Software Defined Wide Area Network (SD-WAN): Challenges, Architecture and Trends

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Abstract—**SD WAN (Software Defined Wide Area Network) is one of the hottest trend to emerge as a technology that has the potential to revolutionize the use of WAN services. SD WAN can help the current and emerging applications to meet the required flexibility, efficiency and security over the network. SD WAN has been regarded as the promising architecture of next generation wide area network. As enterprises continue to grow and use most of the applications through cloud, SD WAN have become increasingly important to adopt in most of the enterprise and service providers in the market. This paper briefly discusses the architecture and functions of the SD WAN. Some of the related technologies and some SD WAN trends that will define the future market will be discussed.**

I. Introduction

The COVID-19 pandemic has made a huge impact on IT enterprises. Remote works has accelerated drastically which forced enterprises to act quickly, securely, and cost effective to enable work from home for their employees. This immense shift in teleworking has put a lot of pressure on network itself as the use of collaborative SaaS (Software as a Service) and IaaS (Infrastructure as a Service) applications have grown dramatically. All these concerns about productivity, security, and cost efficiency to enable teleworking can be addressed with today's SD-WAN technology. Some of the business requirements for which enterprises IT teams are needed to act swiftly includes, using simple to deploy and cost effective measures to enable remote work, network security to be not compromised while enabling home teleworking and each teleworker to be provided with access to the IT business applications that are needed when they need them [5].

As the use of Internet has been growing drastically over the past few decades, one of the most important transmission mediums, wide area networks, such as carrier networks, inter-datacentres and enterprise networks has become the critical infrastructure of the information society. In most of the enterprises the expenditure of building, managing and debugging wide area networks is extremely high and traditional wide area networks have is being pulled down by many aspects such as QoS (Quality of Service) and network upgrading [1].

SD-WAN has the capability to revolutionize WAN service usage by supporting a new concept known as Application driven networking. This concept allows to SD-WAN services to replace the traditional WAN services over costly MPLS (Multiprotocol Label Switching) technology to reduce costs on network administration with application of centralized and automated elements. On the other hand, SD-WAN services operate over more different WAN connections, including affordable public broadband connections (Figure 1).SD-WAN offers newer and better features to the customers with just a fraction of the cost of the MPLS VPN services offered [2].

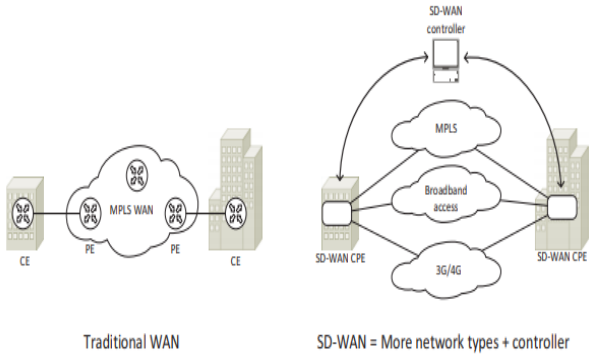

Figure 1. WAN vs SD-WAN

When comparing traditional wide area networks, software defined wide area networks has two advantages that the current market requires. One, SD-WAN provides a built in programming framework for hosting control applications that are developed in a centralized way while taking into consideration the application-level requirements to guarantee the user-perceived quality of experience (QoE). Two, it is able to control network policies and manage network traffic without configuring manually [1].

This paper suggests the following contributions: Firstly, we revisit the challenges of legacy wide area networks. As the enterprises are beginning use more cloud oriented applications, the expectations for quality of experience is high, previous efforts were not good enough to serve these new emerging applications. Due to high expenditure of bandwidth on wide area networks and the low link utilization, wide area networks are also faced with some serious cost efficiency problem.

Then, Section III introduces the technologies related to SD-WAN, the SDN and NFV (Network Functions Virtualization). Section IV introduces the architecture of software defined wide area network. Section V discusses the solutions and benefits what SD-WAN can offer. SD-WAN trends that will define the

future market will be discussed in section VI. Finally, I will conclude my work in Section VII.

II. WAN CHALLENGES

Internet has been a remarkable success for the past few decades, due to it the emerging applications and organizations are in need to design WANs to meet the ever changing requirements of quality and efficiency. There are many other aspects the WAN needs to be met with, which includes network management and high cost efficiency. A survey (Figure 2)[1] taken by ESG with 377 North American senior IT professionals and enterprise class organizations to support the technology requirements of remote office/branch office (ROBO) locations revealed that the most cited responses were securing data-in-flight (38%) and cost of WAN bandwidth (32%) [6].

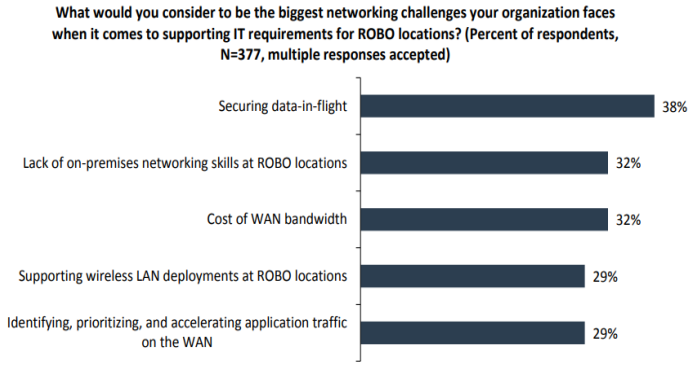

Figure 2. Networking challenges faced in IT

In the above survey we can notice that not one challenge dominated the responses that indicates the organizations are facing a wide variety of challenges. Now let us discuss in detail some of the challenges that should to be addressed.

A. Quality of Service (QoS):

Typically, wide area networks are designed to transfer data over long distances and to provide best effort delivery. In WANs the data traffic is delivered with physical links and network devices in harsh conditions [1]. The links and devices are always in danger of failures which affects the data transmission performance and the user perceived QoE. Also the traditional WANs use routing protocols like OSPF, they are not sensitive enough to the sudden failures on wide area networks, which further deteriorates the network performance [1]. Under these circumstances the required QoS is hard to provide satisfactory services.

Nowadays usage of cloud based applications are increasing and the shift to remote locations in IT industries will introduce applications performance issues based on distance (and therefore latency) of the remote office to cloud [6]. Telemedicine and cloud gaming also depends on low latency networks to achieve real time operations, which often required to be hundreds of milliseconds. These scenarios are not compatible with outdated traditional WAN [1].

B. Network Management:

In the past few years many new business organizations are stepping into the market and the current enterprises are expanding their branch offices in different geographical locations and scale out their networks every now and then. In traditional wide area networks over the years there deployed a hundreds of thousands of devices and each should be configured in a low level vendor specific manner. To meet the fast paces market trends the networks must be upgraded frequently, which in traditional WAN it is to be configured manually [1]. The rapid growth in network with changing network conditions resulting in manual configuration introduces additional configuration errors [1]. In precise managing traditional WANs is often burdensome and error prone task. WANs are faced with flexible and quick network upgrades. For instance, let us take Black Friday, which require e-commerce providers to increase bandwidth to deal with sudden burst in predictable data traffic. Network operators must do a lot of overtime and arduous work to add bandwidth to satisfy the customers and remove it later [1]. As Internet is growing rapidly and these activities are becoming popular, network operators should look forward to easy paradigms of network management.

C. Cost Efficiency:

It is known that bandwidth on wide area networks is an expensive resource, with an annual cost of 100s of millions of dollars to provide 100s of Gbps to Tbps of capacity over long distances [1]. To meet the high volume of data transmission requirements, network operators have to install much more capacity to the bandwidth. A report was published by Cisco, Internet traffic will rise to threefold between 2017 to 2022, which tells WAN's bandwidth cost will surge in next coming years [6]. Even though the bandwidth on wide area network are scarce and a valuable resource its full capacity is never utilized. The average capacity used in busier traffic network is just 40-60% [1]. The reasons behind this inefficiency are, firstly because of link and device failures. Then the lack of coordination among the services used by the same networks. The low network utilization prevents network providers from getting the full return from their investments, against the goal of pursuing high cost-efficiency.

The above discussed are the common challenges faced by the traditional wide area networks, in spite of these, new solutions should be addressed to some of these pain points also which includes: Enhanced productivity and responsiveness to business, network infrastructure simplification, business policy control for application traffic, link aggregation, on-ramp to the cloud, ability to reach remote sites and ability to deploy sites rapidly [6].

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[1]Source: ESG Master Survey Results, IT Plans and Priorities for Remote and Branch Offices.

III. Related Technologies

SD-WAN is an extension of SDN (Software Defined Networking). SD-WAN applies networking connections that covers a wide geographical area. SDN is often paired with NFV (Network Function Virtualization). So, to understand the concept of SD-WAN we have to understand how the combined usage of SDN and NFV are approached in an organization (Figure 3) [4].

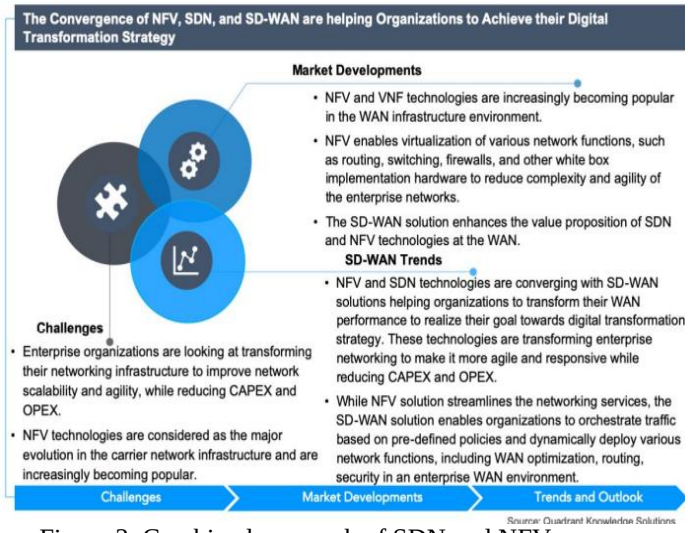

Figure 3. Combined approach of SDN and NFV

SDN focuses on solving one of the fundamental problems faced by the current networking industry. Current networking infrastructure is natively a distributed system, which interconnects control and data plane. To tackle the complex challenges like adaptation or introduction of new services to the infrastructure, SDN creates a new design and operation of network infrastructure, here the control plane is separated from the data plane. The control functions from individual devices are extracted and integrated into a centralized control node called controller [2]. Physical devices in SDN are only used to for data forwarding, eliminating control logic from each device. The simplifies SDN architecture has three logically separated planes: Data plane, Control plane and Application plane and the communication between these are through program APIs [2].

NFV is defined by "the decoupling of network functions from proprietary hardware appliances" and using these functions as virtual machines (VMs). It replaces the physical network devices to Virtual network function (VNF). Ultimately, deployment of NFV benefits an organization in form of reduced electricity consumption, reduced overall equipment costs and increased time to market process [2].

Combined approach of SDN and VNF are increasingly becoming popular in an enterprise WAN infrastructure. NFV enables virtualization of various network functions and other white-box implementations. The SD-WAN uses SDN approaches to enable organizations to orchestrate traffic based on pre-defined polices and dynamically deploy various network functions. So, the combined approach of NFV, SDN and SD-WAN are transforming enterprise networking to make it more agile and responsive while reducing CAPEX and OPEX [4].

IV. Architecture

SD-WAN uses an abstracted architecture for its network. SD-WAN architecture (Figure 4) consists of three architectural planes. They are data plane, control plane and orchestration plane. The main idea of SD-WAN is to provide ease in networking operations, optimize wide area network management and introduce innovation and flexibility as compared to legacy wide area network [2].

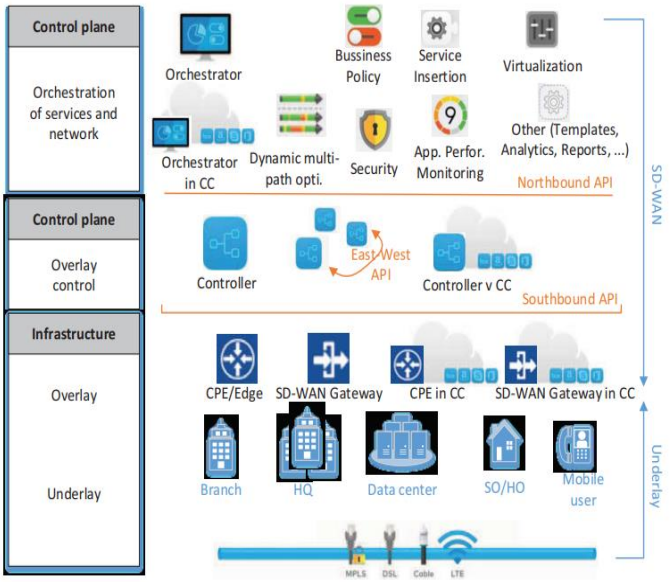

Figure 4. SD-WAN Architecture

A. Data Plane:

The data plane is separated from the control plane in SD-WAN. It consists of hardware or software network devices similar to traditional IP networks, but with excluded control functions [2]. It simplifies the communication between geographically separated sites and with cloud services. So, it creates its own software managed logical infrastructure (Overlay) over the existing physical infrastructure (Underlay). Overlay is usually uniform and consistent whereas underlay WAN network is fragmented and heterogeneous. There are several links that utilizes the bandwidth resources which are pooled together, such as multiprotocol label switching fabric, Internet, 4G and so on [1]. Data plane receives commands from the upper layer network controller through interface protocols such as OpenFlow [1].

B. Control Plane:

The control plane is the key component which controls and manages the network functions. It enables operators to see the network through a single pane of glass, and set policy for the

application plane/orchestrator to execute. The main entity of the plane is the controller, which can be seen at a headquarters, branch office, data centre, or in cloud. This entity ensures all the network devices are configured based the business requirements, while CPE (Customer Premises Equipment) is connected to the controller by a secure control connection (southbound API). It also optimizes the communication flow sent to each services, such as branch services, data centre services and cloud services. The network functions are implemented and managed by this layer, which decouples these and enables the network operators to develop, modify, debug and remove arbitrary one of them at a low cost while not affecting others [1]. These services and functions can work independently, also these can be connected together to create manifold services. This increases the flexibility of the software defined wide area network.

C. Orchestration Plane:

The Orchestration plane has a main entity which is known as orchestrator, also referred as a manager. It works as a virtualized manager for the network, overseeing traffic and applying policy and protocol set by the operators. This plane is a high level abstraction for policy enforcement, configuration management, troubleshooting, monitoring, analytics, predictions, correlations, reporting, and notifications [2]. This plane uses a superior management interface for deployment purposes, which is known as Zero Touch Provisioning (ZTP). Using this each CPE is need not to be configured individually, instead it can download its configuration from the centralized management level after authentication. This eliminates the need for qualified staff at each branch [1]. In the market each manufacturer has their own software solutions for this entity. The implementation can be as a standalone solution or as a component integrated into the controller, including several sub-entities [2]. As the orchestrator actively monitors the network and its parameters, it can send error messages which includes various statistics, graphs or reports to the administrators when certain values are exceeded. Configuration is set on orchestrator, it then sends instructions to controller, which sets end devices (CPE) [2].

D. API Interfaces:

APIs interconnects the separated planes through program (open or proprietary). Using APIs, application communicate with the controller or controller with CPE devices (end devices). Southbound API is used to communicate between CPE and the controller. Most SD-WAN vendors use Open-Flow and RestAPI as South API whereas some like Cisco, Nokia and Riverbed use their own protocols [2]. The Northbound API allows communication between the controller and external applications which sends information or to obtain status data. The RestAPI is usually used for these calls. The vendors who use open Southbound API also use open Northbound API, except Cisco Viptela, which uses NETCONF. The last API which is East-West API, used to communicate through two same entities in a plane. For instance, between two CPEs or controllers. Cisco Viptela uses its own OMP protocol and Nokia Nuage uses MP-BGP for federation of controllers. No more information could be found about the East-West API [2].

V. SD-WAN Solutions And Benefits

SD-WAN solutions provide functions which holds the key to solving real world problems faced by the enterprises and its IT teams.SD-WAN solutions are mostly software centric, running either in centralized locations or at customer location [3]. It also has a problematic side in terms of orientation and generalization of their functions, the view of SD-WAN functions differs from vendor to vendor [2]. So to provide quality SD-WAN solutions, ONUG (Open Networking User Group) developed some criteria which should be satisfied. This is called top ten strategic requirements (ONUG TOP 10) [2].

A. Onug top TEN (Requirements):

Onug top 10 criteria was accepted by all the vendors, these criteria were often compared to each vendors SD-WAN devices. The generic functions which are expected from SD-WAN solutions are as follows [4]:

1. Ability for remote site/branch to leverage public and private WANs in an active fashion for applications in order to better use of total available connection capacity.
2. Ability to manage the equipment remotely by deploying CPE in a physical or virtual form factor on commodity hardware.
3. A secure hybrid WAN architecture that allows dynamic traffic engineering over paths built over both public and private WANs as specified by application policy. Selection of routes per application is decided based on application policies, network availability or degradation at application or transport layer performance.
4. Visibility, prioritization and real-time management of mission-critical and application-based policy, security, and application requirements.
5. A hybrid WAN environment which is resilient is required for optimal client and application experience.
6. Layer 2 and 3 interoperability with directly connected switch and/or router.
7. Site, Application and VPN performance level dashboard reporting.
8. Open Northbound API for controller access, management and ability to forward specific logs to SIEM (Security Information and Event Management).
9. Ability to install and deploy the CPE devices remotely by any personnel without need to make any configurations. ZTD (Zero Touch Deployments) in effect to the branch site. The devices are need to only correctly connected to the API interfaces where automatic process of initialization and authentication will take place.

10. FIPS 140-2 validation certification for cryptography modules/encryption with automated certificate life cycle management and reporting.

Onug also defined six additional features for solving the openness of the network systems in addition to Onug Top 10. Deploying SD-WAN can be for various reasons. In the end the centralized nature of SD-WAN provides a single pane of glass across solution deployment and maintenance lifecycle, encompassing provisioning, configuration, management, visibility, troubleshooting and optimization. Although some of the functions like path control, overlay networks, encryption and subscription-based pricing are already available with existing solutions. SD-WAN bring these functions together [4] as an integrated enterprise network solution. SD-WAN solution generally include the following key benefits it offers in customer's point of view [2][3]:

- *Central management:* SD-WAN solutions provide a single view which is capable of configuring the entire infrastructure across multiple locations and virtual circuits. It also captures performance errors and error reports which opens up opportunities for easier identification of problems.

- *End to end encryption:* SD-WAN solutions provide IPsec encryption that protects private virtual WANs traversing public, shared networks. Also administrators can get problem report (e.g. Violation of SLA) without tracing.

- *Multi-path and Multi-link support with dynamic path selection:* SD-WAN solutions uses a single environment which bonds the multiple physical circuits to increase aggregate capacity and reliability.

- *Local breakouts for cloud services:* SD-WAN solutions allows direct routing of traffic destined to trusted services of cloud, such as salesforce. This helps in saving bandwidth utilization and maximizes the use of cheaper local internet without compromising security.

- *Security and firewalling:* SD-WAN solutions provide platforms which will have some level of firewall and security capabilities. Providers use third party modules to have such security capabilities, or have them built into the platform.

- *Policy based controls and service chaining:* SD-WAN solutions usually provide intelligent policy based routing of traffic and the ability to insert virtual network services (VNFs), such as firewalls, content filters, proxies and so on without disrupting the underlying network dynamically.

- *CPE and NFV:* SD-WAN solutions provide one physical solution at branch for more functions, originally solved on separate devices.

The above mentioned capabilities are no means complete, there are many advanced benefits that are provided by various enterprises. Anyways, the discussed benefits are to be present in most of the SD-WAN solutions present in the market today. electricity consumption, reduced overall equipment costs and increased time to market process [2].

VI. SD-WAN Market Trends

As enterprises are driving towards the growing popularity of hybrid cloud architecture and applications, the amount of data generated demands effective and flexible WAN services. Accordingly, enterprises are considering SD-WAN to address performance and management issues. According to 2017 data by IDC, two-thirds of respondents have plans to deploy within the next two years (Figure 5)[2].

Figure 5. Survey on deploying SD-WAN

According to Quadrant Knowledge Pvt Ltd the global SD-WAN market grew by 70% exceeding the previously forecasted market (growth of 65.5%) in early 2019. SD-WAN vendors are significantly investing in multiple functionalities to help users to attain the next generation of network performance improvement [5]. It is expected the market to grow at a CAGR of 45.5% from 2020-2025 with an estimated market size of $2.32 billion in 2019 to $22.01 billion in 2025 (Figure 6). SD-WAN vendors continued efforts in improving the awareness, and overall value proposition in terms of enhanced integration with best-of-breed security and networking products, orchestration and automation of network processes, improved zero-touch deployment, advanced analytics and application visibility, and improvements in machine learning & artificial intelligence capabilities to drive next-generation of SD-WAN solution is contributing to the market growth [5].

[2]Source: IDC's Software-Defined WAN Survey, August 2017; n = 1,208

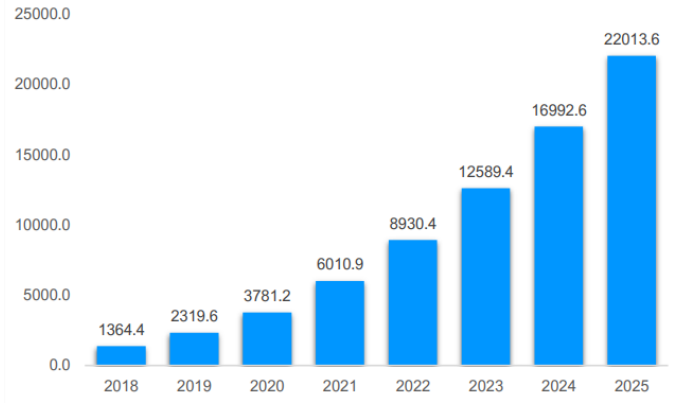

Figure 6. SD-WAN Market Adoption Trend

The following are the dominant technology and market development influencing the overall global SD-WAN solution and market growth [5]:

- SD-WAN is Emerging as a Key Technology for Successful Adoption of Hybrid and Multi-Cloud Strategy.
- The Convergence of NFV, SDN, and SD-WAN are helping Organizations to Achieve their Digital Transformation Strategy.
- Continued Investments for Industrial IoT and Industry 4.0 Strategies are Driving the Global Demand for SD-WAN solutions.
- SD-WAN vendors are Expanding their Security capabilities and Increasingly Embracing Zero Trust Security Model.
- SD-WAN Use Case of Improving UCaaS Experience Continues to Gain Significant Market Traction.
- SD-WAN is well Positioned to Play an Integral Role of Organizations Network to Support 5G Communication

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- Service Providers continues to play a major role in improving SD-WAN market penetration.
- SD-WAN first approach to be deployed as it's a default part of the equation for all WAN deployments moving forward.
- SD-WAN provides user performance management which likely provides greater granularity and treat data flows according to what an individual user determines.

The service providers such as AT&T, Comcast, Verizon, EarthLink, Sprint Windstream and others are increasingly partnering with SD-WAN vendors targeting SMB organizations in providing managed services for smaller branch services. As businesses are deploying and managing SD-WAN solutions by buying from service providers and migrating from the legacy network infrastructure, this trend helps in improving overall technology penetration and market growth [5].

VII. CONCLUSION

In today's business model transformations, network services need to be consumed in flexible, agile, optimized, and cost-effective way. SD-WAN, a significant contributor which has a critical role to play in the next generation wide area networks is worth studying. It responds to the needs and trends of the user development. In this paper, we have discussed the challenges faced by the legacy wide area networks. SD-WAN is considered as the promising architecture of the next generation design of wide area network, the architecture of SD-WAN was briefly explained along with related technologies including SDN and VNF that SD-WAN uses to for its approach. We have also discussed ONUG requirements for the manufacturers to deploy SD-WAN solutions along with its benefits and functionalities that it can offer. At last we have discussed how SD-WAN's market trend and its adoptions using survey reports. I hope this paper helps you to understand how SD-WAN works and its importance for the upcoming business and technology evolutions.

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