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An Analysis of Software-Defined Wide Area Networks: Foundation, Advantages and Difficulties

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***Abstract*—A fresh viewpoint on the quick adaptation, security, and dependability of wide-area networks (WAN) The emergence of Software-Defined Wide Area Networks, or SD-WAN. SD-WAN is the management of the WAN network connecting to cloud computing. SD-WAN can use many types of connections such as MPLS, broadband, 5G/4G, etc., furthermore, it is cost-effectively used in Traditional WAN networks. The main combination of technologies used in SD-WAN is the underlay and overlay method used for the forwarding plane and control plane respectively. In this article, the main focus will be on the architecture, benefits, and challenges of implementing SD-WAN.**

***Keywords*—SD-WAN, WAN, MPLS**

I. INTRODUCTION

In this portion, the main focus will be on why the generation of SD-WAN over Traditional WAN. As we all know Wide Area Network is the most promising technology developed to connect different networks over the world. It can be used to communicate with large multimedia files, videos, audio, and many more on the internet through any part of the world. [5]. As years passed and technologies emerged faster than before all of the people started to use cloud services where there is a large virtual storage space and faster than WAN which needs a data backup remotely where the cloud storage does not need this. As large numbers of users come up with the internet use traffic also increases and data retrieval time and scalability are reduced hence the time taken to access data from the internet became a tedious part and the significant costs associated with WAN development, management, and debugging also contribute to the evolution of SD-WAN [1]. The main concepts used in SD-WAN are Software-defined networking (SDN) and also Network Function Virtualization (NFV) [3]. Additionally, it divides the data and control planes, adheres to standard routing notions, and virtualizes a significant amount of the routing functions [2]. SD-WAN is nowadays considered the most reliable and fastest technology that can be used in the place of WAN where the public, private, and most importantly the educational sector users include. It underscores the significance of software-defined principles in enhancing network agility and flexibility [6].

II. ARCHITECTURE OF SD-WAN

The architecture of Software-Defined Wide Area Network (SD-WAN) consists of three layers which are data layer, the control layer, and the application layer [1]. They work together to provide centralized management, automation, and control of the SD-WAN network, allowing for efficient and flexible network operations. The conceptual and physical architecture of SD-WAN is depicted in the following figure:

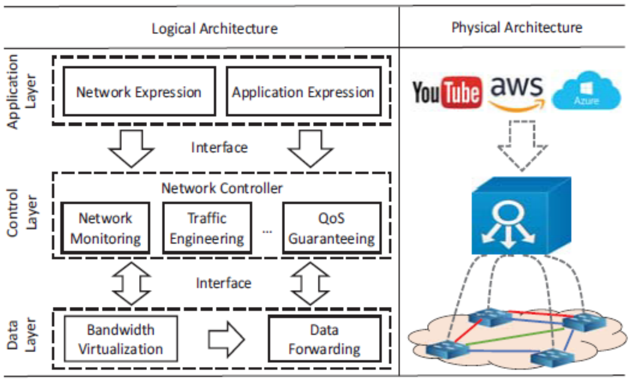

Fig.1: Logical and Physical Architecture of SD-WAN [1]

A. Data Layer

The main functions are bandwidth virtualization and data forwarding. This layer allows for centralized control logic by dividing the control plane from the data plane. Data plane can utilize both private and public IP / WAN infrastructures for doing the connectivity, making communication is simpler between scattered sites and cloud services and applications [2]. The data plane handles the actual forwarding of network traffic [3]. A distributed group of forwarding network elements, such as switches, carry out data forwarding by forwarding packets using the bandwidth made available by bandwidth virtualization, which aggregates various network links into a resource pool for all services and applications, enabling effective use of bandwidth resources [1].

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B. Control Layer:

The control plane controls the configuration of connected devices in the SD-WAN network. It is responsible for managing and orchestrating the network behavior, policies, and services. To guarantee optimal network operation, which involves different network functions that are implemented and controlled independently, the control plane and data plane communicate with one another [3]. Different services can be created by chaining or connecting these functions together [1]. Its goals are to prioritize traffic between two software-defined data centers (SDDCs) and ensure a predetermined quality of service (QoS) [4].

C. Application Layer

Network providers and application developers can specify their unique network requirements using this layer. To convert high-level requirements into compliant network configurations, two tools are available: network expression and application expression.. This layer allows for customization of network policies and considers the characteristics of different applications. It includes the controller(s) is charge of managing the device settings, improving communication flow between VPN tunnels and various types of services, and programming the SD-WAN service towards the orchestrator entity or manager [3]. This layer is also called orchestration plane which integrates and orchestrates the entire SD-WAN solution also includes components such as the orchestrator and manager. The orchestrator is a centralized management entity that monitors and configures the SD-WAN infrastructure in real-time. It collects network status information, measures parameters, and compiles statistics and reports. The orchestration plane is essential to the general administration and control of the SD-WAN network [3]. In general, SD-WAN's design divides the wide area network's control plane from data plane, offering flexibility, centralized control, and monitoring. It simplifies network operations, enables service guarantees for specific applications, and allows for the customization of network policies [1].

III. DIFFERENCES BETWEEN WAN AND SD-WAN

Legacy-wide area networks face several challenges. Firstly, When new apps appear, users have high standards for the perceived quality of their experience, thus the finest work from before mentality of these networks is no longer sufficient to meet the demands of these applications [1]. SD-WAN (Software-Defined Wide Area Network) is a technology that has the potential to revolutionize the use of WAN services. It is a centralized management of WAN networks that aims to meet the needs of applications, services, and customers [2]. SD-WAN solutions can coexist with legacy networks by integrating and cooperating with them [6]. The potential impact of SD-WAN on WAN services is significant. By offering centralized administration, financial savings, and enhanced security, it has the potential to transform the way we utilize communication services [3].

Wide area networks suffer from low link utilization and inefficient traffic engineering techniques, leading to a cost-efficiency problem. Furthermore, network operators must construct more bandwidth capacity due to the increase in Internet traffic volume, which raises expenses. The lack of coordination among services using the same network and the prevalence of link and device failures further contribute to the challenges faced by legacy wide area networks [1].

Sl.No	Catergories	WAN	SD-WAN
1	Approach	Traditional WAN provides a conventional approach of managing Wide Area Network.	Software Defined WAN provides a software defined approach of managing Wide Area Network
2	prioritization option	it offers reliability and predictability with prioritization of critical traffic like voice and vedio.	application prioritization option that let users send important data over the best network link
3	Flexibility	fails to provide better flexibility	provides better flexibility than WAN
4	Time Taken	Take more time for new configuration	takes less time comared to WAN for new Configuration
5	configuration	done by means of human interventions	done automatically without requiring human interventions
6	Cost	very costly	low cost mangement
7	perfomance while using cloud	it provides low perfomance for application in cloud as it connects to intermediate hub then to cloud	high perfomance for the application in cloud as directly access application hosted in cloud.

Table 1-Tabular representation of SD -WAN and WAN [7] [8]

The above table displays a tabular representation of both software-defined wide area networks and wide area networks.

IV. CHALLENGES IN IMPLEMENTING SD-WAN

There are many challenges in implementing SD-WAN. Some of them are as follows.

A. Size and Heterogeneity of the Network

The complexity of the implementation may rise with the network's size, which is correlated with the number of connected devices. The network's heterogeneous structure, which includes services, apps, and equipment from many providers, distributors, and manufacturers, further compounds the complexity. [4]

B. Inactivity Time in Network Elements

Disruptions caused by human factors can result in inactivity time in network elements. This inactivity time can affect the performance and efficiency of the network. [4]

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C. Configuration and Adaptation of request

It is challenging for distributed control and transport protocols to automatically adjust to different user demands since they are separately set within each device. It's possible that outdated network systems lack the programmability, adaptability, and support needed to implement new concepts without interfering with current operations. [4] These challenges highlight the limitations of traditional approaches to configuration, optimization, and problem-solving in the context of SD-WAN implementation.

D. Interoperability with legacy networks

SD-WAN solutions need to coexist with existing infrastructure and protocols, integrating and cooperating with them. This requires ensuring compatibility with traditional networks and protocols, as well as seamless integration with legacy network devices [6].

E. Network Automation

Network automation in SD-WAN involves translating high-level network intents into appropriate network configurations. The richness and diversity of network environments make this difficult. Automating the translation process and effectively managing network policies based on changing business needs is a significant challenge [6].

F. Quality of Service (QoS) assurances

Rather than using conventional dedicated lines and protocols that offer QoS guarantees, SD-WAN depends on the best-effort public Internet. One of the main challenges in SD-WAN is ensuring performance levels that are comparable to dedicated lines and optimizing QoS factors like latency and throughput [6].

Accurate and real-time monitoring in SD-WAN can be achieved through the development of fresh oversight systems that surpass the challenges posed by the reliance since SD-WAN forgoes the use of private lines and instead depends on telco operators' connectivity, monitoring chores become difficult, and to overcome this difficulty, new monitoring mechanisms need to be developed and One proposed technique is "Active Tomography," which involves injecting probe packets into the network to deduce its internal characteristics whereas the another approach is "Active Monitoring," where probe packets are transmitted over alternative overlays connecting two edge routers to estimate their delay [6]. Unobservant observation systems based on transport layer statistics, such as tracking TCP retransmissions, have also been developed. By utilizing these monitoring mechanisms, SD-WAN can obtain precise measurements at the right granularity that enable quasi-real-time network adjustments based on the circumstances at hand. These monitoring mechanisms provide network administrators with the necessary information to make informed decisions and ensure the effective management and optimization of SD-WAN networks [6].

V. ROUTING OPTIMISATION

Optimizing routing policies in SD-WAN suggests the careful selection of overlay by implementing routing policy, we can meet Service Level Agreements (SLAs), improve network performance, and optimize global intents like minimizing congestion or maximizing network quality. Links are determined by application requirements and the overall intents of the network operator. The model integrates Quality of Service (QoS) and traffic predictions to anticipate the impact of routing decisions [7]. The intent-based policy optimization refers to some key points, i.e to optimize routing policies to improve network performance and meet Service Level Agreements (SLAs) of applications, to support various intents such as minimizing congestion, maximizing network quality, and minimizing financial costs, to provide a flexible and adaptive model that can optimize policies in dynamic environments where traffic and transport network quality vary over time; to address large-scale scenarios where the behavior of the network and devices is unknown; and to enhance latency, SLA satisfaction, and overall network performance in comparison to legacy load balancing mechanisms [7]. Always the optimization model considers three different aspects:

A. Safety intent:

Maximizing the satisfaction of Service Level Agreements (SLAs) for flow groups.

B. Low congestion intent:

Minimizing the Maximum Link Utilization (MLU) to reduce congestion.

C. High-quality intent:

Minimizing the average delay to improve network quality

VI. CONCLUSIONS

This paper concludes here by stating the opportunities and challenges for multi-objective networking based on SD-WAN and highlights the possibilities of SD-WAN in improving wide area networks and highlights communication across various locations, improving sales, providing secure connectivity, simplifying network management, reducing costs, and supporting cloud services. WAN services might be completely changed by SD-WAN technology, which offers centralized management, cost reductions, and enhanced security. It is particularly beneficial for industries such as education and healthcare, as well as multi-branch companies and organizations using cloud services. In addition to providing a number of features and advantages that meet the changing requirements of contemporary networks and communication services, SD-WAN also uses traffic and SLA projections to improve routing policy optimization. Future research might concentrate on improving accuracy so that businesses can maximize the use of their network infrastructure. It could also suggest implementing data, audio, and video services in an SDDC while guaranteeing proper QoS regulations.

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