.

The aforementioned nature-inspired load balancing routing strategies seems to offer various promising solutions using different meta-heuristics algorithms. To this end, most of the solutions tried to optimized energy usage among the network resources in the IoT realm considering difference metrics as summarize in Table 9. However, most of them exhibit certain limitations and research gaps. Controller processing overhead is among the most performance concerning. It play a significant role in network operation and overburdening it could significantly affect the network performance, the worst case could bring the entire network down. Selection of control node among cluster nodes is another concern due to its high processing time, affecting flows with stringent delay requirement. Node selection and high controller overhead may come with energy cost. Additionally, the absence of fitness calculation can result in premature convergence of nature-inspired algorithms, leading to suboptimal network performance.

5.4. *Artificial intelligence-based load balancing routing approaches*

IoT environments are characterized by dynamic and complex network conditions due to the large number of devices with different applications generating varying traffic patterns and network loads. As such, load balancing requires quick and informed decisions to optimize resource utilization and reduce latency. Artificial Intelligence (AI) is widely used for load balancing in many emerging networks, including SDN and IoT, due to its ability to analyze complex data, make intelligent decisions, and adapt to dynamic network conditions. The diverse applications in IoT require high-quality service in the transfer of data. An intelligent routing was presented in Ref. [102], and machine learning algorithms were deployed to classify and predict traffic based on protocols. Afterward, multi-composite metrics were used to compute Path for various applications. This way, the performance of six machine learning algorithms was evaluated; Random Forest has 100 % accuracy. Ref. [103] presents an SDN-based framework tailored for IoT environments. Specifically, the proposal introduces two intelligent SDN controllers. The former controller leverage neural network variant to predicts flows in designated sensing area. While, the latter employs an artificial neural network (ANN) to determine and select the cluster head and its members within specified sensing area. This way, QoS is improved; however, achieving better QoS requires further investigation of various traffic flow demands. Further research on latency, throughput, and energy consumption is needed.

Q-learning algorithms are another model widely used to optimize network traffic distribution among various paths in an IoT environment that employs SDN principles. Because IoT devices generate various applications with different QoS demand. Unfortunately, the devices are energy-constraint, and some applications require minimal delay. Addressing the need to optimize energy and network latency is essential in the IoT ecosystem. A research paper in 86] presented a dynamic strategy for scheduling and assigning tasks utilizing deep reinforcement learning (DRL). This approach frames the problem of task assignment and scheduling as a Deep Q-learning process constrained by energy considerations, showing encouraging outcomes. In large-scale IoT networks, Ref. [87] incorporates a Q-routing algorithm to optimize the routing of extensive data with a simultaneous reduction in energy consumption. The proposed approach demonstrated notable enhancements in latency, packet delivery ratio, and energy consumption.

Reinforcement Learning (RL) offers several advantages that contribute to the optimization and efficiency of network operations. As such, other research researchers leverage its advantages to devise load-balancing routing. A software-defined wireless sensor networks (SDWSNs) controller was trained based on reinforcement learning [104] to improve the routing path. The researchers combined reinforcement learning and Software-Defined Networking (SDN) to create routing tables within the SDN controller. To boost network performance, their solution introduced four distinct reward functions. Compared to routing algorithms based solely on reinforcement learning, the proposed solution substantially improved network performance, particularly in terms of its lifetime. However, the authors overlooked the Quality of services, which may reduce network performance. To overcome this challenge, Ref. [105] argued that the existing routing schemes are unoptimized and the need for optimized routing is paramount especially for IoT applications with different flows QoS demand. The authors proposed optimize routing based on RL to select path with optimal capacity while minimizing energy usage in SDWSN based on RL. A reward function was introduced based on energy and QoS. The agent obtain rewards and decide based on the received rewards while SDN controller select the best path based on the previous reward history. This way, network life time was improved with higher packet delivery ratio. However, network are bound to changes and the frequencies of network downtime have been reported lately. Its essential to efficiently design a routing solution for better performance. The authors in Ref. [106] proposed multi-objective energy aware routing based on RL aimed at optimizing energy during routing. The authors noted reward in learning process as one of the challenges affect RL solution. This way, they considered correlated objective to speed up the learning process. As such, their solution can adapt to unprecedented network changes with higher packet delivery ratio.

High traffic volume is one of the factors leading to network congestion and decline in packet delivery ratio, affecting optimal routing. The work in Ref. [107] introduced an intelligent routing based on deep graph reinforcement learning for efficient traffic control. An intelligent was incorporated in the controller to extract the network information. This was information was used to trained the model and the data forwarding elements, including the sensor nodes were instructed by the controller to optimize the forwarding process. This way, the model was able to reduced congestion and improve packet delivery ratio. Unfortunately, their solution overlooked extending network life time. It plays a significant role in sensing devices due to their limited energy constraint. As the life time decline, it may affect the data transmission there by reducing packet delivery ratio. In contrast.

The study in Ref. [108] noted the importance of having an active paths all the time for better quality of QoS especially for delay sensitive applications. The authors proposed application aware routing based on RL for SDWSN ecosystem. They leverage on cluster algorithms and re-clustering delay tactics to save energy during routing. These tactics will reduce the cluster radius on energy consumption as well as quality of transmission links. After the clustering process, an SDN controller was used to determine and optimal path using RL reward function. This way, the solution could improve the energy usage and reduce post-routing network downtime with higher responsiveness.

Although the references mentioned above have made various improvements, SDN controllers may be overwhelmed in wide area networks as the traffic increases. It can exhaust the processing capacity of the controller, affecting the system QoS. To address this challenge, authors in Ref. [109] presented DRL in Software Defined -Wide Area Network (SD-WAN). Their solution can potentially balance the load on network resources with minimal delay and better network sustainability. However, managing distributed controllers in dynamic large scale network with higher energy usage in real-time monitoring may be quite a challenge. In Ref. [110], A conceptual framework known as the Controller Mind Framework was proposed for the automated coordination of multiple controllers

Table 10
Comparison of AI-based load balancing routing approaches.

Reference	Problem address	Approach	Application	Strength	Remark
[102]	Routing in heterogeneous IoT	Machine learning	SDIoT	Support interoperability between heterogeneous devices.	It lacks a detailed implementation analysis.
[103]	Congestion on controller	Artificial neural network	SDIoT	Improved QoS	Further investigation of latency, throughput, and energy consumption is required.
[111]	Energy-aware routing	Deep reinforcement learning (DRL)	SDIoT	Optimized energy and reduced delay	Overlooked incorporating SDN resource constraints component
[112]	Energy efficient routing	Q-routing algorithm	SDIoT	Reduced end-to-end delay and improved packet delivery ratio, energy-consumption	The SDN controller may be overwhelmed in dynamic large-scale network
[105]	Optimized routing path selection	reinforcement learning based SDWSN	SDWSN	Improved network lifetime and packet delivery ratio	May introduce extra processing load on the controller
[106]	energy optimization in IoT networks	Reinforcement Learning with Dynamic Objective Selection	Software-Defined Wireless Sensor Networks	Improved energy enhanced the packet delivery ratio while reducing data delivery latency.	Limited routing parameters were considered, which may not meet the demand of various flows.
[104]	Energy-aware routing	Reinforcement learning	SDWSN	Improves network performance in terms of lifetime	They overlooked the Quality of services, which may reduce network performance.
[107]	Intelligent routing scheme	Deep graph reinforcement learning (DGRL) model-	SDWSN	Improved packet transmission and network congestion.	It may face challenges when dealing with highly complex graph-structured data in large-scale network.
[108]	Application-specific Routing	Reinforcement Learning	Software Defined Wireless Sensor Networks	Improved network operational lifetime and response time	May not perform well in a large-scale dynamic network environment
[110]	Quality of Service (QoS) enabled load balance Energy-aware routing	Markov Decision Process (MDP) and Q-learning	Software energy internet	Improved load variation and average waiting time	It may have lower robustness to the burst traffic in large-scale dynamic networks.
[109]	Load balancing due to congestion	Deep reinforcement learning (DRL)	SD-WAN	Optimize delay and improved network life time	Focused on balancing the load on the controller only without incorporating the data forwarding element

in distributed Software-Defined Edge Infrastructure (SDEI) using Reinforcement Learning (RL). The issue was framed as a Markov Decision Process (MDP). Q-learning was utilized to determine the optimal strategy for distributing packet-in messages from the data plane to the control plane. The aim was to minimize the waiting time for Quality of Service (QoS) flows and maintain an acceptable packet loss rate for best-effort flows.

Table 10 summarizes various solutions that leverage advanced artificial intelligence and machine learning approaches to dynamically distribute load among various resources while optimizing resources with better network performance. The table analyses the problem addressed, and the pros and cons of each solution were highlighted.

6. Summary of load balancing routing approaches proposals

This section summarizes the focus of the existing load-balancing routing based on network resources. Fig. 5 shows the percentage of the research work based on network resources during the load-balancing decision. Most of the proposed research leverages the SDN features to optimize energy consumption and management complexity in WSN and IoT without considering the SDN constraint resources. In contrast, only a few percent incorporate the SDN constraint resources during load balancing decisions. This may represent another deficit, affecting the overall network performance. It is important to note that the SDN controller is constrained by a limited number of rules that must be processed per unit of time. In addition, the central processing unit may be overwhelmed in a large-scale dynamic network environment. Besides, it has limited memory capacity, and the bandwidth between the control channel and the data forwarding element is limited. Unfortunately, most existing studies overlooked these resources and focused on IoT resources.

Conversely, The study findings shown in Fig. 6 indicate that 34 % of the papers focused on reducing energy consumption. Load balancing based on network resources management and optimized routing with Quality of service awareness stand at 22 %, respectively. Since a single controller may not be efficient in managing multiple devices, especially in IoT ecosystems, some controllers may be underutilized, while others may be overutilized. Balancing the load between the former and the latter may lead to better network performance. As such, 12 % of the studies focussed on balancing the load between controllers. Only 3 % of the studies focussed on devising new network architecture to achieve load-balancing routing.

7. Postmortem challenges and future work

7.1. Postmortem challenges

Integrating SDN in IoT ecosystems offers several potential benefits, especially for load-balancing routing. However, it poses another challenge, requiring postmortem analyses to design an effective system for optimal performance. The following highlights some of these postmortem challenges.

7.1.1. Network monitoring

The diversity of IoT devices requires frequent monitoring to get their current state of work. This task could be challenging within an SDN because of its centralized architectural design. The SDN controller is solely responsible for monitoring the overall network after every time interval. Therefore, the mobility nature of IoT devices may add extra processing load on the controller, which may affect the overall system performance. As such, an effective load-balancing routing scheme should analyze the postmortem challenges while focusing on cases where inadequate monitoring leads to performance degradation.

7.1.2. Data volume and processing

IoT devices generate large amounts of traffic flows. SDN is a flow-driven network, as such its required to store the corresponding entries of every flow in the data forwarding elements Flowtable. unfortunately, Flowtable is constrained with limited space and exhibits higher power consumption. Therefore, efficient handling and processing of the corresponding flow rules for each generated traffic flow by IoT devices require careful planning and proper Flowtable management. Postmortem analysis is necessary for rules placement while integrating SDN with IoT for efficient load-balancing routing.

7.1.3. Failure recovery

Network components, including IoT devices, are prone to failure for several reasons. However, SDN has failover features to detour affected flows during failure events. However, the communication between the switch and the controller may represent a single point of failure. Once the switch loses contact with the controller, the network is bound to fail, severely affecting the overall network. Therefore, the effectiveness of the failover features may need further examination through postmortem analysis in the event of device or link failure.

7.1.4. Latency and real-time requirements

Many IoT applications have stringent delay requirements for routing, especially real-time applications. However, the SDN reactive approach is quite effective for real-time applications. However, it can introduce extra processing delay due to frequent interaction between switches and the controller. As the number of IoT devices increases, the delay may increase due to the SDN controller's limited processing capacity. Postmortem analysis may be required to investigate when the switch to controller processing delay spiked beyond acceptable service level agreement, impacting IoT application performance.

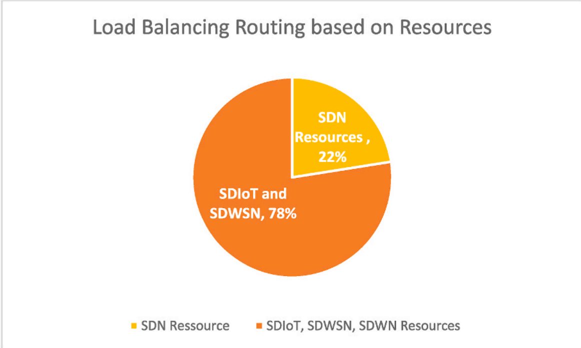

Fig. 5. Percentage of load balancing routing approaches based on resource.

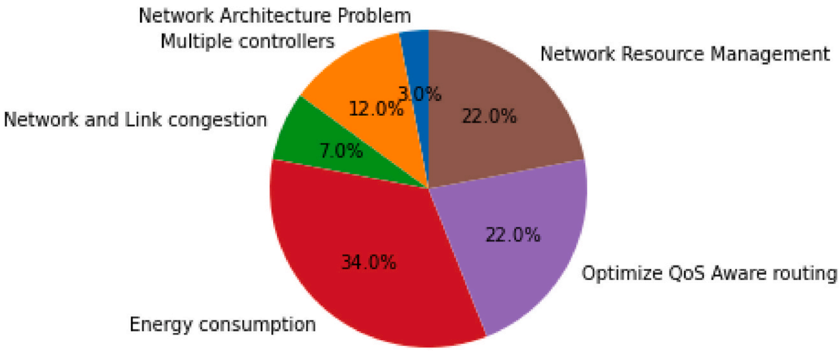

Fig. 6. Summary of Problem addressed.

7.2. Future work

Over the years, many solutions have been introduced to address load-balancing routing for IoT applications. This study synthesizes the most related and available literature with various innovative solutions. However, based on some postmortem challenges and the focus on the existing literature, unanswered questions still need further investigation. This section presents some areas that need further research to drive the adaptation of the SDN concept in the IoT ecosystem.

7.2.1. Rule placement for mobile IoT device for efficient load balancing routing

SDN is a flow-driven network; traffic flows require corresponding flow entries in the switch data structure. The mobility nature of IoT devices in wireless ecosystems may require frequent flow rules updated operation from SDN controllers, affecting the load distributions of SDN controllers. It would be interesting research to leverage machine learning and develop a controller load balancing that will adapt to the mobility patterns of IoT devices to accommodate changes in device locations and network conditions while optimizing load balancing.

7.2.2. Game theory software defined wireless sensor load balancing routing

Network topology often changes in wireless environments due to node mobility and varying traffic flows. The latter and former may affect the load distribution on network resources, affecting the system performance and Quality of Service. It would be interesting research to leverage Dynamic game models to devise load-balancing strategies based on composite metrics such as node mobility, varying traffic patterns, and changing network topologies while adapting to real-time changes in the network environment.

7.2.3. Perception layer standard

The connection between the SDN data forwarding elements and the IoT and wireless ecosystem is called the perception layer. Unfortunately, there is a lack of standardized protocols to manage the communication between the two layers. Developing a framework to manage communication would be another potential research direction.

7.2.4. Context-aware fault recovery strategies for routing

Network resources are prone to routing failures on large network scales like IoT [62]. SDN controller may not always be reachable as the network evolves, and the data forwarding element may be down. The former may bring the network down, while the latter may affect the routing performance. Healthcare IoT generates different traffic flows with stringent delay requirements. Such a failure event may affect data forwarding. It would be an interesting research to develop context-aware recovery strategies considering the criticality of healthcare data and the urgent response while differentiating critical and non-critical data to optimize load balancing during a fault state.

8. Conclusion

Software Defined Network (SDN) is a new network paradigm that is widely used to alleviate the management complexity currently in wired networks and IoT ecosystems. SDIoT and SDWSN are built based on the synergies research efforts between SDN, IoT, and WSNs aimed at solving various problems due to the complexity of IoT and WSN network architecture. Several load-balancing routings were proposed over the years while selecting various network resources. This paper comprehensively reviews SDWSN and SDIoT load-balancing routing research. The study classified the solutions into classical Optimization methods, Context awareness, nature-inspired, and artificial intelligence methods, which were discussed and synthesized. Several tables were presented to summarize the weaknesses of the existing studies. The problem modeling and technologies underlying the solutions are examined and categorized. Although, integrating SDN with other technologies seems to be promising. However, some postmortem challenges are necessary for better network performance. The postmortem challenges of integrating SDN with other emerging technologies were presented for researchers to consider for better network performance. Potential future research directions were also highlighted for those interested in the SDIoT and SDWSN research.

Funding statement

The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through large group Research Project under grant number (RGP.2/175/44).

Data availability

No data was used for the research described in the article.

CRediT authorship contribution statement

Babangida Isyaku: Writing – original draft, Conceptualization. **Kamalrulnizam bin Abu Bakar:** Supervision. **Nura Muhammed Yusuf:** Writing – review & editing. **Mohammed Abaker:** Conceptualization. **Abdelzahir Abdelmaboud:** Validation. **Wamda Nagmeldin:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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