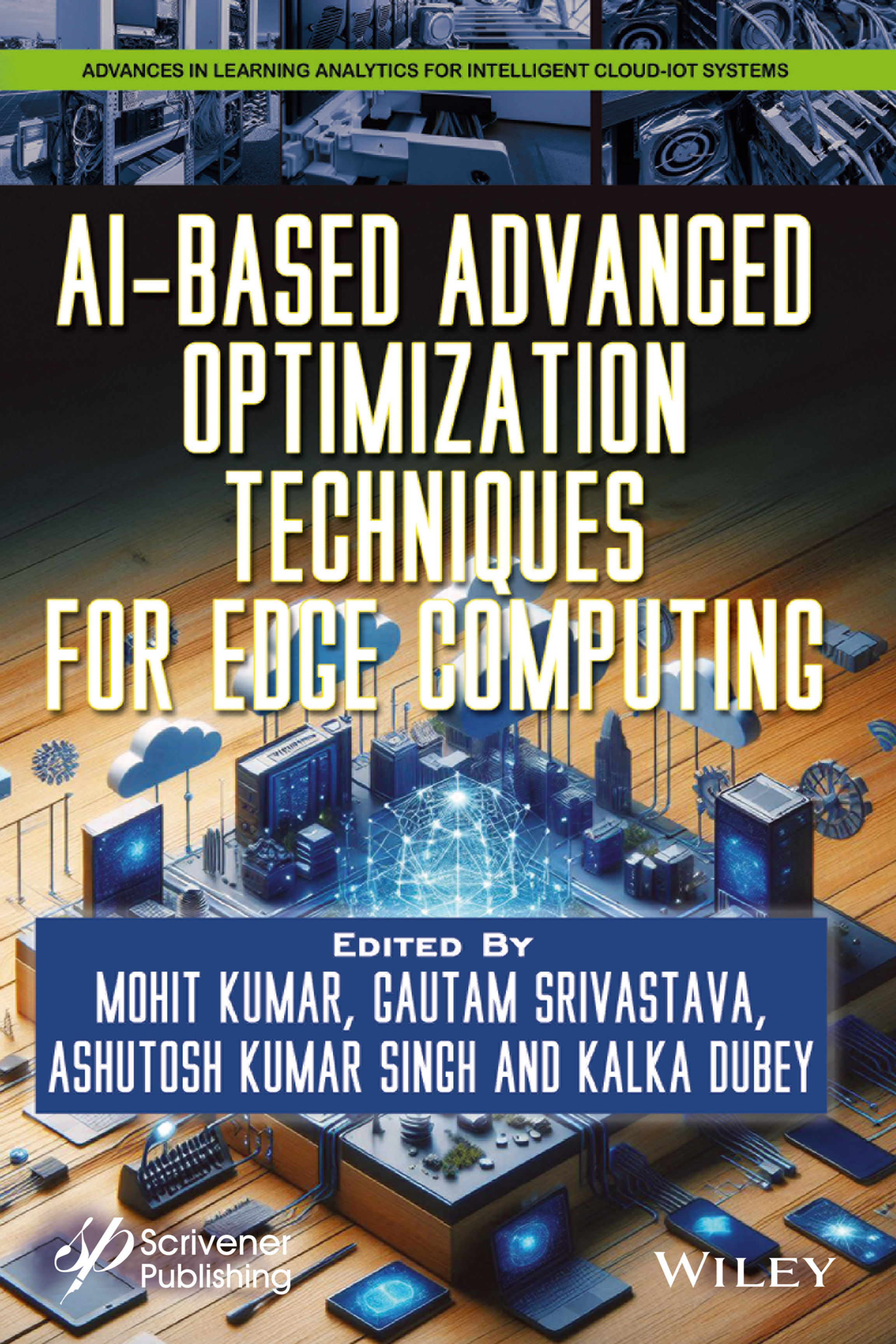

ADVANCES IN LEARNING ANALYTICS FOR INTELLIGENT CLOUD-IOT SYSTEMS

AI-BASED ADVANCED OPTIMIZATION TECHNIQUES FOR EDGE COMPUTING

EDITED BY

MOHIT KUMAR, GAUTAM SRIVASTAVA,
ASHUTOSH KUMAR SINGH AND KALKA DUBEY

Scrivener
Publishing

WILEY

AI-Based Advanced Optimization Techniques for Edge Computing

Scrivener Publishing
100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

Machine Learning in Biomedical Science and Healthcare Informatics

Series Editors: Vishal Jain (drvishaljain83@gmail.com)
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In this series, an attempt has been made to capture the scope of various applications of machine learning in the biomedical engineering and healthcare fields, with a special emphasis on the most representative machine learning techniques, namely deep learning-based approaches. Machine learning tasks are typically classified into two broad categories depending on whether there is a learning 'label' or 'feedback' available to a learning system: supervised learning and unsupervised learning. This series also introduces various types of machine learning tasks in the biomedical engineering field from classification (supervised learning) to clustering (unsupervised learning). The objective of the series is to compile all aspects of biomedical science and healthcare informatics, from fundamental principles to current advanced concepts.

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WILEY

This edition first published 2025 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA
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Library of Congress Cataloging-in-Publication Data

ISBN 978-1-394-28703-1

Front cover images courtesy of Adobe Firefly.
Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Contents

Preface

This book was written to bridge the gap between existing state-of-the-art technologies and the evolving requirements of modern industries. It provides emerging research that explores both theoretical and practical aspects of implementing new and innovative intelligent techniques across a variety of sectors, including Edge Computing, Cloud Computing, the Internet of Things, Agriculture, and Artificial Intelligence. This book serves as a valuable resource for academics, IT specialists, industry professionals, researchers, engineers, and authors seeking insights into emerging trends in AI-enabled Cloud and Edge Computing for IoT applications. It aims to explore the intricate relationship between AI and Edge/Cloud computing, delving into their synergies, applications, and future implications.

This book comprises 16 chapters, each covering intertwining concepts at two key levels of interest to the scientific community: Artificial Intelligence and Edge/Cloud Computing.

Chapter One explores navigating next-generation network architecture, unleashing the power of SDN, NFV, NS, and AI convergence. Chapter Two examines OctoEdge, an octopus-inspired adaptive edge computing architecture. Chapter Three discusses the development of optimized machine learning-oriented models.

Chapter Four focuses on leveraging multimodal data and deep learning for enhanced stock market prediction. Chapter Five delves into context-dependent sentiment analysis using machine learning. Chapter Six investigates enhancing thyroid cancer prediction by applying machine learning algorithms to clinical data.

Chapter Seven presents an LSTM-oriented approach for next-word prediction using deep learning. Chapter Eight analyzes churn prediction in social networks using a modified BiLSTM-CNN model. Chapter Nine addresses security concerns in healthcare fog computing using IoT and blockchain.

Chapter Ten highlights the smart agriculture revolution with cloud and IoT-based solutions for sustainable crop management and precision farming. Chapter Eleven explores a greedy particle swarm optimization approach using the Lecky ReLU function for solving minimum spanning tree problems.

Chapter Twelve introduces an SDN-deployed secure application design framework for IoT using game theory. Chapter Thirteen presents a framework for PLM in Industry 4.0 based on industrial blockchain.

Chapter Fourteen discusses a machine learning-enabled smart agriculture classification technique for edge devices using a remote sensing platform. Chapter Fifteen examines a lightweight intelligent detection approach for interest flooding attacks. Chapter Sixteen describes an Internet of Vehicles model architecture with seven layers.

This book may serve as a reference for a graduate course in Artificial Intelligence and Cloud Computing. Readers are expected to be well-versed in the basic concepts of Machine Learning, Distributed Computing, and the Internet of Things. The theoretical concepts presented will be valuable for coursework.

Writing this book has been a rewarding experience, made possible by the tremendous efforts of a dedicated team. We extend our gratitude to the authors who contributed their respective chapters, as well as to the editors who offered valuable suggestions for improving content delivery. Every piece of feedback was carefully considered, and it has undoubtedly shaped parts of the work. We are especially grateful to Martin Scrivener and Scrivener Publishing for their help and publication. Finally, we thank our families for their unwavering support—without them, this book would not have been possible.

November 2024

Acknowledgement

The writing of this book has been a rewarding experience and elaborates a huge effort from a team of very dedicated contributors. We would like to thank list of authors who contributes their respective chapter and we are also thankful to the list of editors who provides suggestions for better delivery of content. All feedback was considered and there is no doubt that there will be some content influenced by the suggestions. We especially thank to the publisher who believes in the content and provides a platform to reach it out to the audience. Finally, we are thankful to our family for their continued support. Without them, the book would not have been possible.

1

Navigating Next-Generation Network Architecture: Unleashing the Power of SDN, NFV, NS, and AI Convergence

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Abstract

The framework for existing legacy network architecture is massive and complex. It mainly relies on inflexible and expensive equipment, typically constructed from a massive number of switches, routers, firewalls, and hubs. Moreover, this vendor-specific network configuration and complex control protocols are not flexible enough to offer customized quality of services (QoS). Provisioning of next-gen (Next Generation, 5G, and beyond) technologies, software-defined networking (SDN), network function virtualization (NFV), and network slicing (NS) work as catalysts to offer simplified, customized, and clever networking. To provide centralized positioning, SDN decouples the control plane (CP) and data plane (DP) from the traditional router. In the SDN architecture, decision making and network control are now done at a centralized place known as the controller. However, DP is still intact with the routing device. This arrangement privileges the network administrators to control, manage, and alter network behavior dynamically. To contrast the vender-specific networking, NFV allows network functions (NFs) to run on generic hardware. In this direction, NS pioneers QoS-specific use cases as a new business model. NS involves the slicing of a single physical network in the form of multiple slices. It not only supports the customization of QoS

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Mohit Kumar, Gautam Srivastava, Ashutosh Kumar Singh and Kalka Dubey (eds.) AI-Based Advanced Optimization Techniques for Edge Computing, (1–34) © 2025 Scrivener Publishing LLC

services for diverse use cases, but it also improves isolation, independence, multi-tenancy, dynamic resource allocation, and end-to-end service provisioning. In this chapter, we first delved into NexGen's promising technologies and explored their intertwined role and impact on the modern networking framework. We accessed various SDN and NFV architectures and discussed network-slicing framework. Secondly, we have shed light on the importance of AI-driven automated network management over traditional network approaches. In this sequence, we conducted a comparative analysis of AI-driven machine learning (ML) and deep learning (DL) approaches in the context of NextGen technologies. In this chapter, we intend to systematically and intricately navigate the multifaceted landscape of NexGen technologies. This chapter will offer researchers, industry stakeholders, and practitioners a timely and deeper understanding of transformative technology and its impact on modern network paradigms.

Keywords: Next-generation technology, SDN, NFV, QoS, NS

1.1 Introduction

The evolution of network technologies has marked pivotal advancements in the telecom sector. It spans from the radiant stage of ARPANET to modern networking. The existing legacy network architecture is based upon un-flexible and costly network equipment comprising switches, hubs, routers, and firewalls [1]. These proprietary hardware-based traditional networks grapple with the demands of modern networking. The surge of extensive data traffic, dynamic network conditions, and the need for real-time decision-makers pose challenges that traditional networks are not capable of addressing efficiently [2]. Traditional methods, such as Static Routing, Ethernet, Transmission Control Protocol (TCP), and Internet Protocol (IP), are built on manual configuration and static protocols. With the surge of diverse applications, customized QoS, high volume, and unpredicted traffic necessitate a paradigm shift. To address these limitations of the traditional approach, Next-Gen (Next Generation, 5G, and beyond) technologies, Software Defined Networking (SDN), Network Function Virtualization (NFV), and NS act as catalysts for redefining the network paradigm. SDN [3] disrupts traditional decentralized architecture by decoupling the Control Plane (CP) and Data Plane (DP) from conventional routers. This centralized control and decision-making entity is known as the controller. This architectural shift empowers the network controller to dynamically manage, control, and modify the network behavior. Concurrently, NFV [4] revolutionizes network functionality by enabling them to run on generic hardware instead of proprietary hardware, offering cost-effectiveness, flexibility, and simplified maintenance. With the advancement of the network landscape, customize QoS-specific servers are the new business model. In this direction, NS [5] has become a revolutionary approach, involving the partitioning of a single physical network into multiple slices. It not only offers customized QoS requirements to modern applications but also enhances isolation, dynamic resource allocation, multi-tenancy, and security [6].

This book chapter also explored the NextGen promising technologies and their intertwined role and impact on modern networking. Traditional networking approaches are static and require human intervention during changes in the network. The increase in network size and the unpredictable nature of network traffic make them more time-consuming and complex. Therefore, AI emerges as a key driver for NextGen networking. It introduced the level of intelligence with its learning and capability of predictive analysis. This chapter also sheds light on how AI-driven approaches complement and enhance the functionalities of SDN, NFV, and NS.

The contributions and highlight of this book chapter are as follows:

- Initially, we present a concise overview of the evolutionary history of network technologies and the key phases that shaped the modern networking landscape.
- To explore the transformative NexGen technologies (SDN, NFV, and NS), we highlight the influence and intertwining role of NexGen technologies.
- This paper systematically highlights the importance of AI over traditional methods. In this sequence, we conducted a comparative analysis of AI-driven Machine Learning (ML) and Deep Learning (DL) approaches in the context of NextGen technologies.
- Finally, we identify challenges associated with NexGen Technologies and with the integration of these modern technologies.

In a nutshell, this chapter will offer researchers and industry stakeholders a timely and deep understanding of transformative NexGen technologies and the impact of their combination on modern technology. It also includes the contribution and comparative analysis of AI-driven algorithms in the context of NexGen technologies.

1.2 Revolutionizing Infrastructure with SDN, NFV, and NS

Due to increasing day-to-day network traffic, networking technologies have undergone a continuous evolution, and based on this, they can be categorized into several phases, such as traditional networking, Wireless Sensor Networking (WSN), client-server networking, and more. Before discussing NexGen technologies and its specifications, it is crucial to examine the evolutionary changes of networking technologies and the key developments that have been influenced by traditional networking. Concise overview is given as follows:

A. ARPANET and Early Networking:

- **ARPANET:** The Advanced Research Projects Agency Network (ARPANET) [7], established in the 1960s, conducted early experiments for linking computer systems over short distances. It laid the foundation for modern networking. However, these networks remained restricted to research institutions.
- **Packet Switching:** The development of packet switching [8], a key innovation during this era, allowed data to be broken into packets, transmitted independently, and reassembled at the intended destination.

The pioneering work and packet switching laid the fundamental groundwork for the internet.

B. Emergence of the Internet:

- **Standardization (TCP/IP):** During the 1980s, the TCP [9] and IP underwent standardization, forming the backbone of the modern Internet.
- **Commercialization:** The Internet underwent a pivotal shift from being primarily dedicated to research and academia to a commercial platform, leading to the rise of the World Wide Web (WWW). It establishes the fundamental framework for the contemporary Internet.

C. Emergence of Client-Server Architecture and LANs:

- **Client-Server Model:** In 1980s, the paradigm of computing is shifting from centralized mainframes to distributed systems with the client-server model [10].
- **The rise of Local Area Networks (LANs):** The internet and other LAN technologies emerged, allowing computers to share resources within confined spaces.

D. Wireless Networking and Mobility:

- **Wi-Fi Standardization:** In the 2000s, the standardization of wireless technologies, particularly Wi-Fi adoption [11], empowered enhanced mobility and flexibility in network access.
- **Expansion of Mobile Networks:** The surge in mobile device usage during this era empowered enhanced mobility and flexibility in network access [12].

E. Cloud Computing and Virtualization:

- **Evolution of Cloud Services:** The 2010s witnessed a transformative shift with the advent of cloud computing [13], fundamentally changing the way data and applications are stored and accessed.
- **Rise of Virtualization:** The decade also saw the emergence of NFV and SDN [14], contributing to enhanced flexibility and efficiency in the management of network resources.

In the beginning, traditional enterprise networks followed conventional decentralized designs and scattered collections of purpose-built routers, switches, and middle-boxes supplied by various hardware vendors [15]. Each device uses embedded proprietary hardware and logic to make forwarding decisions, filter traffic, or transform flows. This distributed CP closely relates key networking functions to the restrictions of the underlying boxes in terms of capability and flexibility. The conventional decentralized networking architecture imposed significant barriers to change in network arrangements. Every configuration change or new policy meant navigating vendor-specific command-line interfaces to manually reprogram

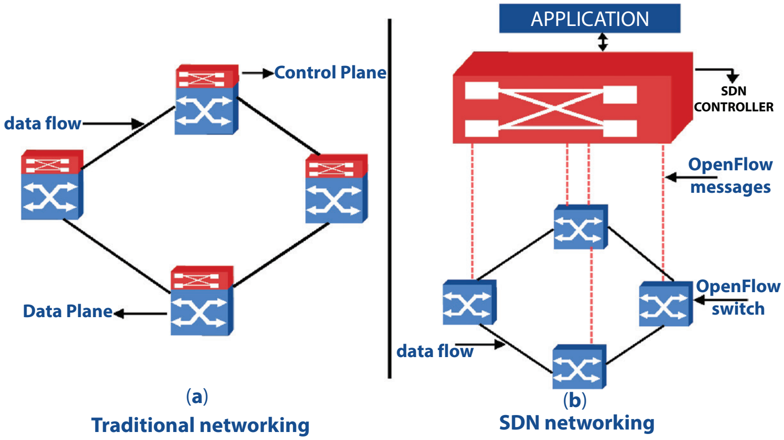

Figure 1.1 (a) Decentralized traditional architecture. (b) Centralized SDN architecture.

individual pieces of equipment. To deal with the huge dynamic traffic, this fragmented model is not appropriate due to the rigidities of closed hardware systems. The massive burden of managing numerous devices running complex embedded protocols eventually became unsustainable. To address the longstanding limitations of traditional network architectures, the SDN paradigm emerged to unlock network flexibility and fundamentally introduce centralized network control [16]. The architectural differences between traditional decentralized architecture and centralized architecture are presented in Figure 1.1(a) and 1(b) respectively.

1.2.1 SDN: Definition and Architecture

SDN architecture [17] is the paramount approach for centralized network control. It is structured to decouple the control plane from the data plane and provides automation and centralized control by delegating specialized functions to each level via programmatic APIs. The centralized control unit, known as the controller, is responsible for network design, decision-making, and network management. The SDN architecture typically comprises three main components:

- **Application Layer:** The topmost layer of SDN consists of software programs that communicate business-related policy and network behavior. This layer interacts with the SDN controller to communicate policies, requirements, or network changes. Common SDN applications include load balancing, traffic monitoring, and security applications.

- **Control Layer:** This intermediary layer, known as the SDN controller, is the brain of the SDN architecture. The controller communicates with network devices in the infrastructure layer via southbound and SDN applications via northbound APIs at the application layer.
- **Infrastructure Layer:** The bottom layer is the infrastructure layer, which consists of the physical and virtual network devices those forward data packets. In contrast to traditional networking by separating the CP, the intelligence for decision-making is moved from individual devices to the centralized controller.

The architecture presented in Figure 1.2 outlines the fundamentals of SDN. However, SDN provides incredible versatility to adapt its core principles into diverse architectural designs to address specific networking needs and challenges. In the realm of single-layer architectures, centralized controller manages the entire network, whereas distributed SDN architecture's [18] CP functions across multiple controllers to provide more scalability

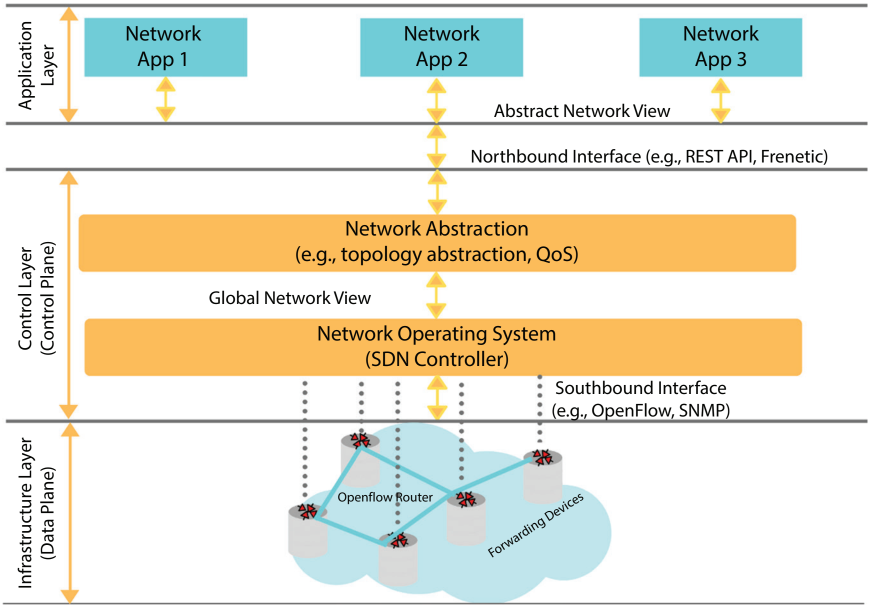

Figure 1.2 A typical architecture of SDN consists of three layers.

Table 1.1 Common SDN protocols and APIs within SDN architecture.

Aspect	SDN protocol/API	Description
Northbound APIs	Open Flow	A standard protocol between SDN controllers and network devices such as switches to define flows.
	REST APIs	Representational State Transfer (REST) APIs leverage controller communication with SDN applications for northbound interactions.
	NETCONF	It is used for northbound communication between controllers and network devices for network management.
Southbound APIs	Open Flow	Southbound protocol, communicate between SDN controllers and network switches to configure data plane behavior.
	P4 (Programming Protocol-Independent Packet Processors)	Southbound API for defining packet forwarding behaviors to define packet processing across devices.
East-West APIs	VXLAN	Facilitating east-west traffic to create virtual overlay networks across data centers.
	Geneve	Another overlay protocol for east-west communication for network virtualization across SDN environments.

in comparison with a single SDN controller. Multi-layer SDN architecture presents hierarchical SDN architecture [19] with multiple layers of controllers. It helps to enhance organization and management in large-scale networks. On the other hand, in a hybrid SDN architecture, SDN coexists with traditional networking (NON-SDN) [20] elements. It allows for seamless integration of SDN principles with traditional networking elements, allowing coexistence and transition. Overlay SDN architectures [21] are commonly prevalent in data centre environments. In this tunneling, protocols are used to create virtual networks on top of the physical infrastructure. Cloud SDN architectures [22] focus on cloud environments, emphasizing automation, agility, and the ability to adapt to the dynamic workloads characteristic of cloud computing. Intent-Based Networking (IBN) architectures [23] are mainly focused on high-level business intent for automated and simplified management of networks on the basis of desired output. Tailored for 5G networks, the 5G SDN architecture integrates SDN with NFV to meet the demands of next-generation network framework. SDN protocols play a crucial role in communication and coordination between various components of SDN. It primarily facilitates communication between components, policy dissemination, dynamic adoption, load balancing, and configuration management. Table 1.1 outlines the common SDN protocols and APIs within SDN architecture.

1.2.2 NFV: Definition and Architecture

Non-virtualized traditional networks run on dedicated proprietary hardware. Unlike them, NFV supports the sharing of infrastructure resources during NF deployments and runs as a software application on generic hardware instead of proprietary hardware. It virtualizes NFs such as firewalls, routers, and load balancers, also known as VNFs (Virtual NFs). The NFV architectural framework defined by ETSI [24] consists of three key domains:

- **Virtualized Network Functions (VNFs):** VNFs are software applications implemented on network functions to replace dedicated appliances. These software instances replicate the functionality of traditional network devices such as firewalls and load balancers.
- **NFV Infrastructure (NFVI):** This includes the infrastructure components (compute, storage, and networking; Commercial-off-the-Shelf (COTS) hardware like servers,

switches, and storage deployed in data centers); and the virtual layer on which VNFs run.

- **NFV Management and Orchestration (NFV MANO):** This includes orchestrators, VNF managers, and it supports the framework for orchestration and management of the lifecycle of VNFs across the NFVI.

ETSI defines the foundational NFV architectural block presented in Figure 1.3. However, the NFV architecture exhibits diverse forms to accommodate diverse scenarios and specific operational requirements. In a centralized NFV architecture [19], management and orchestration functions are consolidated to simplify CP. However, centralized designs focused exclusively on operational efficiency can suffer from latency limitations in distributed deployments. Meanwhile, distributed NFV infrastructure [25] spreads capabilities across multiple localized data centers, catering to scenarios where low-latency communication is critical, as seen in edge computing environments. Hybrid architecture is intended to balance the tradeoffs between centralized and distributed architecture. In this architecture, common network functions get consolidated into a core virtualized infrastructure for efficiency, while other specialized functions continue at the edge for performance.

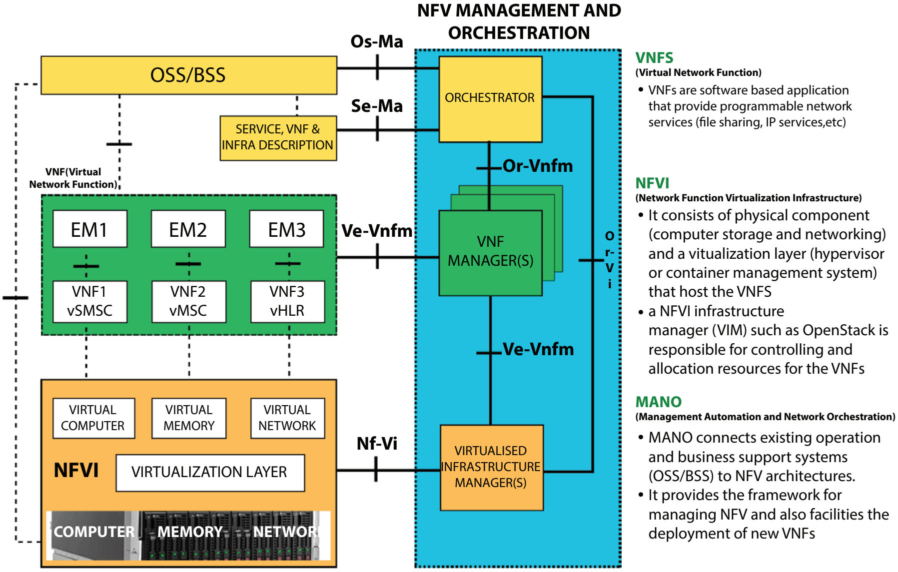

Figure 1.3 NFV layered architecture.