SD-WAN for Bandwidth and Delay Improvements on the Internet

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ABSTRACT: Advancement in applications and operational situations place stringent demands on long-distance data transmission, forcing network operators to rethink how they construct wide area networks [1]. Wide-area network improvement that is indicated by software-defined wide area network (SD-WAN) has been lauded as the most promising next-generation wide-area network design. SD-WAN is able to monitor and manage connection links adaptively based on application requirements [2]. This paper will discuss the newly emerging SD-WAN architecture for the implementation of the Internet. A thorough comparison and challenges that WAN faced before SD-WAN was also discussed to further prove the current features and its benefits. Handling any information accessible over the aspect and exploiting 5G transport for those important applications that demand amazingly low latency and huge bandwidths, SD-WAN will provide a smooth shift for the energy industry to an entire 5G connection [3], also will promote the development of the society.

1. INTRODUCTION

A Wide Area Network (WAN) is a telecommunications network that connects several access nodes located across multiple geographic regions [4]. Conventional WANs, which employ traditional routers, were never designed to be used in the cloud. Conventional WANs would backhaul all traffic from branch offices to a hub or headquarters data center, where improved security inspection services may be installed and are frequently required. Backhaul latencies cause app performance to suffer, leading to a poor user experience and decreased productivity.

Nowadays, WAN is used commonly in large organizations to facilitate communication quickly and efficiently. However, there are limitations in the development of WAN [5]. The most commonly faced problem in WAN is the security gap of WAN due to the implementation of several technologies. There are remarkable security threats and insufficient performance guarantees in an end-to-end WAN connection. In addition, data delivery is done using physical devices and links with poor vulnerability; malfunction of devices and links might occur regularly, which may affect the quality of transmitted data [6]. Another issue of WAN is that high cost is needed for installation and maintenance due to the high complexity and large geographical coverage of WAN. Since the network contains layers of underlying hardware, a large amount of manpower and cost is needed to control it. When there are changes in policies, it is necessary for administrators to interact with each device individually.

Several improvements are currently enforced by embracing software-defined WAN solutions, such as improved network performance, networking deployment automation, cost reduction, and faster service delivery [7]. SD-WAN is a network topology that shifts the management and administration layers to a cloud and gives an overlay design that is far easier to handle than conventional WANs. While offering the greatest levels of application performance, the SD-WAN paradigm is designed to fully assist applications housed in on-premises data centers, public or private clouds, and SaaS services like Salesforce.com, Workday, Dropbox, Microsoft 365, and more.

There are two main improvements in SD-WAN that are suitable for current Internet usage. First, it has a built-in programmatic framework for hosting control applications that are constructed in a centralized manner while taking into account application-level needs to provide a high quality of experience (QoE) [1]. Second, it can create network policies and control network traffic from a central location without requiring manual configuration at each device. The former allows it to ensure service for certain applications, locations, and users, while the latter might make network administration jobs easier and network upgrades faster.

In this paper, the concept of SD-WAN will be dissected further where the architecture is discovered. Next, the SD-WAN improvements of bandwidth and delay will be linked with the current Internet usage. Moreover, SD-WAN improvised features and benefits are analyzed. The challenges of SD-WAN are concluded and the future of SD-WAN is foreseen. This paper suggests that SD-WAN has significant potential for satisfying the growing requirements brought by the burgeoning development of IoT applications; thus, it is worth putting more effort into researching SD-WAN and related fields.

2. INTRODUCTION OF SD-WAN

Before diving into the concept of SD-WAN, this paper will go through the three layers of a software-defined wide area network, from bottom to top, including the data layer, control layer, and application layer.

The first is the data layer, which has two functions: bandwidth virtualization and data forwarding. Bandwidth virtualization connects multiple network lines acting as one location into a pool of resources accessible to all applications and services to fully utilize bandwidth resources. Moving on to data forwarding, it consists of a distributed collection of forwarding network nodes (mainly switches) in charge of forwarding packets using

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bandwidth virtualization. Through the interface protocol, they all receive instructions from the upper-layer network controller [1].

Next, is the control layer, which has a number of network functions that are implemented and managed independently. Because these operations are decoupled, network operators may build, alter, debug, and delete any one of them at a reasonable cost without impacting the others [1].

Third, the application layer lets network providers and application developers describe their own network needs using network terms and application representation, both of which can be used to turn high-level requirements into network configurations that work well together. People who make apps and run networks may be more in charge of the networks thanks to the application layer [1].

With respect to the operating principle of SD-WANs, SD-WANs are made up of encrypted tunnels (known as the "overlay") that connect two or more places. At each location, SD-WAN devices are deployed. Those devices begin to automatically download custom-defined configuration and traffic rules as soon as they are connected to local networks, as well as create tunnels with one another or with a point of presence (PoP), depending on the network architecture.

The SD-WAN is in charge of managing routing and traffic management. Based on application rules and real-time traffic circumstances, outbound traffic is routed along the most direct and efficient channel possible. If one of the last mile connections goes down, the SD-WAN device switches over to the other connection right away. It uses predefined rules to control the traffic load on both connections, even if one connection is down.

As a result, policy-based management is unquestionably a critical component of an SD-WAN architecture. The policy is used to define dynamic route selection, and traffic will be directed in accordance with the amount of priority, such as quality of service (QoS), that it is assigned. A wide variety of rules may be defined to fulfill particular business requirements, such as allocating packet transmission priority to VoIP and other interactive services in order to increase performance and reliability [8]. To conclude, SD-WAN is a software-based wide area network architecture in which all control is abstracted away from the underlying hardware and software. An SD-WAN may be managed fully in software, and it can be distributed over many forms of network transport, eliminating the need to establish particular equipment to handle application traffic through Multiprotocol Label Switching (MPLS). An SD-WAN may have both cellular and satellite connections for high-speed data transmission. In conjunction with MPLS, SD-WAN can provide additional bandwidth and a better user experience, which is particularly important for performance-sensitive cloud applications.

3. SD-WAN FOR BANDWIDTH AND DELAY

This part will show how SD-WAN can improve matters with bandwidth and delay. In general, a good IoT device should have less bandwidth and less delay or latency. There are a lot of applications that need a lot of bandwidth, but Multiprotocol Label Switching (MPLS) cannot keep up and can no longer satisfy the demands in this modern world. Because of that, the generation firewall (NGFW) and data analytics in SD-WAN can replace Multiprotocol Label Switching, which can lower the use of bandwidth compared to use of bandwidth in Multiprotocol Label Switching. How can SD-WAN help? SD-WAN solves this problem with the integration of the cloud. The SD-WAN deploys most cloud benefits, such as the capability to aid several connection types (such as frame relay, MPLS, and LTE/4G/5G wireless interactions), able to provide an expected user experience by using centrally-configured applications, able to provide a user-friendly interface that is easy to access and handle, depend less relying on technology, and automatic provisioning that is simple and flexible (about 10,000+ sites are possible) [9]. In short, SD-WAN chooses the route with the least resistance for application transport that reduces the cost of the WAN and makes the most of available bandwidth by using the cloud to connect to it. The implication is that SD-WAN will use less bandwidth.

When it comes to delay, in MPLS-enabled WAN, internet-bound traffic must be sent back to a corporate data center before being routed via the data center again on its way to its destination. This is known as the trombone effect, representing a fundamental weakness in MPLS networking. Backhauling traffic degrades performance, affecting current services such as videoconferencing. SD-WAN tackles this problem with policy-based routing (dynamic path selection), which forwards and routes data in real-time depending on rules specified by system administrators. For instance, in the case of a problem or outage on one of the communication pathways, SD-WAN'S policy-based routing will instantly switch data path routing to available connections to keep the network working smoothly [10]. These findings indicate that SD-WAN helps decrease network downtime while also decreasing productivity loss by identifying failures in real time, which is advantageous for energy infrastructure. SD-WAN not only offers several secure, high-performance connections, but also enables load-sharing within connections [10]. This reliability and flexibility to alter data flow depending on network circumstances will thus provide the optimum quality of service under a variety of operational scenarios. As a consequence, every device that utilizes SD-WAN will have lesser latency.

To conclude, SD-WAN improves bandwidth and latency by connecting SD-WAN to the cloud, leveraging the best of the cloud's features to consume less bandwidth, and utilizing policy-based routing (dynamic route selection) to reduce delay and keep the network running smoothly.

4. FEATURES & BENEFITS OF SD-WAN

4.1. Zero-Touch Provisioning (ZTP)

ZTP is a standard feature on most SD-WAN devices. As its name suggests, ZTP means physical installation is not required for device configuration; the device finds the management system that will provide device configuration for a specific location and organization [11]. In other words, experts are not necessarily needed to deploy SD-WAN devices. Customers need to connect devices to the internet and they will auto-configure themselves. Predefined templates enable this feature of SD-WAN devices. As a result, devices can be auto-configured quickly, efficiently, and in a standardized manner.

4.2. Encryption Key Rotation

Traditional manual VPN key rotations are replaced by an automated mechanism on SD-WAN platforms. SD-WAN allows network managers to set critical rotations in advance, eliminating mandatory manpower intervention or network outage. As a result, SD-WAN provides improved security, no downtime (in comparison to VPNs), and eliminates the need for manual resources [12].

4.3. Multiplexed VPNs

Multiple virtual routing and forwarding (VRF) and VPN lines can be multiplexed with a single overlay using SD-WAN technology. With SD-WAN, complex, multifaceted organizations may segment and isolate traffic by implementing policies. This functionality is especially beneficial in large enterprises with several divisions and departments. A merger or acquisition may occur, in which a formerly independent business is incorporated into a larger corporation but continues to operate as a separate entity. At other times, departments within an organization have different functions that operate independently. It may be safer to keep a particular departments' traffic isolated from one another for security and confidentiality concerns. SD-WAN allows businesses to segment apps without the need to buy physical devices [12].

4.4. Microsegmentation

In the event of a breach, microsegmentation improves network security by limiting hackers' lateral mobility. Over the last few years, it is becoming more commonly used by businesses. It gives businesses more control over east-west traffic and aids in the security of applications running in the cloud or data center-like environments. Microsegmentation is made easier with SD-WAN overlays. When a security breach is discovered, centrally set policies can take immediate action to isolate impacted branches from the rest of the network.

4.5. Cloud breakout

The SD-WAN cloud breakout functionality enables branch office users to connect directly and securely to cloud-hosted apps, reducing the bottlenecks of backhauling all traffic destined to the cloud from branch offices to a hub or headquarters data center. As the relevance of SaaS (Software-as-a-Service) and IaaS (Infrastructure-as-a-Service) advance, many businesses and other organizations require efficient and dependable cloud access. While using IaaS, a virtual instance of the SD-WAN router can be configured within the cloud service provider's domain. The app's performance is then measured, giving administrators insight into the app's performance. When using SaaS, the SD-WAN device links to the closest SaaS point of presence. It makes decisions in real time and chooses the optimum path. When it comes to basic productivity apps that traverse the public internet such as Office 365, end-users have witnessed performance improvements of up to 40% in some circumstances. Therefore, SD-WAN makes setting up breakouts faster and easier by streamlining the way branch traffic is routed.

4.6. Flexible bandwidth allocation

SD-WAN allows flexible bandwidth allocation, eliminating the need for manual bandwidth allocation for specific applications. Applications are divided into various categories, each with its own set of service level requirements. As a result, the set-up is better prepared for smoother operation, reducing the possibility of stuttering and delayed performance on applications like audio conference calls.

4.7. Improved data analytics

Data analytics are critical for a variety of reasons, including network reliability and capacity estimation. SD-WAN improves analytics, resulting in new, more in-detail insights into overall network performance [12]. It provides an outstanding depth of traffic data via selected assessment tools, allowing for a considerably more extensive examination of performance than was previously feasible. These data and insights help a business to deploy network resources more efficiently. It also allows for more liability and transparency when it comes to network performance. As a result, customers will be better informed and receive improved customer service.

5. RESEARCH CHALLENGES OF SD-WAN

After researching the concept and basic features of SD-WAN, it is worth introducing some research challenges faced by SD-WAN that deserve further investigations, including control plane management, scalability and reliability, traffic engineering and monitoring, and security.

5.1. Control plane management

An SD-WAN solution's controller is the most important component. Its location can have an impact on performance, especially if the network is spread out geographically. Because of the distance between the CPEs on the edge, there may be delays in the execution of controller decisions by the CPEs [13]. Because the controller is asymmetrically located in relation to the CPEs, the CPEs may react asynchronously, causing routing decisions at various customer locations to be inconsistent on switching transients.

5.2. Scalability and reliability

When adopting an SD-WAN edge solution, they are an essential factor to consider. Indeed, when the network expands in size, including by adding CPEs, the centralized SD-WAN controller becomes increasingly solicited and hence possibly overburdened with respect to bandwidth, processing power, and memory. Furthermore, the breakdown of the central controller might bring the entire network down [13].

5.3. Traffic engineering and monitoring

Because the SD-WAN control plane provides a centralized, global view of the network, it is able to obtain network information and attributes via monitoring algorithms. This data may be used to discover globally optimum path assignments using centralized traffic engineering techniques. Traditional traffic engineering solutions for MPLS, like RSVP-TE or LDP, depend on the ingress router's local, restricted view of the network. SD-WAN's programmability allows for the creation of bespoke, quick, and efficient adaptive routing systems [13]. In SD-WAN edge solutions, effective network monitoring is necessary for the creation of control and management applications. Collecting the relevant data and analytics without impacting network performance, on the other hand, is a difficult issue. In reality, constant network data and statistics monitoring can incur unnecessary overheads and degrade network performance, whereas a lack of monitoring can lead management programs to behave incorrectly.

5.4. Security

Another significant problem for SD-WAN is security. The deployment of VPN tunnels between CPEs and controllers helps lessen the danger of DDoS attacks, which are one of the most prevalent network attacks [13]. However, if a hostile CPE connects to the network, all security is jeopardized. SD-WAN relies heavily on the development of secure overlay tunnel authentication procedures in order to minimize network security issues.

6. FUTURE OF THE SD-WAN

Based on research, there are several ways to be used to improve the SD-WAN; for instance, researchers can explore the possibility of applying new techniques to it, including network function virtualization, machine learning for networking, and new transport protocols, to facilitate SD-WAN based multi-objective networking development. Given that there are huge breakthroughs brought by these techniques in a variety of areas, they can offer to the burgeoning networking the opportunities and challenges which are a worthwhile topic [14].

6.1. Multi-Objective Networking

The increasingly stringent network needs were brought about by the fact that applications and operational situations occur in tandem with the rapid expansion of the Internet. Services have other network needs outside data transport, including high stability, low latency, and high throughput [15]. Industry and academics have researched multi-objective networking extensively, and plenty of promise is offered by SD-WAN based multi-objective networking.

Low-latency networking is a kind of multi-objective networking since stringent latency constraints are imposed by new applications and operational scenarios [15]. Cloud gaming participants, for example, rely on low-latency data transfer through networks to engage with one another [15]. As a computationally expensive application, virtual reality (VR) relies on data communication whose latency is low between local devices and cloud servers to enhance user experience and the efficiency of rendering. Zuo and his colleagues give an overview related to network latency and techniques aiming at reducing it, focusing on delays caused by protocol architecture and functionality. They evaluate several cutting-edge techniques to minimize latency at each layer and describe the reasons affecting delay that occurs in various network architecture layers [15]. Furion is a VR framework developed by Lai's team that allows for superb immersive mobile VR on today's wireless networks and mobile equipment [16]. It divides foreground interactions and the background environment and also achieves low-latency transmission by running render architecture separately on the server and the phone. Although these solutions are capable of alleviating the negative consequences of increasing network latency in some instances, they are not appropriate in all cases. With the popularity of cloud applications, data communication between local equipment and remote servers will be increasingly common. Low-latency networking necessitates network operators eliminating the long time spent by a journey to a remote server and back again. It also necessitates the operators bringing clouds considerably closer to consumers because the two factors mentioned before are significant to multi-objective networking to be realized [14].

6.2. Machine Learning for Networking

Utilizing machine learning technologies is a good way to tackle networking challenges in recent years and has shown significant potential. Mao's team created Pensieve, a system that uses reinforcement learning approaches to construct adaptive bitrate algorithms that surpasses the most cutting-edge scheme, with gains in overall quality of experience of 12-25 percent [17]. Unlike traditional solutions, adaptive bitrate algorithms, which apply to a broad spectrum of applications and quality of experience measurements, can be learned by Pensieve automatically. Except for Pensieve, Chen's team executed traffic optimization in data center-scale networks using deep reinforcement learning approaches. It can reduce average flow completion time by up to 48 percent when compared to conventional methods [18]. Despite the fact that network state changes as time goes by and machine learning for networking presents significant potential in dealing with environments constantly changing, balancing the efficacy as well as generalization capabilities of models using machine learning techniques in the context of networking is a difficult topic. Furthermore, selecting the appropriate optimization objectives is a crucial yet difficult challenge for models using machine learning techniques.

6.3. Network Function Virtualization

Network function virtualization offers a novel approach to developing IT applications. Virtual network capabilities, unlike traditional network services that need unique hardware, can operate as software on commercial devices. It has several advantages. The first is a decrease in capital expenditures. Virtual network functions can be executed on low-cost commercial devices rather than expensive bespoke hardware, lowering network expenses. Furthermore, it has the potential to reduce operational costs. Network function virtualization simplifies the whole provisioning process from start to finish. With a single press of a button, a network operator may spin up the suitable at their necessary devices, complete with prerequisite setup and capacity. Network function virtualization minimizes the amount of labor, different provisioning, and administration systems required when compared to manual operations in vendor-specific devices. Moreover, it also features a high level of service agility and adaptability. In network function virtualization, the use of microservices and service chaining makes it simple to add new features and capabilities [19]. Network function virtualization, when combined with flexible open service environments and software-defined networking approaches, alters the service evolution process and cuts the time it takes to launch new services from years to months [20]. Despite the fact that there are plenty of advantages and promises as a supplement to software-defined wide area networks, its performance under current solutions is not equal to what bespoke hardware can do.

6.4. New Transport Protocols

It is promising to develop new transport protocols like Quick UDP Internet Connection (QUIC) to attain low latency and keep the level of reliability and security; the reason is that applications always hold limitations caused by applying TCP as the underlying protocol [21]. To be more specific, the handshake mechanism of TCP may cause more latency than QUIC. QUIC is a protocol built on top of UDP. In the best situation, it seeks to decrease connection latency through transmitting data directly while a connection is constructed. It also has multiplexing capabilities that are designed for HTTP/2, as well as more detailed feedback information that might lead to new congestion control methods. Unlike TCP, which is embedded in the kernel and makes protocol changing difficult, it is effortless to implement and modify QUIC in user space [22]. Because the majority of applications are built using outdated transport protocols, replacing them with new transport protocols is still a long way off.

7. CONCLUSION

To meet the increasing demands of the digital era, classic WAN architecture has to modernize. Hence, SD-WAN is critically important for the next era of wide area networks. SD-WAN allows for a safe migration to cloud apps as well as a flexible deployment architecture. Furthermore, SD-WAN can link any application with bandwidth and latency needs utilizing a variety of communication frameworks, including MPLS, 5G, 4G/LTE, and broadband Internet. In this paper, it could be concluded that the SD-WAN technique has boosted network application performance. SD-WAN outperforms other current competitor technologies in terms of network performance while lowering expenses. This is why companies are progressively moving away from traditional WAN solutions and toward SD-WAN solutions. While this paper summarizes the bottlenecks expected to be improved in the development of the industry, including control plane management, scalability and reliability, traffic engineering and monitoring, and security problems, it also suggests to researchers some directions probably used for improvement and exploration, so as to further improve the performance of this technology, such as incorporating machine learning and network function virtualization technology in SD-WAN, and developing new protocols rather than TCP. If these bottlenecks of SD-WAN are broken through and SD-WAN based multi-objective networking can be facilitated, it will greatly promote the development of network industries.

AUTHORS' CONTRIBUTIONS

This paper is independently completed by Zheyang Qin.

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REFERENCES

1. Z. Yang, Y. Cui, B. Li, Y. Liu and Y. Xu, Software-Defined Wide Area Network (SD-WAN):

Architecture, Advances and Opportunities, 2019 28th International Conference on Computer Communication and Networks (ICCCN), 2019, pp. 1-9, doi: 10.1109/ICCCN.2019.8847124.

2. Rachuri, S.P. et al.. Network-coded SD-WAN in Multi-Access Systems for delay control. 2019 International Conference on contemporary Computing and Informatics (IC3I), 2019.
3. Asif, R. & Ghanem, K.. Ai secured SD-WAN architecture as a latency critical IOT enabler for 5G and beyond communications. 2021 IEEE 18th Annual Consumer Communications & Networking Conference (CCNC), 2021.
4. Troia, S. et al.. SD-WAN: An open-source implementation for enterprise networking services. 2020 22nd International Conference on Transparent Optical Networks (ICTON), 2020.
5. M. Room, 6 Advantages and Disadvantages of Wide Area Network | Limitations & Benefits of Wide Area Network, Hitechwhizz, Jul. 13, 2020. Available: https://www.hitechwhizz.com/2020/07/6-advantages-and-disadvantages-drawbacks-benefits-of-wan.htm
6. Uppal, S., Woo, S. & Pitt, D. . Software-Defined WAN for Dummies, John Wiley & Sons, Ltd, 2015.
7. “Bandwidth management for IoT Devices,” tantiv4, 2020. [Online]. Available: https://www.tantiv4.com/insights/internet-bandwidth-management/wifi-s-growing-role-in-iot
8. “What is SD WAN?- Definition, Benefits, Deployment and Vendors,” Field Manager, 2022. [Online]. Available: https://www.fieldengineer.com/sd-wan/what-is-sd-wan.
9. Asif, R., & Ghanem, K. AI Secured SD-WAN Architecture as a Latency Critical IoT Enabler for 5G and Beyond Communications. 2021 IEEE 18th Annual Consumer Communications & Networking Conference (CCNC), 2021. doi:10.1109/ccnc49032.2021.93694
10. Rachuri, S. P., Ansari, A. A., Tandur, D., Kherani, A. A., & Chouksey, S. Network-Coded SD-WAN in Multi-Access Systems for Delay Control. 2019 International Conference on Contemporary Computing and Informatics (IC3I), 2019. doi:10.1109/ic3i46837.2019.905556
11. “What is zero touch provisioning and is it useful for me?,” Nomios Group. [Online]. Available: https://www.nomios.com/news-blog/what-is-zero-touch-provisioning/.
12. “SD-WAN offers superior responsiveness, enhanced application performance, more robust security, and improved visibility: Aruba blogs,” blogs.arubanetworks.com, Sep 10, 2021. Available: https://blogs.arubanetworks.com/solutions/8-sd-wan-features-you-shouldnt-be-ignoring/.
13. S. Troia, L. M. Moreira Zorello, and G. Maier, SD-WAN: how the control of the network can be shifted from core to edge, in 2021 International Conference on Optical Network Design and Modeling (ONDM), 2021.
14. Z. Yang, Y. Cui, B. Li, Y. Liu, and Y. Xu, Software-defined wide area network (SD-WAN): Architecture, advances and opportunities, in 2019 28th International Conference on Computer Communication and Networks (ICCCN), 2019.
15. X. Zuo, Y. Cui, M. Wang, T. Xiao, and X. Wang, Low-latency networking: Architecture, techniques, and opportunities,” IEEE Internet Comput., vol. 22, no. 5, 2018, pp. 56–63..
16. Z. Lai, Y. C. Hu, Y. Cui, L. Sun, N. Dai, and H.-S. Lee, Furion: Engineering high-quality immersive virtual reality on today’s mobile devices, IEEE Trans. Mob. Comput., vol. 19, no. 7, 2020, pp. 1586–1602 .
17. H. Mao, R. Netravali, and M. Alizadeh, Neural adaptive video streaming with pensieve, in Proceedings of the Conference of the ACM Special Interest Group on Data Communication, 2017.
18. L. Chen, J. Lingys, K. Chen, and F. Liu, AuTO: Scaling deep reinforcement learning for datacenter-scale automatic traffic optimization, in Proceedings of the 2018 Conference of the ACM Special Interest Group on Data Communication, 2018.
19. C. Sun, J. Bi, Z. Zheng, H. Yu, and H. Hu, NFP: Enabling network function parallelism in NFV, in Proceedings of the Conference of the ACM Special Interest Group on Data Communication, 2017.
20. H. Hawilo, A. Shami, M. Mirahmadi, and R. Asal, NFV: State of the art, challenges and implementation in next generation mobile networks (vEPC), 2014.
21. A. Langley et al., The QUIC transport protocol: Design and internet-scale deployment, in Proceedings of the Conference of the ACM Special Interest Group on Data Communication, 2017.
22. Y. Cui, T. Li, C. Liu, X. Wang, and M. Kuhlewind, Innovating transport with QUIC: Design approaches and research challenges, IEEE Internet Comput., vol. 21, no. 2, 2017, pp.72–76.