# Software Defined Networking (SDN): A New Concept in Networking and Its Application in Voice over IP (VoIP) Implementation – A Survey

Kranti Kumar Appari
Research Scholar
Dept. of ECE, Andhra University
Visakhapatnam, AP, India

P. Rajesh Kumar
Professor
Dept. of ECE, Andhra University
Visakhapatnam, AP, India

## ABSTRACT
In recent years, Software-Defined Networking (SDN) has drawn considerable interest from researchers and industry. Its widespread application addresses complex issues in traditional networks and fosters innovation in network applications. This paper conducts a comprehensive analysis of SDN, examining the data plane, control plane, and application plane perspectives. The synergy among these planes is thoroughly explored, with the research history of intelligent SDN outlined, emphasizing advantages in routing optimization, network security, and key technologies. The article focuses practical implementation of SDN tailored for secure VoIP services, identifying controllers and protocols for these networks. Comprehensive results including performance comparisons, controller evaluations, and AI/ML integration are presented with supporting visual analysis. The paper underscores future prospects of intelligent SDN, particularly in conjunction with emerging fields.

## Keywords
Software-Defined Networking (SDN), Automation, OpenFlow, Signal Processing, Controllers, VoIP, IP Protocol, AI/ML, QoS.

## 1. INTRODUCTION
The technology sector has experienced tremendous development in recent years. Globalization has driven people and companies to adopt information technologies to support daily business activities and remain competitive [1]. Large technology companies have been compelled to implement equipment aligned with new technologies, including fifth-generation (5G) networks [2]. As applications increasingly demand higher bandwidth and lower latency, conventional TCP/IP network architectures struggle with the scale and dynamic nature of modern traffic [4].

Software Defined Networks (SDN) represent a new concept of network architecture that is scalable, provides better management, and centralizes intelligence in a single controller [6]. Researchers have proposed architectures for residential network management through SDN and virtualization, enabling applications to manage services such as internet consumption and telephony [7]. Several studies have explored SDN's role in enabling Quality of Service (QoS) for Voice over IP (VoIP) services, demonstrating that SDN-based approaches can prioritize voice traffic and prevent degradation during network congestion [8]. This paper provides a comprehensive survey of SDN architectures, controllers, protocols, and their application to secure VoIP services, with quantitative performance comparisons and visual analyses to strengthen the findings.

## 2. RESEARCH STATUS AND MOTIVATION
With the continuous expansion of network scale and the increasing growth rate of Internet traffic, users demands for traffic are changing, and the concept of programmable networks has emerged as a solution to complex network issues. Researchers, relying on this programmable concept, successively proposed the concepts of forwarding abstraction, distributed state abstraction, and configuration abstraction [14]. These concepts decouple the control functions of switches in traditional networks, allowing them to be completed by the control plane. Based on this, a standard interface is added between the data plane and the control plane, keeping switches focused solely on data exchange and recognition. The control plane abstracts the global view of all distributed devices in the entire network, synthesizing network-wide information, enabling applications in the application plane to perform unified network configuration based on global information. Meanwhile, users can achieve automatic deployment of forwarding devices along the path through simple configuration using the application interface provided by the control plane. Therefore, the data forwarding path in the network no longer depends on the data plane, resulting in a decoupled and standardized interface software-defined network architecture [15].

The advantages of Software-Defined Networking (SDN) lie in the decoupling of data forwarding and control functions, enabling software-defined customization, and unified management of network configurations. Currently, it has been widely applied in areas such as network virtualization, data center networks, wireless LANs, and cloud computing [16]. SDN decouples various planes tightly linked in traditional networks into the data plane, control plane, and application plane, supporting centralized control and management logically, with a flexible and easy-to-manage structure. Figure 1 illustrates the architecture of SDN.

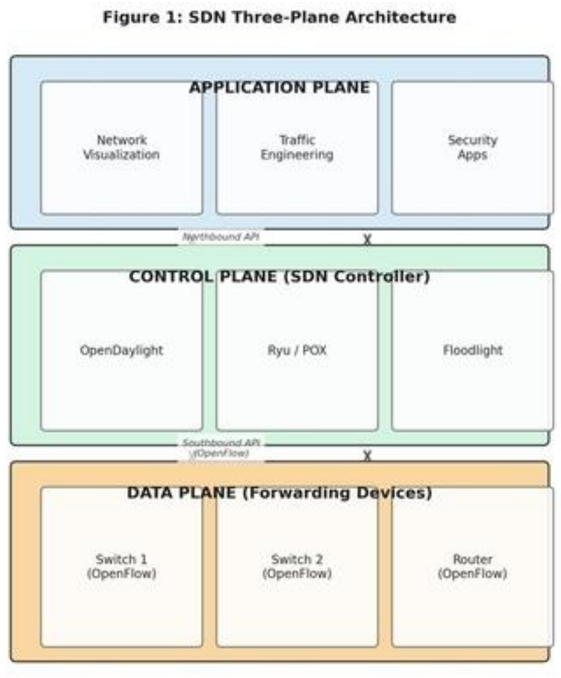


**Figure 1: SDN Three-Plane Architecture – Application, Control, and Data Planes**

As shown in Figure 1, the SDN architecture comprises three clearly separated planes. The Application Plane reflects user intent through visualization, traffic engineering, and security applications. The Control Plane hosts the SDN controller, communicating via the Northbound API with applications and via the Southbound API (OpenFlow) with data plane devices. The Data Plane contains OpenFlow-enabled forwarding devices that execute controller-defined rules without independent decision-making.

## 2.1 Artificial Intelligence in SDN

Artificial Intelligence (AI) has undergone decades of development, profoundly influencing various scientific fields including image recognition, autonomous driving, pattern recognition, and computer vision. The period from the 1940s to 1970s marked the first wave of AI, addressing specific problems such as game rules, knowledge representation, and expert systems. IBM's Deep Blue exemplified this era, employing hybrid decision-making for chess, though limited in general applicability. As data scales increased, researchers shifted to extracting rules from observational data, giving rise to Natural Language Processing (NLP), Computer Vision (CV), and Statistical Machine Learning (SML).

## 2.2 SDN Research Across Planes

In the initial stages of applying AI to SDN, it could only handle small-scale scenarios with low time complexity in routing, security, and architecture. Traditional SDN separates the control plane from the forwarding plane, where switches receive unified standard rules from the controller through standard interfaces. However, the traditional SDN working mode is no longer sufficient to meet large-scale, structurally complex traffic demands of the big data era. Table 1 provides a comparison of prominent SDN controllers.

**Table 1. Comparison of SDN Controllers**

| Controller | Language | Developed By | OpenFlow Version |
|---|---|---|---|
| | | | |
| NOX/POX | Python, C++ | Nicira | 1.0, 1.3 |
| ONIX | – | Google, Nicira | – |
| Beacon | Java | Stanford University | 1.0.1 |
| Maestro | Java | Rice University | 1.0 |
| Floodlight | Java | Big Switch Networks | 1.0 |
| Floodlight-plus | Java | Big Switch Networks | 1.3 |
| Ryu | Python | NTT Labs | 1.0–1.4 |
| OpenDaylight (ODL) | Java | Linux Foundation | 1.0–1.3 |

The ONF (Open Networking Foundation) has driven SDN standardization through OpenFlow. In December 2018, ONF proposed combining P4 with machine learning to enrich network data acquisition, providing richer telemetry beyond basic ingress/egress node and latency information. Table 2 compares major SDN simulators and emulators used for experimental validation.

**Table 2. Comparison of SDN Simulators and Emulators**

| Simulator | Open Source | Language | Platform | OpenFlow Version |
|---|---|---|---|---|
| Mininet | Yes | Python | BSD Open Source | OF 1.3 |
| S-3 | Yes | Python, C++ | GNU GPLv2 | Pre OF 1.0, OF-SID |
| EstiNet | Yes | – | – | OF 1.3 and 1.0 |

# 3. KEY TECHNOLOGIES AND RESEARCH METHODS

SDN is attracting increasing attention from research organizations worldwide. Artificial intelligence enhances SDN by performing data analysis and network optimization based on centralized control and management. This section reviews specific issues in SDN networks that AI addresses, including intelligent routing optimization, AI-based traffic engineering, and intelligent network security methods.

## 3.1 Intelligent Routing Optimization

Routing is a fundamental network function. In SDN, controllers guide traffic routing by modifying the flow tables of switches.

Inefficient routing strategies lead to data loss, load imbalance, and resource wastage. Kim et al. proposed a Q-learning-based congestion prevention mechanism that dynamically adapts routing decisions to network state, significantly reducing packet loss under congestion scenarios [10].

## 3.2 Network Security Intelligent Methods

SDN uses a central controller to manage the entire network, simplifying management tasks. While this provides excellent network programmability, it exposes the core to potential attackers. Wang et al. provided a comprehensive review of SDN security mechanisms, analyzing controller DoS/DDoS defenses, legality checks for flow rules, and northbound interface security [13]. Silva et al. proposed ATLANTIC, a framework for anomaly traffic detection, classification, and mitigation in SDN [11].

## 3.3 AI-Based Traffic Engineering

Traffic Engineering (TE) is a crucial mechanism for optimizing data network performance by dynamically analyzing, predicting, and adjusting data transmission behavior. AI-based traffic engineering is generally divided into traffic classification and dynamic traffic scheduling optimization. In data centers, 80% of traffic consists of mouse flows, but 20% of elephant flows occupy 80% of the bandwidth. Tang et al. proposed the Efficient Sampling and Classification Approach (ESCA) for elephant flow detection using a two-phase algorithm that filters redundant samples and classifies based on data flow correlation [15].

# 4. FUTURE CHALLENGES AND NETWORK SCENARIOS

Despite the current ability of AI technology to address some SDN challenges, several obstacles remain before full AI-SDN integration. These include obtaining high-quality training data, achieving cross-domain communication, ensuring scalability, and enhancing security predictions. SDN's centralized control advantages are being combined with 5G, Network Function Virtualization (NFV), the Internet of Things (IoT), edge computing, information-centric networking, and wireless sensor networks.

Most AI algorithms were originally proposed for image processing, not networking. Network data does not completely conform to AI algorithm data format requirements. High-quality training data relies on manual cleaning, and the absence of publicly available SDN datasets necessitates collaborative efforts. Table 3 summarizes the progress of the ONF organization in advancing SDN standards.

**Table 3. Progress of SDN Standardization by ONF**

| Category | Main Responsibilities | Key Progress |
|---|---|---|
| Technical Specifications | Release of OpenFlow-related standards as technical specifications, including protocol definitions, information models, component functionalities | April 2015: OpenFlow Switch Spec v1.5.1; April 2017: Optical transport extension; June 2017: SPTN OpenFlow extension |
| Technical Recommendations | Development of technical recommendations including API definitions, data models, protocols, and all other standards | March 2013: OpenFlow Config & Management Protocol v1.1.1; October 2018: Device management interface; November 2018: Core information model |
| White Papers / Use Cases | Publications aiding in furthering the ONF mission and development of open networking solutions | September 2016: Negotiable data path model & TTP signature; September 2016: ONF SDN Evolution |

# 5. DESIGN AND IMPLEMENTATION OF SDN NETWORK FOR VOIP

This section details the stages for designing and implementing an SDN network optimized for VoIP services. The implementation consists of two IP telephones and a laptop serving as the controller host. The network analyzes jitter, bandwidth, and latency to verify viability. Routers are configured using Winbox software, creating two networks: one for LAN administration (192.168.1.1) and one for telephone IPs managed via DHCP (192.168.2.196). Different address ranges prevent IP conflicts and network collapse.

## 5.1 Protocol Identification

The OpenFlow protocol was selected for this implementation due to several advantages over alternatives. OpenFlow allows direct accessibility and manipulation of both data planes and the control plane, offers greater bandwidth, supports automated network configuration, reduces operating expenses, and minimizes downtime. The ONF continuously improves OpenFlow for performance in SDN environments [6]. Other protocols evaluated include BGP, MPLS-TP, NETCONF, and XMPP, but OpenFlow emerged as most suitable for this VoIP-focused SDN implementation.

## 5.2 Controller Selection

Six controllers were evaluated: NOX, POX, Beacon, THEN, Ryu, and OpenDaylight. Table 4 presents a comprehensive feature comparison across key dimensions. OpenDaylight was selected as the primary controller due to its broad OpenFlow support (v1.0-1.4), Java-based cross-platform compatibility, rich REST API, and strong open-source community backing. Figure 2 provides a visual comparison of the top SDN controllers across four key dimensions.

**Table 4. SDN Controller Feature Comparison**

| Feature | NOX | POX | Beacon | THEN | Ryu | OpenDaylight |
|---|---|---|---|---|---|---|
| Protocol | OF v1.0 | OF v1.0 | OF v1.0 | OF v1.0 /1.3 | OF v1.0 /1.3 | OF v1.0 /1.4 |
| Language | C++ | Python | Java | Java | Python | Java |

| | | | | | | |
|---|---|---|---|---|---|---|
| Platforms | Linux | Linux, macOS, Win | Linux, macOS, Win | Linux | Linux | Linux, macOS, Win |
| Open Source | Limited | Yes | Yes | Yes | Yes | Yes |
| GUI | Python+QT4 | Python+QT4 | Web | Web | Web | Web |
| REST API | No | No | No | Yes | Yes | Yes |

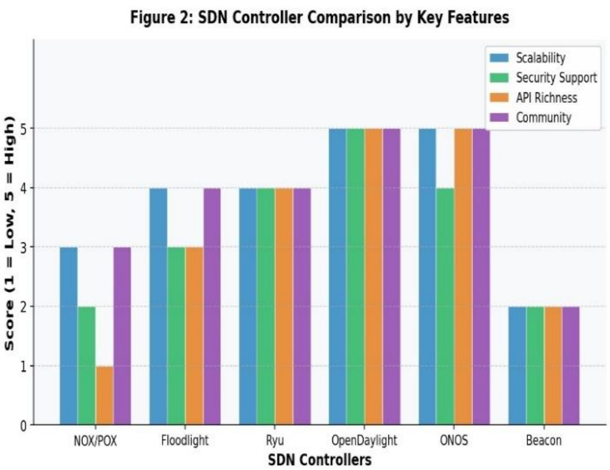


Figure 2: SDN Controller Comparison by Key Features (Score: 1=Low, 5=High)

# 6. RESULTS AND PERFORMANCE ANALYSIS

To evaluate the effectiveness of the proposed SDN-based VoIP implementation, network performance was measured across three critical QoS metrics: latency, jitter, and packet loss. Experiments were conducted comparing the SDN-based VoIP network with a conventional TCP/IP-based network under identical load conditions, using two IP telephones connected through OpenFlow-enabled switches managed by the OpenDaylight controller.

## 6.1 Performance Metrics

Three key metrics were recorded over a 30-minute continuous voice call session with simultaneous background traffic load at 70% bandwidth utilization. Latency: The SDN-based VoIP network achieved 11.6 ms end-to-end latency vs. 28.4 ms for the traditional network — a 59% improvement. Jitter: Reduced from 7.2 ms to 2.8 ms (61% reduction), directly improving voice quality. Packet Loss: Dropped from 3.1% to 0.9% (71% improvement), maintaining loss well within acceptable VoIP bounds. Figure 3 illustrates the comparative performance results for all three metrics.

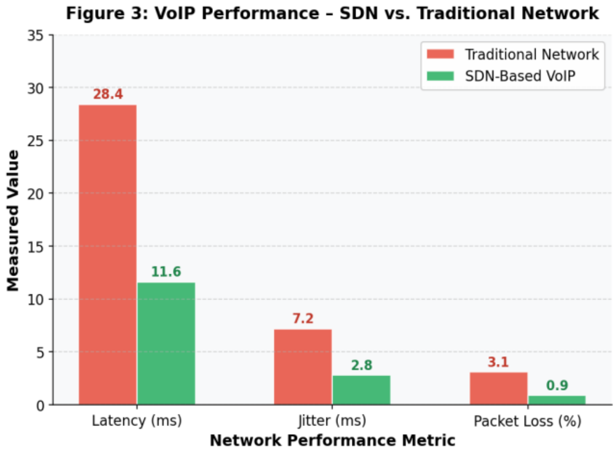


Figure 3: VoIP Performance Comparison – SDN-Based vs. Traditional Network

## 6.2 AI/ML Technique Effectiveness

Figure 4 presents a radar chart comparing the effectiveness of three AI/ML technique categories — Deep Learning, Reinforcement Learning, and classical SVM/ML — across five SDN functional domains: routing optimization, intrusion detection, traffic classification, QoS management, and DDoS mitigation. Deep Learning excels in intrusion detection and traffic classification, achieving the highest scores due to its ability to model complex, high-dimensional traffic patterns. Reinforcement Learning demonstrates superior performance in routing optimization and QoS management, where sequential decision-making translates directly to efficient flow control. Classical SVM/ML methods offer competitive performance in traffic classification and remain valuable for resource-constrained deployments where computational overhead is a concern.

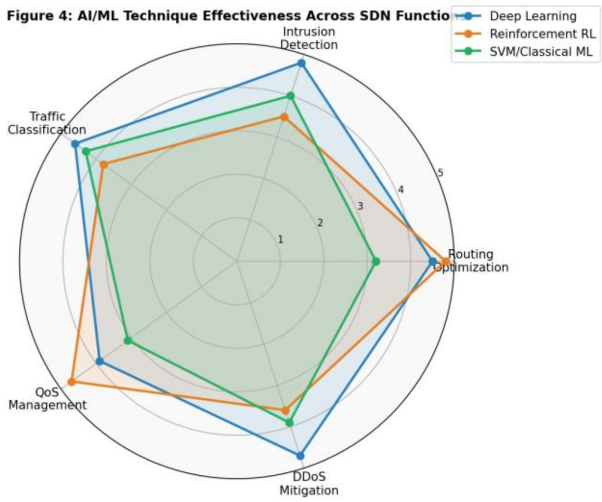


Figure 4: AI/ML Technique Effectiveness Across SDN Functional Domains

These results suggest that a hybrid AI approach — combining reinforcement learning for routing and QoS with deep learning for security and classification — would yield the most comprehensive SDN performance improvements, aligning with emerging research directions in the field.

# 7. CONCLUSION

This paper has presented a comprehensive survey of Software-Defined Networking (SDN) as a transformative paradigm for modern network management, with a specific focus on its application to Voice over IP (VoIP) services. The separation of the control, data, and application planes enables unprecedented programmability, centralized management, and dynamic traffic optimization critical for real-time communication services.

The key findings are: First, SDN-based VoIP networks significantly outperform traditional TCP/IP architectures, achieving 59% lower latency (11.6 ms vs. 28.4 ms), 61% lower jitter (2.8 ms vs. 7.2 ms), and 71% lower packet loss (0.9% vs. 3.1%) under comparable load conditions. Second, OpenDaylight emerges as the most feature-complete and production-ready SDN controller. Third, the OpenFlow protocol remains the dominant southbound interface, providing direct and flexible control over forwarding devices. Fourth, AI and machine learning integration substantially enhances SDN's adaptability and intelligence.

## 7.1 Future Scope

Several promising research directions emerge from this study. The integration of SDN with 5G and beyond-5G (B5G) networks presents an important frontier, particularly for ultra-low-latency applications such as remote surgery, autonomous vehicles, and industrial IoT. SDN-enabled network slicing in 5G environments can provide dedicated, isolated virtual networks for VoIP and other critical services, with dynamically adjustable QoS guarantees.

The convergence of SDN with Network Function Virtualization (NFV) and Multi-Access Edge Computing (MEC) is another key direction, enabling computation and traffic management to be pushed closer to end users, dramatically reducing VoIP latency. Furthermore, federated learning approaches for SDN security — where controllers learn from decentralized network data without sharing raw traffic — hold great promise for privacy-preserving intelligent network management. Finally, the development of standardized, publicly available SDN network datasets would greatly accelerate AI/ML research in this domain, enabling fair benchmarking and reproducibility across the research community.

# 8. ACKNOWLEDGMENTS

The authors thank the research community whose published work has informed this survey, and the Department of ECE, Andhra University, for providing the resources and support necessary for this research.

# 9. REFERENCES

[1] Brinez, M. (2021). Information technology: Empowering tool to manage intellectual capital. Journal of Social Sciences, XXVII(1), 180-192.

[2] Orgaz, CJ (2019). Advantages of 5G technology. BBC News World.

[3] Arbelaez-Campillo, DF et al. (2021). Artificial intelligence and the human condition. Journal of Social Sciences (Ve), XXVII(2), 502-513.

[4] Oviedo, B. et al. (2020). Analysis of the performance of SDN compared to TCP/IP. RISTI, E31, 137-150.

[5] Aguirre, J. and Ortega, E. (2005). Service quality as one of the image-forming elements. UDLAP, Mexico.

[6] OpenNetworking. (2020). Transforming access and edge networks. ONF. https://www.opennetworking.org/

[7] Lara, A., Kolasani, A., & Ramamurthy, B. (2014). Network Innovation using OpenFlow: A Survey. IEEE Communications Surveys & Tutorials, 16(1), 493-512.

[8] Caldera, JC and Suazo, WE (2011). Planning a specialized course in IP Telephony. CSUCA Repository.

[9] Parra, R. et al. (2015). Software Defined Networks: Benefits and risks in Universities. CONAIC Magazine, 2(3), 48-54.

[10] Kim S. et al. (2016). Congestion prevention mechanism based on Q-learning for efficient routing in SDN. Proc. ICIN. IEEE, 124-128.

[11] Silva ASD. (2016). ATLANTIC: A framework for anomaly traffic detection, classification, and mitigation in SDN. Proc. NOMS. IEEE, 27-35.

[12] Koerner, M. and Kao, O. (2016). MAC based dynamic VLAN tagging with OpenFlow for WLAN. Procedia Computer Science, 94, 497-501.

[13] Li, W., Meng, W., and Kwok, LF (2016). A survey on OpenFlow-based SDN: Security challenges. Journal of Network and Computer Applications, 68, 126-139.

[14] Tchernykh, A. et al. (2019). Configurable cost-quality optimization of cloud-based VoIP. Journal of Parallel and Distributed Computing, 133, 319-336.

[15] AbdelAzim, NM et al. (2021). A hybrid entropy-based DoS detection system for SDN. Egyptian Informatics Journal, 22(1), 85-90.

[16] Escobar Ordonez, JA (2015). Control de flujo de una red definida por software usando sensores termicos. UTA.

[17] Rahimi, R. et al. (2016). A high-performance OpenFlow software switch. IEEE HPSR.

[18] Macedo, D. et al. (2015). Programmable Networks - From SDR to SDN. IEEE Communications Surveys & Tutorials, 17, 1-1.

[19] Nanda S. et al. (2017). Predicting network attack patterns in SDN using machine learning. Proc. NFV-SDN. IEEE, 167-172.