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AN OVERVIEW ON NETWORK RESOURCE ALLOCATION AND MANAGEMENT INSIDE SDN NETWORKS

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Abstract**—** At the present time one of the most challenging issues of the network is resource allocation. Mostly traditional networks depend on hardware in resource allocation. But Software Defined Networking uses software to control and manage the network. The SDN-enabled sixth-generation (6G) networks must allocate resources dynamically and efficiently, ensure flexibility and optimizing resource consumption. Software-Defined Network (SDN) is a significant spread in make simpler network deployment and operation by reducing costs and enabling the network to be programmable. SDNs provide a practical solution for networking issues like scalability and network efficiency. The main disadvantage of conventional resource management systems is that they are not totally dynamic and cannot handle an unstable network. Nowadays, network resource management in software-defined data centers has been ready using Artificial Intelligence (AI) approaches, which allow for the automatic allocation of resources base on different network metrics and measurements. This article provides an in depth overview on most significant studies regarding network resource allocation and management inside SDN networks. In this study starts with explaining the SDN architecture, applications, as well as the usage of AI in SDN. Finally, this study is concluded with some modification to get better resource allocation in SDN.

Keywords—Software-Defined Networking, Resource Management, Artificial Intelligence, Data center, Resource Allocation.

I. INTRODUCTION

The understanding of a computer network is that it consists of linked computing devices like hubs, switches, and routers that use various protocols. Include computing, scalability is a defining factor in the face of huge changes that the network undergoes in any split millisecond, the management of such a network is error-prone, hard to scale, and difficult to manage routing tables. It cannot keep up with today's increasing demand from the Internet [1].

The idea of programmable networks has arisen as a solution for the issues with the old network design like conventional networking. As it allows for programmability, SDN is suitable for the networking environment because it is dynamic, controllable, cost-effective, and flexible. To accomplish this task, the network is divided into two parts. First one the control plane, oversees tasks like determining the best path for data, managing network policies, and handling routing protocols.. The second one Data Plane is also known as the forwarding plane. It is used to handle the actual movement of data through the network that manages sending traffic to the destinations [2]. This separation allows for more flexibility in the networking sector.

Architecture of SDN:

Figure 1 illustrates the basic design of SDN. Applications use the two levels of the management plane and forwarding plane for interaction, arranged hierarchically. It is important to note that switches in SDN do not autonomously generate the forwarding table, rather they depend on the controller to create a flow table. The control plane of the SDN model comprises a centralized controller, which is the most significant novel work offered by SDN [3]. The Application Layer is the first layer of the SDN architecture. This layer include various applications that use the capabilities of the SDN Controller to perform some tasks, like traffic management, security services, and load balancing. The Infrastructure Layer is known as the physical layer. It is the foundation of the SDN architecture. It has network devices both physical and virtual for Data Plane. These devices like switches and routers are used to forward data according to the instructions of the SDN Controller .Programmable Switches are used as building blocks of the Data Plane. SDN Controller manages these switches, upgrade the network simply.

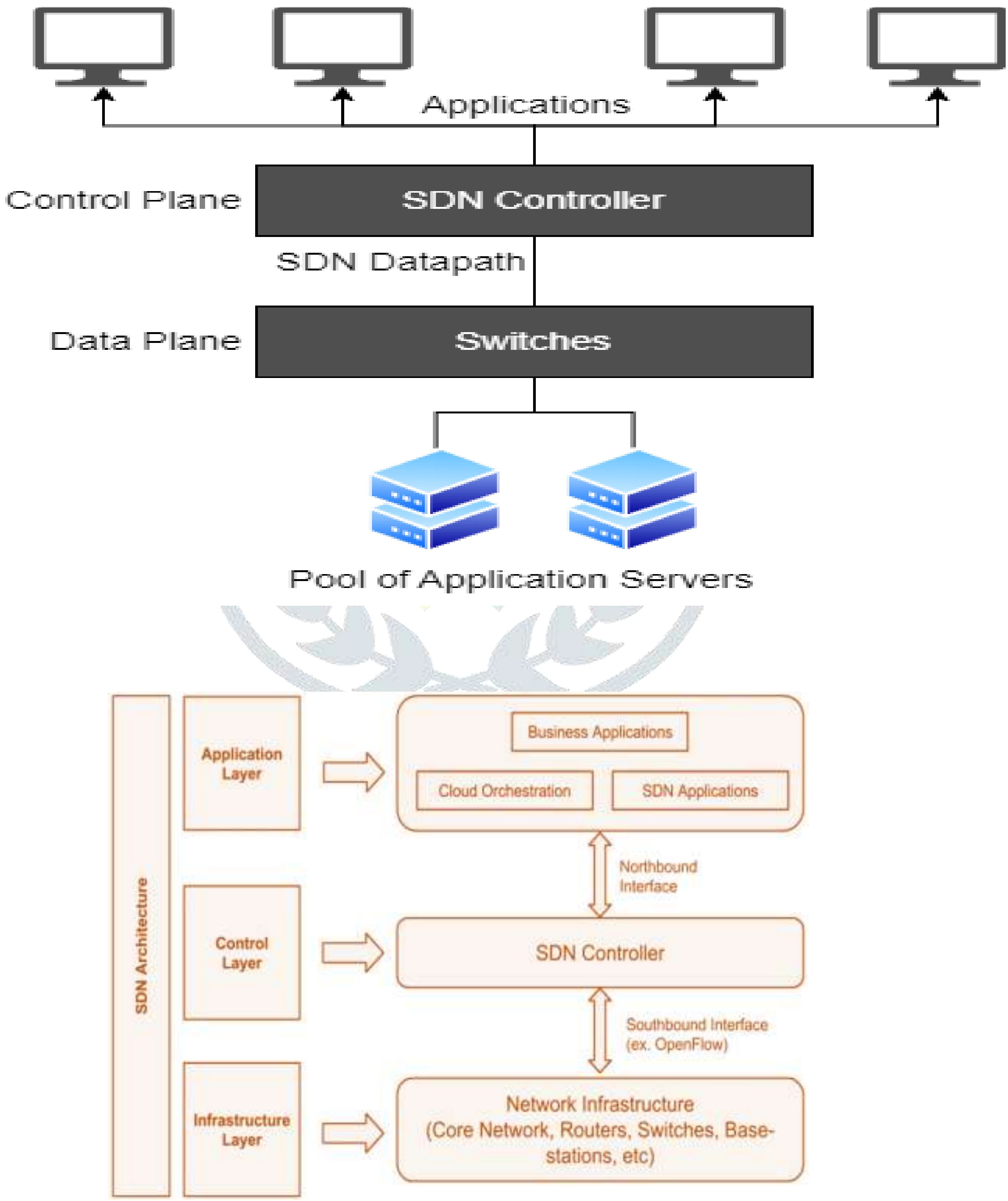

Fig. 1. Architecture of SDN

Table 1 highlights the basic differences between conventional networking and SDN.

TABLE I.

COMPARISON BETWEEN CONVENTIONAL NETWORKING VS SDN

Criteria	Conventional Networking	Software Defined Networking
Data and control planes	Connected	Interconnected
Management plane	Distributed	Concentrated
Management of networks	Modifications executed independently at all devices	Easier by using the controller
Network supervision	Limited view	Global view
Network flexibility	Minimal	Maximum
Versatility	Rigid and unyielding	Elevated
Cost of maintenance	Superior	Inferior

A. *Applications of SDN*

SDN allows for central administration via decoupling the controller plane from the bearer plane, eliminating the need for middle boxes that conventionally complicate network operations. This decoupling is especially advantageous for corporate networks, which often run massive server nodes and must conform to stringent security and performance criteria. In corporate settings where reliability is critical, SDN can efficiently automate these needs [4].

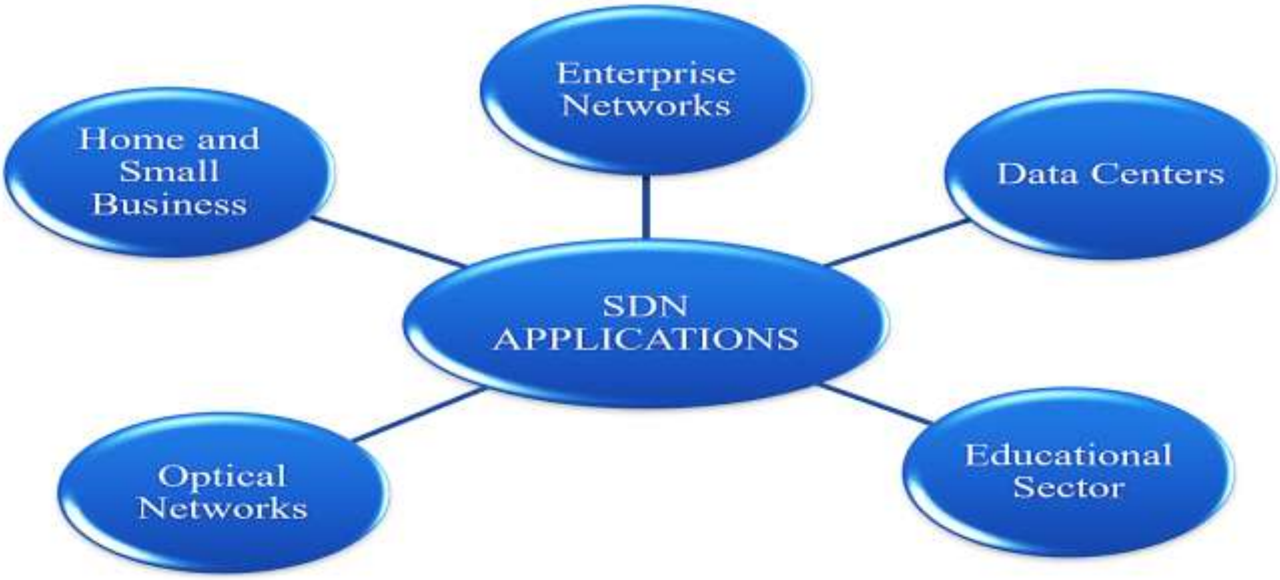

Fig. 2. Applications of SDN

However, network stability issues caused by the frequent modifications related to SDN setups, demonstrating that such instability leads to service disruptions and data privacy breaches. Data Centers (DCs) are another key SDN use in how they manage network traffic under high-demand conditions [5]. SDN enables the separation of network management activities from hardware configurations, allowing for proactive modifications without requiring client-side equipment changes. SDN has shown potential in optical network applications by controlling traffic as streams and facilitating integration across several network technologies [6].

SDN is also vital for home networking, where both small and big businesses benefit from the technology's extensive monitoring and management capabilities. The availability of low-cost technologies that add complexity to network administration has raised the need for tight network management [7]. The significance of identifying harmful traffic early and keeping user control over home networking equipment is also discussed, with SDN options giving customers clear visibility and control over their network operations, therefore improving both security and performance.

B. Resource Allocation for SDN

Resource allocation is an essential aspect of network architecture that can profoundly influence the security and reliability of a network. In this sense, resources include network bandwidth, processing power, memory, storage capacity, and other analogous assets essential for the optimal operation of a network [8]. Due to temporal variation and unpredictability, wireless channels under the wireless context, especially for 5G systems, necessitate flexible allocation of resources rather than predictable distribution [9].

Techniques for allocating resources in SDN-based cellular designs may target the backhaul network or the core network (SDN-enabled switch), which is one level of resource allocation [10]. However, given the high networking dynamism and the existence of particular mechanisms for resource allocation depending on user needs, a entire Quality of Service (QoS) becomes achievable in SDN-based cellular architecture.

a) ***Resource Allocation Challenges in SDN*****:** Numerous issues, including connection separation, channels calculation, radio frequency volatility, as limited capacity, are faced by SDN-based cellular networks. These difficulties restrict the user's demand in terms of data rate. Resource allocation and dynamic management need to be restructured since the criteria and execution of variable allocation of resourcesremain unclear. The allocation of resources in a conventional cellular network is based on its availability. Round Robin (RR), Round Trip Time (RTT), leaky bucket, etc., are common methods for allocating resources [11]. In SDN, flow-based resource allocation schemes are commonly utilized. Isolating the fronthaul and backhaul resources is also necessary to provide a high rates of data across the identicalreal network. Nevertheless, the SDN paradigm requires that stream entries in tables be modified continuously based on the process. A collection of packets with one or more common attributes, like the origin IP addresses, target IP address, original MAC address, etc., may be used to construct flows. Therefore, the specification of rules and regulations onuser plane for data rapid forwarding is constantly changing.

C. Applications of Artificial Intelligence (AI) in SDN:

At first, AI was only used in low-complexity SDN contexts like security and routing. Conventional SDN divided the forwarding frame about the control layer, wherein switches carried out operations according to pre-established rules after receiving directives through a controller over a standardized connection. But in the age of Big Data, when it is difficult to create exact rules based on data circumstances, this conventional methodology is no longer enough to manage the complexity and size of traffic today. As a result, researchers are concentrating on improving SDN architecture, security, routing intelligence, and scalability. To comprehend their benefits and drawbacks, the use of AI among three domains, such as data ,regulation, and implementation has been researched and examined [12]. This shows that AI can be included in every facet of SDN, producing positive outcomes for the advancement and development of this technology.

a) ***Data Plane****:* The design of switches and the creation of forwarding rules are the two primary focuses of data plane research. When it comes to router designs, the emphasis consists of developing scalable along with swift advancing gadgets that can handle data flows rapidly, utilizing adaptable matching algorithms. There are two types of switches: hardware controllers and software converters.Huawei,Cisco, HP, Juniper, and H3C dominateworldwide hardware switching industry. Over-reliance on hardware exchanges may impede while raise the expense of internet upgrades, although these devices offer the benefit of storing and speeding up data forwarding [13].

b) Software switches are defined precisely by the International Forum on Software Switches as systems and equipment that provide packet network-based call control services via program-controlled software, allowing for a greater range of data analysis techniques.But,the added feature necessitates handling a substantial quantity of codes and introducing changes offramework'sbasis, requiring engineers to possess a high degree of expertise. The two primary areas of focus for data plane forwarding rule research are either the development of new s southern interaction methods or proposal of smart algorithms. The separation between SDN Signaling plane withbearer plane, which offers a unified computing platform, enhances network management flexibility [14].

However, this separation necessitates frequent communication between the controller and the Open Flow switch via the southbound interface. This constant communication may cause the controller to become overloaded, which would delay data flow processing and increase the channel's bandwidth demands [15].

Control Plane: The controller, which oversees the switches centrally and facilitates data transmission while guaranteeing safe worldwide administration, makes up the control plane, the key component of the network. Current controller research covers a wide range of topics, from improving security and effective resource management to optimizing routing algorithms. [16].

II. A STUDY ON AI BASED RESORCE ALLOCATION IN SDN

Ibrahim et al. [17] proposed a Dynamic Capacitated Controller Placement Problem (DCCPP) algorithm to determine the optimal controller allocation in distributed SDN control layers under fluctuating traffic conditions. They further introduced an optimal solution for selecting both the number and placement of controllers using a generalized K-center approach integrated with graph theory. Additionally, resource scheduling efficiency was examined through a switch-to-controller assignment strategy based on a Greedy Randomized Search (GRS) algorithm. However, despite its effectiveness, the approach becomes computationally intensive and less practical for large-scale networks with highly dynamic traffic patterns.

Zhang et al. [18] proposed an SDN-assisted Mobile Edge Computing (MEC) architecture called Joint Task Offloading and Resource Allocation (JTORA) method for vehicular networks to enhance network flexibility and global state awareness. Initially, they formulated a vehicle-to-everything (V2X) dumping and scheduling of resources mechanism that jointly determines offloading decisions, transmission energy, sub-channel assignments, and computational resource distribution. To handle both complexity and NP- characteristics of this issue, a model was divided into three stages: analytic hierarchy process for selecting the primary transfer node, stateless Q-learning for allocating power and channels, and a potential game-based strategy to finalize stable offloading decisions. However, the approach may face limitations in rapidly changing vehicular environments, where multi-stage processing can introduce delays and reduce adaptability.

Java dpour& Wang [19] introduced the cTMvSDN method to improve resource management in SDN by combining a Markov process with a Time Division Multiple Access (TDMA)-based slicing model. In this approach, a specialized controller module performs packet-to-resource mapping only when adequate resources are available, while the Markov–TDMA scheme predicts future time intervals to enhance response time and overall QoS. Tests conducted in NS2 and Mininet showed that the new method worked better than the old ones in terms of cost and delay. However, the method may still struggle to scale effectively in highly dynamic and large SDN deployments.

Du et al. [20] proposed an SDN structure for sharing of computing resources in Edge and Cloud Computing (ECC) platforms, leveraging SDN controllers to optimize dynamic pricing along with resource allocation. They created a stochastic divergence games to find best price and allocation techniques. This worked better than static methods because it led to higher overall utility and faster decision convergence. Additionally, a multilayer fluid game architecture integrating theory of evolutionary games at consumer layer and the Stackel berg game at the border cloud layer was introduced to encourage cooperative resource sharing and efficient service selection. However, despite its effectiveness, the framework involves complex multi-layer game modeling, making it challenging to apply directly in large-scale and highly dynamic real-world environments.

Ahmed et al. [21] proposed an SDN-based load balancing approach for vehicular networks to optimize sensor task execution by considering current node states. The model improves resource utilization, throughput, and execution time by distributing sensor data collection and minimizing redundant requests from heterogeneous applications. It also uses deep active learning to detect intrusions at the packet level. However, the approach may face scalability challenges in large or highly dynamic vehicular networks due to the overhead of real-time data monitoring and processing.

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Table 2 summarizes the above-studied resource allocation schemes in SDN according to their advantages, disadvantages, and performance metrics.

TABLE II. COMPARISON OF EXISTING AI-DRIVEN RESOURCE ALLOCATION SCHEMES IN SDN

Ref. No.	Techniques	Advantages	Disadvantages	Performance metrics
[17]	DCCPP	It achieved higher resource assignment efficiency.	The deployment cost was high and more resource wastes occurred when using a higher number of controllers, especially for dense networks.	**@No. of controllers = 8:** Assignment cost = 7.99E+02; Average delay = 0.75ms; Efficiency of resource scheduling = 95%
[18]	JTORA	It minimized energy consumption.	The network load and latency were not reduced significantly.	**@Data size of task = 25 MB:** Energy consumption = 2J
[19]	cTMvSDN	It optimized response time and QoS of SDN efficiently.	It has a high computational complexity. It needs AI and heuristic schemes to further enhance resources in SDN.	**@Total requests = 1500:** Average link resource utilization = 0.42; Acceptance ratio = 0.78; Average cost = 750; Average switch resource utilization = 0.7; Network delay for 10 switches = 24.2ms
[20]	Evolutionary Stackel berg differential game scheme	It optimized resource usage and executed the time-dependent computing tasks submitted by individual devices.	Its computational complexity was high.	**@Time = 100 s:** Price of cloud computing resource released per unit resource per unit time = 1.8 Proportion of cloud computing resource remaining to the CCP = 0.3;
[21]	Entropy-based active learning with convergence-	It improved resource utilization and security of SDN effectively.	Throughput was low and accuracy was low due to inappropriate choice of each class sub-sample.	Accuracy = 0.94 **@Data size = 1000 from synthetic dataset 1:** Makespan = 119.97;

	based scheme			Throughput = 8.34; Average resource use ratio = 0.9997 **@ Data size = 850 from synthetic dataset 2:** Makespan = 1516.02; Throughput = 0.56; Average resource use ratio = 0.98

CHALLENGES IN AI MODELS AND FUTURE ENHANCEMENTS

Even with the nowadays efforts in SDN, there are still a lot of important research issues that need to be resolved before a fully intelligent SDN is widely used in the near future due to the field's need for robustness.

- High-quality training data: Enough training datasets are required to increase the estimate or classification accuracy of the models built using machine learning methods. In networking, what constitutes enough training data? Studying the connection between the size of the training dataset, the properties of the network, and the effectiveness of the machine learning models is thus a line of inquiry. However, the availability of high-quality, standardized training datasets is crucial to the advancement of machine learning algorithms.
- Distributed multi-controller platform: In SDN, network scalability is a crucial concern. Due to a controller's computational limitations, a single controller placed in the control plane often faces scalability issues as the infrastructure's size and flowing quantity increases. To address the scaling problem, distributed multi-controller systems have been suggested
- Inter-layer optimization of network: A Networking is often categorized across multiple levels, with types of conventions created to facilitate communication between neighboring layers. Direct connections between non-adjacent levels are prohibited in classical networks. Nonetheless, the layered architecture violates modularity concept, rendering the network excessively complicated that conventional methods are unable to optimization including networks. In addition,
- Gradually implemented SDN: Although SDN's tremendous prospects, its implementation requires that every switched networks possess SDN awareness. Given the circumstances, significant adoption of solely financial SDN is unlikely in the foreseeable years. Progressive implementation constitutes a viable option. In this network, SDN gateways and servers are gradually introduced inside conventional environment, while the controller merely controls a portion of the internet traffic. In these contexts, the execution of effective traffic management strategies and the optimization of distributing resources is still an ongoing investigate on topic..

III. CONCLUSION & FUTURE WORK

SDN provides effective and automatic network monitoring that addresses the demands of sharp network complexity and various functional domains. This study presents an analysis at the dangerous findings concerning network capacity allocation and command in SDN.SDN-based resource management facilitates the optimization of various resources inside a data center network. This study starts with the SDN architecture, its applications, and the integration of AI into SDN. Subsequently, several studies on resource allocation and management using AI methodologies are briefly examined, highlighting their advantages and disadvantages. According to the practical challenges, future research can focus on implementing lightweight, scalable AI models to improve real-time decisions in large and highly dynamic SDNs. Additionally, developing combined structures that collectively optimize the allocation of resources, security, and coordination of controllers would also improve overall network efficiency.

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