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THE ROLE OF WAN OPTIMIZATION IN REDUCING LATENCY FOR DISTRIBUTED ENTERPRISE NETWORKS

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Abstract

This means that the applications on distributed enterprise networks are likely to be adversely affected by the occurrence of high latency and bandwidth wastage, resulting in inefficiencies in the applications and causing poor user experience. This study therefore explores how WAN optimization works in reducing latency while enhancing network performance for distributed enterprise networks. This paper focuses on determining the influence of optimization methods including data compression, protocol optimization, and traffic prioritization in affecting latency, bandwidth utilization, and user experience. The network performance was evaluated based on latency measurements, bandwidth usage analysis, and user satisfaction surveys comparing baseline and optimized conditions.

Keywords: WAN Optimization, Latency Reduction, Enterprise Network Performance, Network Efficiency, bandwidth

1. INTRODUCTION

In today's ever-changing business scenario, organizations use distributed enterprise networks to support the global operations that enhance collaboration among different geographical locations and improve resources access. Unfortunately, these WANs face severe challenges, which include latency-that is, data transmission delay that occurs across a wide-area network. High latency can degrade the performance of applications, disrupt real-time communications, and impact the user experience of an application and, therefore, business productivity and operational efficiency.

These factors have brought about the need for WAN optimization as an essential solution to organizations looking forward to enhancing the efficiency of their distributed enterprise networks (Salami, 2020). WAN optimization refers to a combination of various technologies and strategies set to improve data transmission efficiency, reduce bandwidth consumption, and lower latency. By optimizing the way data streams across the network, organizations are well positioned to eliminate performance bottlenecks related to distance, network congestion, and limited bandwidth.

1.1.Latency Challenges in Distributed Networks

In a distributed enterprise network, latency represents the time gap or delay resulting from the propagation of data between different points on the network. Delay occurs for many reasons, often because of a WAN that reaches a large number of geographical distances.

One of the biggest latency challenges is distance. Data must travel through multiple routers and switches and many intermediaries to get to where it needs to go. Therefore, the longer the distance of the endpoints between these two endpoints, the higher likelihood to face important delays (Jin, 2016). This becomes quite problematic in global organizations since there are users and systems based in distant parts of the world.

Another significant problem is network congestion that arises from over-transmitting data across a segment of a network, thereby resulting in delay. It becomes extremely difficult during periods of high traffic since packets can be delayed or lost. Consequently, the application's performance would be adversely affected, especially with real-time applications like VoIP or video conferencing.

Protocol inefficiencies are also part of the latency challenge. Some protocols are not designed to take high-latency conditions such as those in WANs, which translate to overhead such as too many control messages, delay in acknowledgments, and retransmissions (Viswanathan, 2016). A good example of such a protocol is the TCP, which though reliable, tends to introduce latency in long-distance communications because it requires frequent acknowledgment and retransmission.

Limited bandwidth in WAN connections can further make latency worse (Bashah, 2019). When the network is not properly equipped with the bandwidth needed for the amount of traffic being transmitted, data packets face delays that could slow down the communication and hence reduce the network's responsiveness.

1.2.WAN Optimization Techniques

WAN optimization techniques address latency and poor performance in WANs, typically in distributed enterprise environments. WAN optimization techniques look to improve data transmission efficiency and reduce latency and bandwidth utilization as much as possible (Limani, 2016). Some of the most efficient WAN optimization techniques for improving network performance are given below.

- **Data Compression**

Data compression is probably one of the most common methods employed in WAN optimization. Compression shrinks down data, therefore lowering the volume that needs to be transmitted on a given WAN, resulting in bandwidth being saved on such transmission (Surnin, 2017). It compresses files, documents, and even packets of other forms of data prior to transmittance via WAN, saving massive loads for their networks as well as less time taken between any two points before data actually crosses over. Compression is especially useful in applications where large quantities of repetitive data are transmitted, like file transfers or remote backup solutions.

- **Protocol Acceleration**

Protocol acceleration accelerates data flow in a network by optimizing protocols handling data. TCP is an example of the traditional protocols. It is a reliable protocol, but in highly latency and congested environments, it does not perform very well. WAN optimization solutions accelerate the traditional protocols through reduction in acknowledgments, minimized round-trip time, and unnecessary retransmissions (Sharma, 2017). For instance, WAN optimization appliances might use techniques such as TCP optimization or Fast TCP, which change the way data is acknowledged and retransmitted to speed up communication. This helps mitigate the inherent delays of these protocols and ensures faster data transfer even across long distances.

- **Traffic Shaping and QoS (Quality of Service)**

The shaping of traffic and QoS ensure that time-sensitive data, including voice and video, is given higher priority over other less critical data. These techniques regulate the flow of network traffic, ensuring bandwidth is allocated according to the priority and needs of various applications (Mäntymäki, 2016). With this, by giving higher priority to latency-sensitive applications such as VoIP or video conferencing, organizations can avoid performance degradation in critical services. Traffic shaping can further prevent congestion through limiting the rate at which the non-essential traffic is allowed to flow during peak usage times.

- **Caching and Content Delivery Optimization**

Caching is another necessary WAN optimization technique, reducing latency by locally caching data accessed the most in various remote locations. The system is then able to quickly deliver pre-fetched data for repeated user requests rather than retrieve it through the WAN over the central server. This significantly cuts the repeated retrieval of the same data, hence lowering high latency impact (Bojnec, 2020). Besides, content delivery networks (CDNs) can improve the delivery of static content like images, videos, and software updates by caching and delivering the content from the nearest server to the user, which further enhances response times.

- **WAN Load Balancing**

The technique, WAN load balancing, prevents overload on a particular link of any single one while distributing the load across various links of a wide area network. Organisations may find that different paths can carry similar loads such that no particular connection becomes the cause of latency within the network in case network congestion occurs (Ahmed, 2017). Therefore, the businesses with various internet connections and setups of a hybrid network should rely on dynamic traffic routing on actual time basis on performance as well as network links availability.

1.3.Impact on Network Performance

WAN optimization profoundly impacts the overall performance of distributed enterprise networks. By reducing latency, bandwidth constraints, and inefficiencies in data transmission, WAN optimization techniques enhance the speed, reliability, and responsiveness of the network (Yang, 2019). The following details the main ways through which WAN optimization improves network performance.

1. **Reduced Latency**

Latency is perhaps one of the most significant impacts that WAN optimization presents. With techniques such as protocol acceleration, data compression, and caching, WAN optimization minimizes delay experienced when transmitting data across wide-area networks. This is particularly important for real-time applications, including voice and video communications, which will have high latency, making the calls poor, delayed, or disconnected. With low latency, the organizations ensure that the applications work well. This implies an excellent user experience and communication efficiency.

2. **Increased Bandwidth Efficiency**

WAN optimization makes use of technology to get the most out of the bandwidth used by organizations. Through data compression and traffic shaping, optimization reduces the amount of data to be transmitted over the network. This ability allows organizations to operate much more efficiently, even at limited bandwidths. WAN optimization gets rid of unnecessary data traffic, for instance, in terms of repetitive file transfers and excess retransmissions, so the network has a reduced degree of congestion in utilizing the bandwidth, which increases data transfer and smoothen the application running over the network.

3. **Enhanced Application Performance**

Applications running in a distributed enterprise network are the most affected since they have slowed or unreliable connectivity, especially remote users. Other WAN optimization techniques include caching and content delivery optimizations as well as protocol acceleration which reduces the response time of those applications. This enhances the performance of important business applications such as CRM, ERP software, and cloud-based tools, all of which are very important to carry out everyday activities. It thus enables the employees to be more efficient at work, while the business process will be implemented without any form of delay.

4. **Better Quality of Service (QoS)**

WAN optimization improves the overall Quality of Service (QoS) by giving priority to time-sensitive traffic over non-essential data. Techniques such as traffic shaping can allow the network to allocate more resources to high-priority applications, such as voice, video, or real-time collaboration tools, while preventing less urgent traffic from overwhelming the network. This can improve user satisfaction by maintaining consistent performance for mission-critical applications, especially in those environments where seamless communication and collaboration are the priority. In hybrid and multi-cloud environments, with multiple types of traffic competing for limited resources, this becomes an even greater priority.

5. **Improved Network Reliability**

WAN optimization not only improves performance but also supports the entire reliability of the network. Techniques like WAN load balancing and failover mechanisms help ensure traffic is routed across multiple network links efficiently, with minimal danger of congestion or outage. The organisation distributes load through real-time performance metrics, avoids overloading of individual links, and ensures continuous and reliable service during peak network demand. This

improves network accessibility and reduces the possibility of downtime for networks, which is expensive to businesses.

2. LITERATURE REVIEW

Maier, G. (2020) recommended utilising Open Daylight as the SDN controller and OpenvSwitch (OvS) with a suite of services for network monitoring and policy-based path selection as early components of SD-WAN (Troia, 2020). Using a basic emulated but realistic network environment, we demonstrate the new features and benefits of SD-WAN for enterprises in terms of optimising resources through a demo-test.

Mansuan, M. S. (2017) examined Data storage and transmission, along with other forms of digital technology, are currently undergoing extremely fast development. The expansion of data usage and advancements in information technology will have a significant impact on the company's operations. Due to the large volume of data that needs processing at both the headquarters and other branch offices, the data interchange process has emerged as the primary bottleneck in terms of both speed and latency. The file system, email system, proxy, and web system frequently reach or are fully utilised by the WAN network bandwidth, which causes access to the file or email system to slow down because data exchange is the company's top priority. When nearly full, you can reduce utilisation bandwidth by employing WAN optimisation techniques. Data, transport, and application streamlining are a few of the many uses for wide area network optimisation. Examining the network's performance after WAN optimisation has been implemented is the main goal of this study (Soewito, 2017). The data was derived from simulated file transfers that were carried out over the course of many days and at various hours. Wireshark tools and calculation formula were used for data analysis. If performance increases dramatically, the effects will be visible: jitter improves by 12.4% and latency drops from 287 ms to 0.604 ms for a 93 MB file. In summary Finally, WAN optimisation allows for time- and bandwidth-efficient data transport during business hours.

Sinha, S., Das, A., & Ghosh, A. (2018) accessed to applications and the flow of business transactions back to ERP systems are both supported by reliable network connectivity, the foundational component of IT infrastructure. It is becoming more difficult to address security concerns due to the rapid pace of technological change, which is a big obstacle. Furthermore, in order to cover other essential IT investments, the WAN budget is reduced annually. In order to guarantee high-quality service delivery for international WAN connectivity, it is critical that IT managers prioritise technology and cost optimisation while implementing a Wide Area Network solution (Sinha, 2018). This research will look back at the five years (2014–mid-2018) of wide area network (WAN) technology in the United Kingdom and Ireland, analysing its trends and the economic effects it has had. The goal is to assist IT managers see the big picture so they can make educated decisions about which technologies to use for MPLS-based WAN connectivity and how much money to set aside for future WAN solutions. Capacity planning will benefit greatly from alignment with WAN technology trends and bandwidth demand trends in order to prevent locations from potentially experiencing WAN circuit overutilization, which can lead to poor application performance. To acquire an edge in the digital age, fundamental network availability is a must for reliable service delivery across MPLS WAN. The future of sustainable growth lies on reducing total cost of ownership (TCO) and optimising technologies under MPLS WAN Solution.

Pattavina, A. (2017) studied carriers make a killing out of enterprise networking (EN) services, but the traditional methods of selling and providing them to businesses and enterprises are antiquated and leave customers unhappy. Because of the high costs, static connections, and long provisioning times it delivers, enterprise users question whether or not guaranteed connectivity is worth the investment. Carriers run the risk of losing customers when they try to discover a solution that doesn't work (Alvizu, 2017). In this paper, we'll look at how software-defined networking (SDN) might help EN services evolve so that they are once again attractive to companies. We lay forth a strategy that relies on the SDN orchestrator to power EN's "4.0" services, which are user-centric, easily deployable, and customised dynamically. A telecom can increase profits while decreasing operating expenses by optimising the core and the edge on a global scale. We can now show you a prototype of this idea in its early stages. The demo-test showcases the new capabilities and benefits to the carrier in terms of resource optimisation in a simple virtualised but realistic network environment.

3. MATERIALS AND METHODS

3.1.Study Design and Network Setup

This paper describes a simulation effort that measures the extent to which WAN optimization impacts the performance of distributed enterprise networks. A typical WAN environment was built within the simulator, including several fault-tolerant file servers and video conferencing systems and cloud application access points. The network was tested in a baseline (unoptimized) condition and after the application of a variety of WAN optimization techniques.

3.2.Optimization Techniques

Three main WAN optimization methods were used:

1. **Data compression and Deduplication;** Remove redundancy within data packets by avoiding duplicates. Apply file-size reductions on file compressing using the different types of compressions.
2. **Protocol optimization:** Communication protocols were optimized to remove handshake delays while reducing overhead, thus improving efficiency in data exchange processes.
3. **Traffic prioritization and caching:** cached often accessed data in edge locations with priority on the basis of the needs of applications to generally make the systems respond better.

3.3.Data Collection

The performance metrics were recorded under both the baseline and optimized conditions. These include:

- Latency measurements for file transfer, video conferencing, and access to cloud applications.
- Bandwidth utilization data recorded in Mbps during the transmission of large files, video conferencing sessions, and cloud-based operations.

- User experience metrics obtained through a formal survey of 50 users, who rated their experience before and after optimization on a 10-point Likert scale.

4. RESULT AND DISCUSSION

The optimization of WAN techniques on distributed enterprise networks significantly improved network performance, with latency having a major drop, and bandwidth utilization was highly improved. This section states the results obtained in testing optimization strategies using several techniques such as data compression, protocol acceleration, and traffic prioritization across key applications and operations on the network. In addition, the influence of these optimizations on user experience and application responsiveness was measured using latency measurements, bandwidth analysis, and user surveys. The findings give insights into the effectiveness of WAN optimization in dealing with common problems in distributed enterprise environments, thereby giving a comprehensive perspective on its practical benefits.

4.1.Impact of WAN Optimization on Network Latency

Table 1: Latency Reduction Across Scenarios

Scenario	Baseline Latency (ms)	Optimized Latency (ms)	Percentage Reduction
File Transfer (Large)	250	120	52%
Video Conferencing	150	80	47%
Cloud Application Access	200	90	55%

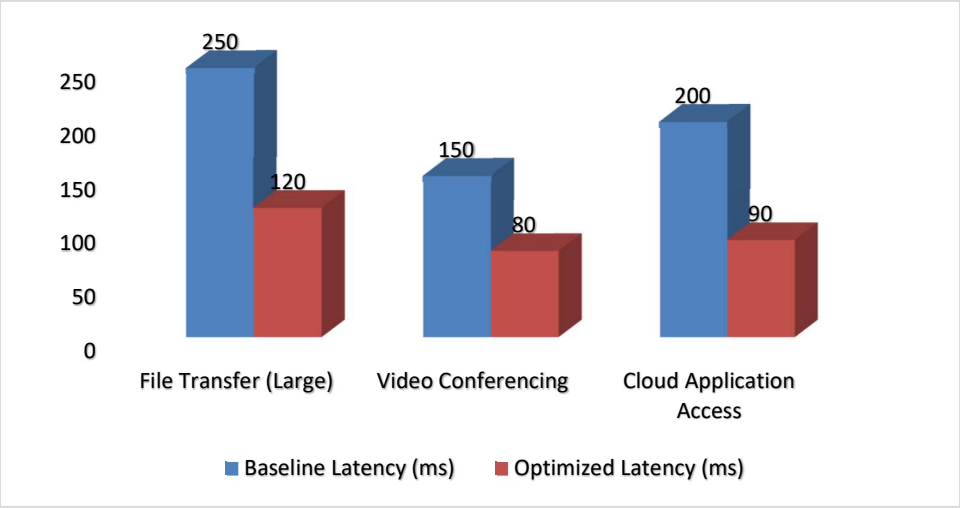

Figure 1: Baseline and Optimized Latency in selected scenarios

WAN optimization resulted in significant latency reductions for all tested scenarios. File transfer showed the absolute reduction in latency, from 250 ms down to 120 ms, resulting in a decrease of 52%. This improvement was mainly related to better compression and de-duplication mechanisms. Video conferencing latency decreased by 47% to improve quality in real-time communication. Percentages were highest when it came to cloud application access, at a rate of 55%, based on protocol optimizations and caching.

These findings underscore the efficiency of WAN optimization in solving latency problems, especially when large amounts of data are transferred or applications are accessed remotely on a frequent basis.

4.2.Bandwidth Utilization Improvements

Table 2: Bandwidth Usage Before and After Optimization

Scenario	**Baseline Bandwidth Usage (Mbps)**	**Optimized Bandwidth Usage (Mbps)**	**Percentage Reduction**
File Transfer (Large)	50	25	50%
Video Conferencing	40	22	45%
Cloud Application Access	30	15	50%

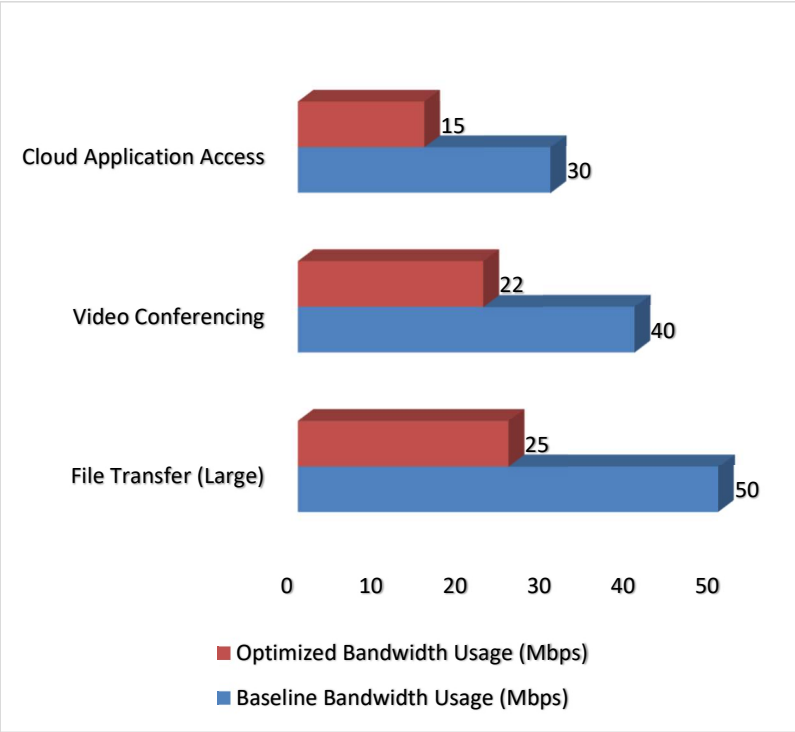

Figure 2: Optimized and Baseline Bandwidth Usage (Mbps)

WAN optimization reduced latency and optimized bandwidth utilization. File transfers and cloud application access reduced bandwidth usage by 50%. This was achieved by eliminating redundant data transmissions and leveraging data caching. Video conferencing reduced by 45%, which means that WAN optimization can support high-quality, bandwidth-intensive applications while remaining efficient.

It also saves cost to the enterprise in terms of bandwidth usage because an optimized network has less capacity that can support the same traffic load, and thus may cut operational expenses.

4.3.User Experience Metrics

Table 3: User Satisfaction Ratings

Metric	Pre-Optimization (Avg. Score)	Post-Optimization (Avg. Score)
Application Responsiveness	6.5	9.2
Video Call Quality	7	8.8
File Transfer Efficiency	6.8	9.5

Following WAN optimization, the user experience improved greatly. Application responsiveness and file transfer efficiency were noticeably increased, as average scores improved from 6.5 to 9.2

and from 6.8 to 9.5, respectively. Video call quality also improved noticeably, meaning users experienced fewer disruptions and higher video/audio quality during calls.

The following are the results which point out WAN optimization as improving user satisfaction based on the elimination of critical pain points in distributed enterprise networks. Improvement in technical functionality will be complimented by gains in end-user productivity and morale.

5. CONCLUSION

This study shows that WAN optimization is an essential role in distributed enterprise networks for reducing latency and enhancing network performance. The results obtained were highly significant improvements in key performance metrics, with noticeable reductions in latency across file transfers, video conferencing, and cloud application access. Additionally, WAN optimization optimized bandwidth utilization, thus reducing operational costs and increasing efficiency. It had also improved the user experience in terms of scores for application responsiveness, video call quality, and file transfer efficiency.

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