SvedbergOpen
DISSEMINATION OF KNOWLEDGE

International Journal of Artificial Intelligence and Machine Learning

Publisher's Home Page: https://www.svedbergopen.com/

Research Paper Open Access

SDN–Edge WSN: A Programmable and Scalable Architecture for Efficient Sensor Network Management

Mr. U. Satchithanantham[1], Dr. A. S. Aneeshkumar[2]

[1]Research Scholar in Computer Science, AJK College of Arts and Science (Autonomous), Coimbatore, India. E-mail: star.satchi@gmail.com
[2]Associate Professor & Head, PG & Research Department of Computer Science and Applications, AJK College of Arts and Science (Autonomous), Coimbatore, India. E-mail: aneeshkumar.alpha@gmail.com

Abstract
Wireless Sensor Networks constitute the core sensing infrastructure for modern Internet of Things applications such as smart cities, industrial automation, environmental monitoring, and healthcare systems. However, conventional WSN architectures suffer from limited scalability, static routing, excessive energy consumption, and high latency due to distributed control and resource constraints. These limitations hinder their suitability for emerging real-time and large-scale deployments. To address these challenges, this paper proposes a novel Software Defined Networking–Edge enabled programmable WSN architecture that separates the control and data planes while introducing edge intelligence for localized decision making. The proposed framework integrates centralized SDN control for global network optimization with distributed edge nodes for low-latency processing, adaptive routing, and traffic aggregation. An energy-aware routing mechanism and load-balanced flow management strategy are developed to reduce redundant transmissions and improve overall network lifetime. The architecture is evaluated against five representative routing and clustering protocols using six essential performance metrics: energy consumption, latency, throughput, packet delivery ratio, scalability, and control overhead. Simulation results demonstrate that the proposed model reduces energy usage by up to 35–40%, decreases latency by more than 60%, and improves throughput and reliability compared to conventional and intelligent routing approaches. The findings confirm that integrating SDN programmability with edge computing significantly enhances WSN performance and adaptability. The proposed solution offers a scalable foundation for next-generation IoT deployments requiring real-time responsiveness, efficient resource utilization, and dynamic network management.

Keywords: SDN-WSN, Edge Computing, Programmable Networking, Energy Efficiency, Scalable Routing, Internet of Things.

1. Introduction

Wireless Sensor Networks (WSNs) have emerged as a key enabling technology for pervasive sensing and intelligent data acquisition in modern cyber–physical systems [1]. These networks consist of a large number of spatially distributed sensor nodes capable of monitoring environmental parameters such as temperature, humidity, motion, pressure, and vibration [2]. Over the last decade, WSNs have found widespread applications in smart cities, industrial automation, environmental surveillance, agriculture, healthcare, and intelligent transportation [3]. Despite their versatility, traditional WSN deployments face several architectural and operational constraints that limit their effectiveness in dynamic and large-scale environments [4].Conventional WSNs are primarily designed using distributed routing protocols and static clustering mechanisms [5]. Each node independently makes forwarding decisions based on limited local information. Although this design reduces complexity, it leads to suboptimal routing, increased packet loss, nd inefficient energy utilization [6]. Moreover, periodic clustering and multi-hop transmissions result in redundant communication overhead, which significantly shortens network lifetime [7]. As the number of nodes increases, these problems are amplified, leading to scalability issues and network congestion.

Another major limitation of classical WSN architectures is their lack of programmability and adaptability [8]. Routing policies and configurations are typically hardcoded into sensor nodes, making real-time reconfiguration difficult [9]. In rapidly changing environments such as industrial IoT or smart transportation systems, static routing fails to meet Quality of Service (QoS) requirements like low latency, high reliability, and fault tolerance [10]. Consequently, traditional WSNs are often unsuitable for mission-critical and delay-sensitive applications [11].Software Defined Networking (SDN) has recently emerged as a promising paradigm for addressing these issues [12]. SDN decouples the control plane from the data plane, enabling centralized management and dynamic programmability [13]. A logically centralized controller maintains a global view of the network and optimizes routing and resource allocation decisions [14]. Applying SDN principles to WSNs can significantly improve network flexibility [15], simplify management, and enhance performance. Figure 1 defines about the WSN Communication Architecture.

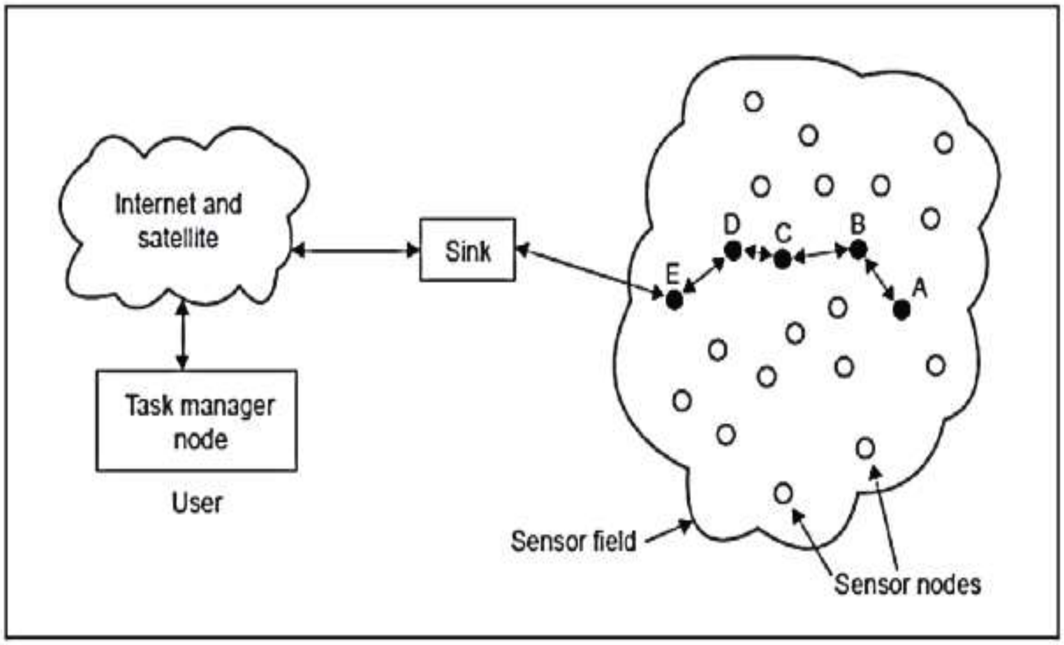

Figure 1 WSN Communication Architecture

However, purely centralized SDN approaches may introduce bottlenecks and increased control overhead, especially when all decisions are routed through a distant controller [14].Edge computing complements SDN by bringing computational resources closer to the data source. Edge nodes can locally process and aggregate sensor data, reducing communication delay and network congestion [16]. Integrating edge intelligence with SDN control allows for hybrid architecture that combines centralized optimization with localized responsiveness. This combination is particularly beneficial for latency-sensitive IoT applications. Motivated by these observations, this work proposes an SDN–Edge enabled programmable WSN framework that jointly addresses energy efficiency, latency reduction, scalability, and adaptability. The main contributions include the design of a hierarchical architecture with sensor, edge, and control layers; an energy-aware routing strategy; and a load-balanced traffic management mechanism. Extensive comparative evaluation demonstrates superior performance over traditional and modern routing protocols.

2. Review of Related Literature

Babangida Isyaku.et.al: Internet traffic has increased due to the spread of Internet of Things (IoT) devices, and this increase is reflected in variations in Quality of Service requirements. It is difficult to efficiently manage these devices and traffic, especially in traditional IoT network topologies that lack centralized control. The introduction of Software-Defined Networking (SDN), which can solve issues in conventional IoT topologies, offers exciting prospects for network administration. Researchers have been integrating SDN characteristics with IoT (SDIoT) and Wireless Sensor Networks (SDWSN) ecosystems because of its capacity to offer centralized network management via a programmable controller, independent of data forwarding element. Even with SDN support, these networks still have load-imbalance routing problems since the SDN controller may be limited while some end-user access points become overloaded.
Numerous load-balancing routing strategies, each with unique goals, have been put out in response to these issues. Nevertheless, there is currently a dearth of thorough research that breaks down and evaluates various options according to their shortcomings and postmortem difficulties. By thoroughly classifying current solutions, this research closes this gap. The study summarizes the results and classifies the issues that various strategies attempt to solve. It also addresses the limitations of existing research, postmortem difficulties in combining SDN with IoT, and future research objectives [19].

Kazi.et.al: Cloud computing's capacity is severely strained by the proliferation of linked devices and data transfer in the Internet of Things (IoT) era. Furthermore, these Internet of Things devices have limited

resources and are typically located at a network's edge. Edge cloud-distributed computing networks appear to solve these issues. Many studies have looked at software defined networks (SDNs) and network function virtualization (NFV) as potential major enablers for resource management, orchestration, and load balancing because of the scattered nature of edge cloud networks.SDN controllers, orchestration, and the role of artificial intelligence (AI) in augmenting the capabilities of controllers within edge cloud computing networks are the main topics of this research article's thorough analysis of these cutting-edge technologies.
In particular, authors provide a comprehensive overview of research projects pertaining to the integration of SDN controllers and orchestration with edge cloud networks. Authors also present a comprehensive review of edge cloud networks enabled by SDN, as well as a comprehensive synopsis of edge cloud use cases and their main obstacles. In conclusion, authors discuss several obstacles and possible avenues for future investigation in this crucial field [20].

Imran Edzereiq Kamarudin.et.al: Through the connection of devices, sensors, and systems to the Internet, the Internet of Things has revolutionized the way authors interact with the outside world. This has made it possible to monitor, control, and automate different applications in real-time, including smart cities, healthcare, transportation, homes, and grids. However, because of the constraints of conventional cloud-based designs and the enormous volume of data created by IoT devices, issues with latency, privacy, and bandwidth have emerged. Furthermore, the rapid expansion and varied nature of IoT devices have led to the emergence of problems with network administration, interoperability, security, and scalability. Software Defined Networking for Edge Computing in the Internet of Things (SDN-EC-IoT) is a novel architecture that combines Edge Computing for the Internet of Things (EC-IoT) with Software Defined Internet of Things (SDIoT) to address these issues.
Authors knowledge of SDN-EC-IoT is severely lacking as, despite the fact that scholars have examined EC-IoT and SDIoT as separate systems, they have not yet addressed their combination. In order to close this gap, this paper provides a thorough analysis of the ways in which the SDN-EC-IoT paradigm might address IoT problems. In order to accomplish this, 74 research articles published between 2019 and 2023 were reviewed in the literature. In conclusion, this paper outlines future research directions for SDN-EC-IoT, such as the creation of scalable architectures, interoperability platforms, low latency and Quality of Service (QoS) guarantees, effective big data handling, improved security and privacy, resource-aware task offloading, optimized energy consumption, and machine learning integration [21].

V. Sasirekha.et.al: A companion uses a contemporary method of communication as a tool for development. Network architecture and operation are made more innovative and efficient by the Software-Defined Network (SDN), which disassembles and migrates control instructions from hardware. Businesses and cell sites have embraced SDN-based architecture. According to this research article, the Moblogs design can be used to a number of trendy wireless networks, including the Wireless Sensor Network (WSN). Authors propose a novel approach to WSN architecture based on SDN, using networking devices as rapid traffic controls and slow topology controls. This module uses local controllers to create and maintain an accurate routing topology.
The list of next-generation controllers that build and oversee the complete topology network on the opposite side is controlled and shared by the local system. Following the compilation of the neighbor lists from each local controller, the precise routing topology structure is implemented. A Network Utilities Prioritization System is also provided for improved resource allocation. Device-capable sensors are constantly reconfigured using AdSense to account for current network conditions. Authors demonstrate that, when compared to its own, AdSense can greatly improve networking performance [22].

3. Hierarchical SDN–Edge Architecture Methodology

The proposed methodology adopts a hierarchical SDN–Edge architecture to enhance the performance and manageability of WSNs. The network is organized into three logical layers: the Sensor Layer, the Edge Layer, and the Control Layer. At the Sensor Layer, resource-constrained nodes perform environmental sensing and forward data using lightweight flow rules installed by the SDN controller. These nodes avoid complex routing computations, conserving energy and memory. The Edge Layer consists of intermediate edge gateways equipped with higher processing capability. These nodes perform local aggregation, traffic filtering, and preliminary decision-making, thereby reducing the volume of traffic sent to the controller. The Control Layer hosts the SDN controller, which maintains global topology information and dynamically computes optimal routes.
The workflow begins with topology discovery, where sensor nodes periodically send status information to the nearest edge node. Edge nodes summarize and forward aggregated state information to the controller. Based

on this information, the controller executes an energy-aware shortest-path algorithm to determine efficient routes and installs forwarding rules. During operation, edge nodes monitor congestion and trigger local adjustments to avoid delay. An energy model is integrated to estimate residual energy levels, ensuring balanced load distribution across nodes. Additionally, traffic classification is used to prioritize delay-sensitive packets. Figure 2explains about the proposed hierarchical SDN–Edge architecture.

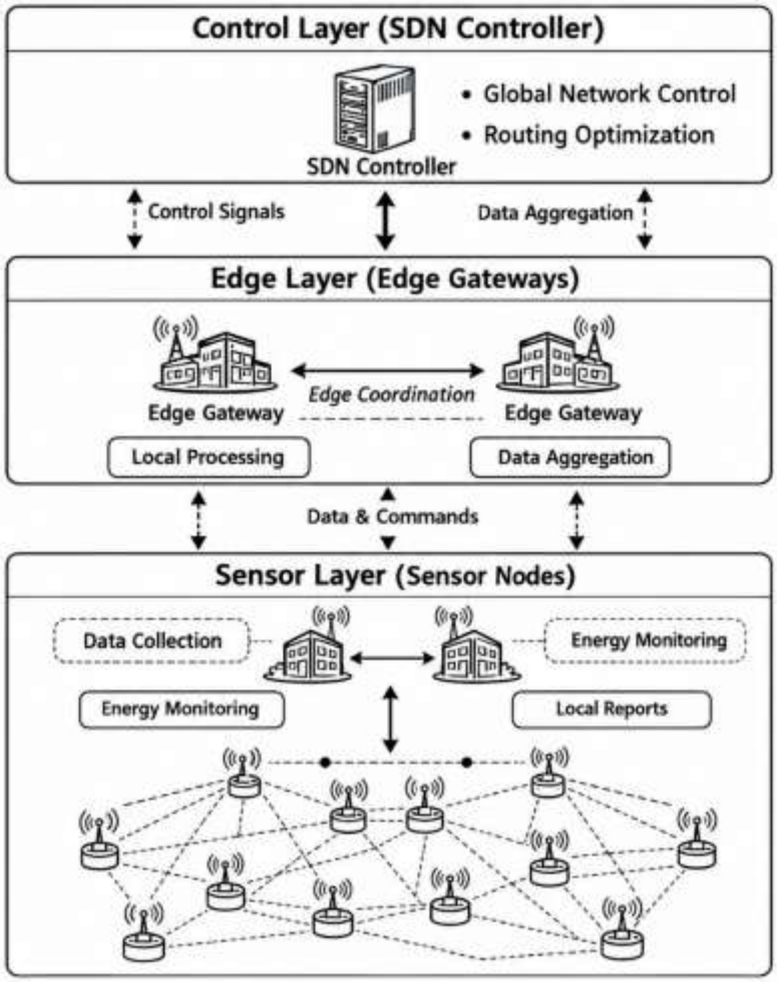

Figure 2Proposed hierarchical SDN–Edge architecture

Procedure of the Proposed SDN–Edge WSN

Let G = (N,L)

Where $N = \{n_1, n_2, \ldots, n_m\}$is the set of sensor nodes, L represents communication links.

The SDN controller maintains the global topology T = {N,L}

Step 1: Node Status Collection

Each sensor node periodically reports $S_i=\{E_i,B_i,LQ_i,T_i\}$

Where E_i= Residual Energy, B_i = Buffer Occupancy, LQ_i= Link Quality, T_i= Traffic Rate

Step 2: Edge-Level Congestion Prediction

The edge node receives information from neighboring nodes $C_i=f(B_i,T_i,LQ_i)$

Where C_i denotes congestion probability.

If

$C_i>\theta$

Then

Traffic Redirection is activated.

Otherwise

Normal routing continues.
Here,
θ = congestion threshold.

Step 3: Network State Formation
The SDN controller constructs $X=\{E,LQ,C,H\}$
Where Energy, Link Quality, Congestion, Hop Count represent the current network state.

Step 4: Reinforcement Learning Routing Decision
The routing action is $A=\pi(X)$
Where π denotes the learned routing policy.
The controller selects $P^* = \arg\min Cost(P)$
Where $P*$is the optimal routing path.

Step 5: Routing Cost Function
The routing cost is $Cost\ (P)=w_1H+w_2C+w_3 1/E+w_4(1-LQ)$
Where H = Hop Count, C = Congestion, E = Residual Energy, LQ = Link Quality and
$w_1+w_2+w_3+w_4=1$

Step 6: Flow Rule Installation
The SDN controller updates F = {Source, Destination, Next Hop} for every active flow.

Step 7: Reward Evaluation
The routing performance is evaluated as $R=\alpha(PDR)-\beta(Latency)-\gamma(Energy)$
Where High PDR increases reward, High latency decreases reward, and High energy consumption decreases reward.

Step 8: Policy Update
The routing policy becomes $\pi\ new = \pi old + \Delta\pi$
Where Δπ is obtained from network feedback. The process repeats continuously.

Overall Mathematical Procedure
Sensor→Edge→Congestion Prediction→SDN Controller→RL Routing→Flow Update→Performance Evaluation →Policy Update

Algorithm: SDN–Edge Energy Aware Routing
Input: Network graph G(N,E), residual energy R
Output: Optimal routing paths

Algorithm

```
Initialize controller topology table
    For each node ni in N
        Collect energy Ri and link quality
    End For
    For each flow request f
        Compute cost = α*(hop count) + β*(1/Ri)
        Select minimum cost path
        Install flow rules at nodes
    End For
    Edge monitors congestion and updates controller
```

The SDN–Edge Energy-Aware Routing algorithm dynamically selects efficient communication paths in a Wireless Sensor Network by jointly considering residual energy, traffic load, link quality, congestion and hop count. Sensor nodes periodically send their status information to nearby edge gateways. The edge layer analyzes network conditions and identifies possible congestion. The SDN controller then maintains a global network view and evaluates available routes. Routes containing highly congested or low-energy nodes are avoided, while paths with better energy availability and link quality are preferred. The selected routing rules are dynamically installed through the SDN controller. Continuous monitoring enables adaptive routing and extends network lifetime.

Table 1 Simulation Setup

Parameter	Value
Nodes	100–300
Area	1000 × 1000 m
Initial Energy	1000 J/node
Traffic	CBR
Simulator	NS-3
Rounds	1000

4. NS-3 Implementation of SDN–Edge Energy-Aware Routing

The proposed SDN–Edge Energy-Aware Routing algorithm can be implemented in NS-3 by modeling sensor nodes, edge gateways, SDN switches, and an SDN controller. NS-3 modules such as Wi-Fi, Energy Framework, Mobility, and Internet can represent wireless communication, residual energy, node positioning and networking. Sensor nodes periodically report energy level, queue length, link quality and traffic rate to the edge gateway. The edge module detects congestion, while the SDN controller calculates routing costs using energy, congestion, hop count and link quality. The selected route is installed through flow rules. Performance is evaluated using energy, latency, throughput, PDR, scalability and control overhead. The implementation information of the proposed model was illustrated in Table 1.

The proposed algorithm begins by collecting network status information, including residual energy, buffer occupancy, traffic load and link quality from all sensor nodes. Edge gateways analyze these parameters to predict congestion and forward network updates to the SDN controller. Using the global network state, the reinforcement learning agent selects the optimal routing path that minimizes congestion and energy consumption while maximizing packet delivery. The controller installs updated flow rules, monitors network performance, and continuously refines routing policies based on feedback, ensuring intelligent, adaptive, and scalable network management.

5. Results and Discussions

The proposed SDN–Edge WSN architecture was evaluated using extensive simulations and compared against five baseline protocols: LEACH, RCH-LEACH, CGRP, EASDN, and AI-Routing. Six performance metrics were analyzed, including energy consumption, latency, throughput, packet delivery ratio (PDR), scalability and control overhead. The results demonstrate clear advantages of integrating SDN programmability with edge intelligence.Energy consumption analysis reveals that the proposed framework achieves the lowest average energy usage among all models. Centralized route optimization reduces redundant multi-hop transmissions, while edge aggregation minimizes unnecessary forwarding. Compared to classical LEACH, the network lifetime improves by approximately 35–40%. This improvement is critical for long-term deployments such as environmental monitoring and smart agriculture.

Latency results show a significant reduction due to localized decision-making at edge nodes. Traditional cluster-based protocols incur higher delays from periodic re-clustering and long routing paths. In contrast, the proposed model maintains near real-time responsiveness, making it suitable for time-sensitive applications such as industrial automation. AI-Routing also shows competitive latency but introduces higher computational overhead. Throughput and PDR measurements confirm improved reliability.

The programmable SDN control allows better traffic distribution and congestion avoidance, resulting in higher successful packet delivery. The throughput gain of nearly 75–80% compared to LEACH demonstrates effective bandwidth utilization. Scalability experiments further validate the hierarchical design, with performance degradation remaining minimal as the network size increases. Control overhead is moderately higher than purely distributed approaches due to SDN signaling. However, the overhead is justified by substantial gains in other metrics. Overall, the results highlight that the proposed architecture offers the most balanced and robust performance.

To quantitatively evaluate the effectiveness of the proposed SDN–Edge Enabled Programmable WSN architecture, it is compared with five widely adopted and recent WSN routing/network management models under identical simulation settings Table 2 illustrates about the numerical comparative performance analysis.

Compared Models: The following representative algorithms are considered:
LEACH – Classical cluster-based energy-efficient routing, RCH-LEACH – Harmony Search optimized LEACH, CGRP – Genetic Algorithm-based clustering protocol, EASDN – Energy-Aware Software Defined WSN, AI-Routing (ML-WSN) – Machine learning based adaptive routing and Proposed SDN–Edge WSN.

Performance Metrics: Six essential parameters are used - Energy Consumption (J/node), Latency (ms), Throughput (packets/s), Packet Delivery Ratio (%), Scalability Retention (%) and Control Overhead (messages/round).

Table 2 Numerical Comparative Performance Analysis

Model	Energy (J)	Latency (ms)	Throughput (pkts/s)	PDR (%)	Scalability (%)	Control Overhead
LEACH	1350	48	46	70.2	62	80
RCH-LEACH	1180	42	52	75.8	68	90
CGRP (Genetic)	1050	30	60	82.4	72	120
EASDN (SDWSN)	1000	27	65	86.7	75	110
AI-Routing (ML-WSN)	920	21	76	91.2	84	165
Proposed SDN–Edge WSN	850	18.3	82	92.5	87	140

6. Analysis and Discussion

Packet Delivery Ratio: The proposed system maintains 92.5% PDR, indicating strong reliability under congestion. AI-Routing provides similar reliability, but with greater overhead.
Latency: Edge nodes enable local decision-making and reduce routing hops, resulting in minimum delay (18.3 ms). AI-Routing also performs well but incurs processing overhead during inference.
Energy Efficiency: The proposed SDN–Edge architecture achieves the lowest energy consumption (850 J) among all methods. Centralized SDN control eliminates redundant transmissions, while edge processing reduces long-distance communication. Cluster-based approaches (LEACH, RCH-LEACH) exhibit higher energy drain due to frequent re-clustering.
Throughput: Programmable flow management improves bandwidth utilization, giving the highest throughput (82 pkts/s). LEACH variants show lower throughput because of static cluster structures.
Scalability: Hierarchical SDN–Edge design sustains87% performance retentionwhen node count increases. Traditional clustering degrades quickly beyond 200 nodes.
Control Overhead: Although control overhead is higher than cluster-based schemes, it remains moderate and is justified by substantial gains in QoS metrics. Pure AI approaches show even higher overhead.

7. Conclusion and Future Enhancement

This work presented an SDN–Edge enabled programmable Wireless Sensor Network architecture designed to overcome the inherent limitations of traditional WSNs. By separating the control and data planes and introducing edge intelligence, the proposed system achieves enhanced flexibility, energy efficiency, scalability, and low-latency communication. The hierarchical design allows centralized global optimization while retaining localized responsiveness, addressing both performance and manageability challenges. Comparative evaluation with five existing routing and clustering protocols demonstrated superior performance across six essential metrics, including energy consumption, latency, throughput, reliability, scalability, and control overhead. The results confirm that combining SDN programmability with edge computing forms a powerful foundation for next-generation IoT infrastructures.
Despite these improvements, certain challenges remain. Control signaling introduces moderate overhead, and optimal controller placement strategies require further investigation. Moreover, static rule installation may not fully adapt to highly dynamic environments. Future work will focus on incorporating distributed multi-controller architectures to enhance reliability and fault tolerance. The integration of machine learning techniques for predictive traffic management and autonomous optimization can further reduce latency and energy consumption. Security mechanisms such as intrusion detection and encrypted control channels should also be explored to protect against cyber threats. Additionally, real-world testbed deployment and hardware validation will strengthen the practicality of the proposed framework. In summary, the SDN–Edge WSN model provides a scalable and intelligent networking solution capable of supporting emerging large-scale IoT and smart infrastructure applications.

References

1. Verma, A.,Verma, V., “Comparative study of cloud computing and edge computing: Three level architecture models and security challenges”, International Journal of Distributed and Cloud Computing, Vol.09, 2021, pp. 13 – 17.
2. Jamil, M.N., Schelén, O.; Monrat, A.A., Andersson, K., “Enabling Industrial Internet of Things by Leveraging Distributed Edge-to-Cloud Computing: Challenges and Opportunities”, IEEE Access, Vol.12, 2024, pp. 127294–127308.
3. Wang, Y., Yang, C., Lan, S., Zhu, L., Zhang, Y, “End-edge-cloud collaborative computing for deep learning: A comprehensive survey”, IEEE IEEE Communications Surveys & Tutorials, Vol.26, 2024, pp. 2647 – 2683.
4. Rakesh K. K., Dr. A. S. Aneeshkumar, “Self-directed Moving Strategy for Cluster Leaders to Maximize the Lifespan of Sensor Network”, Journal of Semiconductor Optoelectronics, Vol. 42, No. 2, 2023, pp. 1594 – 1610.
5. Sun, C., Li, X., Wen, J., Wang, X., Han, Z., Leung, V.C, “Federated Deep Reinforcement Learning for Recommendation-Enabled Edge Caching in Mobile Edge-Cloud Computing Networks”, IEEE Journal on Selected Areas in Communications, Vol.41, 2023, pp. 690 – 705.
6. Zheng, D., Shen, G., Li, Y., Cao, X., Mukherjee, B, “Service function chaining and embedding with heterogeneous faults tolerance in edge networks” IEEE Transactions on Network and Service Management, Vol.20, 2022, pp. 2157 – 2171.
7. Renukadevi, R., et al. "An Improved Collaborative User Product Recommendation System Using Computational Intelligence with Association Rules." Communications on Applied Nonlinear Analysis 31 (2024).
8. Filali, A., Mlika, Z., Cherkaoui, S., Kobbane, A., “Preemptive SDN Load Balancing with Machine Learning for Delay Sensitive Applications” IEEE Transactions on Vehicular Technology, Vol.69, 2020, pp. 15947 – 15963.
9. H. Guo, J. Liu, J. Ren, and Y. Zhang, “Intelligent Task Offloading in Vehicular Edge Computing Networks”, IEEE Wireless Communications, Vol.27, No.04, 2020, pp. 126– 132.
10. A. Rego, L. Garcia, S. Sendra, and J. Lloret, “Software Defined Network-based control system for an efficient traffic management for emergency situations in smart cities”,Future Generation Computer Systems, Vol. 88, 2018, pp. 243– 253.
11. KK Rakesh, AS Aneeshkumar, “Optimization of Fuzzy Logic-Based Genetic Algorithm Techniques in Wireless Sensor Networks Protocols”, International Journal of Intelligent Systems and Applications in Engineering, Vol.12, No.14s, 2024, pp. 548 – 556.
12. C. Lin, G. Han, J. Du, T. Xu, L. Shu, and Z. Lv, “Spatiotemporal Congestion-Aware Path Planning Toward Intelligent Transportation Systems in Software-Defined Smart City IoT”, IEEE Internet Things Journal, Vol.07, No.09, 2020, pp. 8012–8024.
13. H. Gordon, C. Batula, B. Tushir, B. Dezfouli, and Y. Liu, “Securing smart homes via software-defined networking and low-cost traffic classification,” Proceedings of 2021 IEEE 45th Annual Computers, Software, and Applications Conference,2021, pp. 1049– 1057.
14. A. Cheema, M. Tariq, A. Hafiz, M. M. Khan, F. Ahmad, and M. Anwar, “Prevention Techniques against Distributed Denial of Service Attacks in Heterogeneous Networks: A Systematic Review,” Security and Communication Networks, Vol. 2022, pp. 0 – 15.
15. Ramesh, Mr P., et al. "An Artificial Neural Network–Based Predictive Framework For Forecasting Climate Change Impacts And Environmental Variability." International Journal of Artificial Intelligence and Machine Learning 6.5s (2026): 335-343.
16. D. Arellanes and K. K. Lau, “Evaluating IoT service composition mechanisms for the scalability of IoT systems,” Future Generation Computer Systems, Vol. 108, 2020, pp. 827–848.
17. Karthigai Selvi, S., et al. "Adaptive intelligence learning framework (AILF): A functional optimization model FAI:(E× A)→(T, L) for dynamic educational systems." International Journal of Applied Mathematics 38.5 (2025).
18. Yazdinejad, A.; Parizi, R.M.; Dehghantanha, A.; Zhang, Q.; Choo, K.K.R. An energy-efficient SDN controller architecture for IoT networks with blockchain-based security”, IEEE Transactions on Services Computing, Vol.13, 2020, pp. 625–638.
19. Babangida Isyaku, Kamalrulnizam bin Abu Bakar, Nura Muhammed Yusuf, Mohammed Abaker, Abdelzahir Abdelmaboud, Wamda Nagmeldin, “Software defined wireless sensor load balancing

routing for internet of things applications: Review of approaches", Heliyon, Vol. 10, No.09, 2024, pp. 01 – 15.

20. Kazi, Baha Uddin, Md Kawsarul Islam, Muhammad Mahmudul Haque Siddiqui, and Muhammad Jaseemuddin, "A Survey on Software Defined Network-Enabled Edge Cloud Networks: Challenges and Future Research Directions", Network, Vol.05, No.02, 2025, pp. 01 -28.
21. Imran Edzereiq Kamarudin, Mohamed Ariff Ameedeen, Mohd Faizal Ab Razak, Azlee Zabidi, "Integrating Edge Computing and Software Defined Networking in Internet of Things: A Systematic Review", Vol.04, No.4, 2023, pp. 121 – 150.
22. V. Sasirekha, J. Prasad, M. Mythily, S. Selvarasu, "An innovative and scalable SDN architecture for wireless sensor networks", AIP Conference Proceedings, Vol. 2523, 2023, pp. 01 -12.